Exhibit 223

Mortality Among Rocketdyne Workers Who Tested Rocket Engines, 1948–1999

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Objective: *The objective of this study was to evaluate potential health risks associated with testing rocket engines.* ***Methods:*** *A retrospective cohort mortality study was conducted of 8372 Rocketdyne workers employed 1948 to 1999 at the Santa Susana Field Laboratory (SSFL). Standardized mortality ratios (SMRs) and 95% confidence intervals (CIs) were calculated for all workers, including those employed at specific test areas where particular fuels, solvents, and chemicals were used. Dose–response trends were evaluated using Cox proportional hazards models.* ***Results:*** *SMRs for all cancers were close to population expectations among SSFL workers overall (SMR = 0.89; CI = 0.82–0.96) and test stand mechanics in particular (n = 1651; SMR = 1.00; CI = 0.86–1.16), including those likely exposed to hydrazines (n = 315; SMR = 1.09; CI = 0.75–1.52) or trichloroethylene (TCE) (n = 1111; SMR = 1.00; CI = 0.83–1.19). Nonsignificant associations were seen between kidney cancer and TCE, lung cancer and hydrazines, and stomach cancer and years worked as a test stand mechanic. No trends over exposure categories were statistically significant.* ***Conclusion:*** *Work at the SSFL rocket engine test facility or as a test stand mechanic was not associated with a significant increase in cancer mortality overall or for any specific cancer.* (J Occup Environ Med. *2006;48:1070–1092*)

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The results presented here represent the conclusions and opinions solely of the authors. Its publication does not imply endorsement by The Boeing Company, the UAW, or any of the acknowledged agencies.

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In 1948, North American Aviation established the Santa Susana Field Laboratory (SSFL) at the boundary of Los Angeles and Ventura counties as a rocket engine testing facility. The 2668-acre site is located approximately 30 miles northwest of Los Angeles. During the next 50 years, 11 major rocket engine and component test areas were developed at SSFL. The Rocketdyne Propulsion Division was formed in 1955. North American Rockwell (1967–1973), Rockwell International (1973–1996), and The Boeing Company (1996+) have been the corporate owners of the test facilities. Pratt & Whitney purchased Rocketdyne in 2005. "Rocketdyne" is used in the remainder of this article to mean all workers at SSFL and nearby facilities regardless of corporate affiliation. Many rocket engines were tested over the years, including the Saturn rocket engine used for the Apollo moon landing and the Redstone rocket engine that launched the first U.S. satellite, Explorer. During the testing of rocket engines, there was potential exposure to a wide range of engine fuels, solvents, and other chemicals, including hydrazine-based fuels (such as hydrazine, monomethyl hydrazine, and unsymmetric dimethyl hydrazine) and tricholoroethylene (TCE). A previous study of the workforce at SSFL had concluded that jobs involving hydrazines or other chemicals during the testing of rocket engines were associated with increased deaths from lung cancer and possibly other cancers.[1] The current study is an independent evaluation of the Rocketdyne workforce that extends the previous period of observation by 5 years, expands the SSFL population by over 2000 workers, and includes Rocketdyne workers at nearby facilities as an additional comparison group. A major difference between the current and previous investigation was our ability to assign workers to specific test areas where hydrazines and TCE were used. This improvement in exposure assessment resulted in a smaller number of workers classified as having potential exposure to hydrazines as well as a new evaluation of TCE exposure associated with engine cleaning.

Materials and Methods

Cohort Definition

The study cohort comprised all Rocketdyne workers who were employed on or after January 1, 1948, for at least 6 months at SSFL. Rocketdyne workers employed for at least 6 months at nearby facilities, mainly at the Canoga Park and De Soto Avenue facilities, were also included as an additional comparison group. These nearby Rocketdyne facilities were involved over the years with manufacturing rocket engines and components and other related activities, but not rocket engine testing. Workers at these nearby facilities lived in the same communities as SSFL workers and had similar socioeconomic characteristics and access to medical care.

Several overlapping record sources were used to identify the worker population: work history (Kardex) cards available up to 1971 and computerized personnel files, including retirement records available after 1971. Other personnel records included lists of workers who were transferred to other divisions over the years, personnel listings (phone books) available from 1956 to 1994, medical records, and medical record index cards. An intense effort was made to locate and obtain the Kardex cards for over 1000 workers who had transferred to other Rocketdyne divisions. Information on the work history cards, available for over 35,000 workers, included name, social security number, employee serial number, date of first hire, date of birth, a complete history of jobs (occupational title, occupational code, pay type, location, date of job change, date of termination), and occasionally prior employment information. Similar work information was available on the computerized personnel listing available for over 26,000 workers. The overlapping sources identified 54,384 unique workers (Fig. 1). Persons who worked for less than 6 months (6601), persons with missing or inadequate work histories and identifying information (289), and persons who were not Rocketdyne employees (524) were excluded. Also excluded were 5619 workers engaged in radiation work at Rocketdyne/Atomics International who were studied separately.[2] Because of the relatively small numbers of test stand mechanics available for study (n = 1651), test stand mechanics monitored for radiation (n = 182) were included. The final study population comprised 41,351 Rocketdyne workers: 8372 SSFL workers and 32,979 workers at nearby facilities.

The large number of job title entries on the Kardex job history cards (>73,000) and the electronic personnel file (>257,000) were collapsed into job title categories. Each job category was designated as "administrative/scientific" (eg, office, technical, clerical, scientific, engineering, and management personnel) or "nonadministrative" (eg, metal and structural mechanics, machinists, welders, metal fitters, painters, and test stand me-

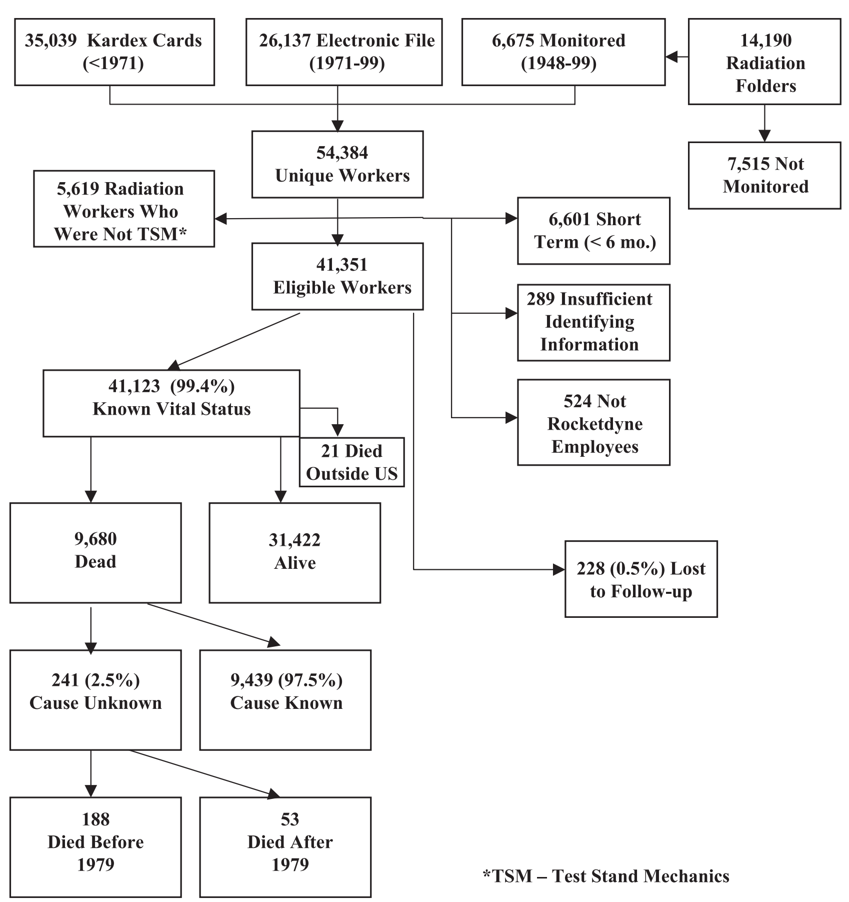

Fig. 1. Rocketdyne worker population and vital status as of December 31, 1999. Kardex work history cards were available up to 1971; electronic work histories were available 1971 through 1999; radiation folders were available 1948 through 1999 and contained personnel and radiation exposure information. Radiation workers were excluded from the study, except for 182 test stand mechanics who had been monitored for radiation sometime during their career at Rocketdyne.

chanics). There were 23,970 workers who primarily held "administrative/scientific" positions and 17,331 workers who primarily held "nonadministrative" positions. Pay type (hourly/salary) was extracted from the personnel records as a measure of socioeconomic status. Workers who held hourly jobs for at least 20% of their career were classified as hourly workers.

Based on job titles, there were 4401 workers at SSFL who had some direct association with test stand work, including test stand mechanics (1651), instrument mechanics (436), inspectors (142), test stand engineers (1084), and research engineers (1088). Test stand mechanics had the greatest likelihood for chemical exposures at test stands due to their hands-on responsibilities. Test stand mechanics were all hourly workers, whereas practically all the other workers associated with test stand work were salaried and had a much lower potential for chemical exposures. Because there were only nine female test stand mechanics, analyses of test stand mechanics are restricted to males.

Vital Status

Vital status as of December 31, 1999, was sought for all workers. Mortality was determined from the California death tapes (1960–1999), California death index (1940–1960), National Death Index (1979–1999), Pension Benefit Information files, Social Security Master File, the Health Care Financing Administration beneficiary files (now the Centers for Medicare and Medicaid Services [CMS]), employment work history cards, pension records, and retirement records. Cause of death, coded according to the International Classification of Diseases in use at the time of death, was obtained from the California death tape for those dying in California after 1959 and from the National Death Index for non-California residents dying after 1978. For all other deaths, death certificates were obtained from company sources or state vital statistics departments and then coded by a trained nosologist for the underlying cause of death. Over 4000 death certificates were available from the Rocketdyne personnel files. Cause of death was obtained for all but 241 (2.5%) of the 9680 workers who were found to have died. The 1651 test stand mechanics were considerably older than other members of the cohort, and nearly 35% had died compared with 23.4% for the entire cohort (Table 1).

Sources to confirm alive status included company employment and retirement records, CMS files for study subjects over age 65, and Social Security Administration files for study subjects under age 65. Cohort members not confirmed as alive by these sources were considered lost to follow up and assumed to be alive up until their date of last employment at Rocketdyne. Overall, 31,443 (76.0%) of the 41,351 study subjects were alive on December 31, 1999, with only 228 (0.6%) lost to follow up.

Rocket Engine Testing and Exposure Classification

The SSFL workforce, and test stand mechanics in particular, worked in an environment for which exposure to a wide range of rocket fuels, oxidizers, exhaust gasses, solvents, and other chemicals was possible. The potential for chemical exposures at test stands from 1948 until 1999 was estimated from job titles extracted from work and personnel listings (special phone directories). The potential exposure to a mixture of substances at rocket engine test areas was evaluated in terms of years of employment as a test stand mechanic. The specific chemicals evaluated included hydrazines used as a fuel in some rocket engines and trichloroethylene (TCE) used to clean ("flush") engines and as a utility solvent to clean small metal parts. Because the work history information available on Kardex cards and the electronic personnel file were not specific enough to assign individual workers to specific test stands, historical personnel listings (in a phone book format) were relied on. These personnel listings were used to place 1440 (87.7%) of the 1642 male test stand mechanics at specific test stands during specific calendar years in which particular chemicals (hydrazines and TCE) were used. These assignments were important because most test stand mechanics were found not to have worked with hydrazines. Validation of these assignments was based on information gathered from walkthrough surveys at operating and closed test stands with knowledgeable personnel who were involved with engine tests over the years, discussions with over 100 long-term employees (both retired and active), and review of medical records of workers, which often identified the test stands and the chemicals used.

Patterns of Exposure to Chemicals by Job Title. There were four groups of workers associated with rocket engine testing who had potential for exposure to hydrazines and TCE: mechanics and technicians, instrumentation mechanics, inspectors, and engineers. The test stand mechanics and technicians (combined to a single category "test stand mechanics") had the potential for heaviest chemical exposures. These workers transferred hydrazines from drums to run tanks, disconnected fuel lines, performed the engine flush with TCE, and most frequently washed their parts, tools, and hands in TCE. The other three categories of workers did not typically have "hands-on" responsibilities so that their potential exposure to chemicals was much less than for test stand mechanics. Some instrumentation mechanics, for example, worked in the test stand control room and not actually at the test stand. Exposures would have varied widely among the engineers because some would occasionally come to a test stand and work along with the mechanics, whereas others would rarely leave the control room or their office.

TABLE 1
Demographic and Occupational Characteristics of Rocketdyne Workers*

Characteristic	SSFL Workers		Test Stand Mechanics		All Rocketdyne Workers	
	No.	Percent	No.	Percent	No.	Percent
Gender						
Male	7083	84.6	1642	99.5	31,858	77.0
Female	1289	15.4	9	0.5	9493	23.0
Race						
White	6629	79.2	1349	81.7	31,272	75.6
Nonwhite	412	4.9	43	2.7	3420	8.3
Unknown	1331	15.9	259	15.7	6659	16.1
Pay type						
Hourly						
Administrative/scientific	1906	22.8	0	0.0	10,080	24.4
Nonadministrative	3335	39.8	1651	100.0	16,237	39.3
Salary						
Administrative/scientific	3062	36.5	0	0.0	13,890	33.6
Nonadministrative	69	0.8	0	0.0	1144	2.8
Job category						
Test stand mechanic	1651	19.7	1651	100.0	1651	4.0
Research engineer	1088	13.0	0	0.0	1088	2.6
Test stand engineer	1084	12.9	0	0.0	1084	2.6
Instrument mechanic	436	5.2	0	0.0	436	1.1
Inspector	142	1.7	0	0.0	142	0.3
Other SSFL workers	3971	47.4	0	0.0	3971	9.6
Other Rocketdyne workers	0	0.0	0	0.0	32,979	79.8
Year of birth						
<1920	1419	16.9	360	21.8	6266	15.2
1920–1929	2155	25.7	497	30.1	8219	19.9
1930–1939	2663	31.8	546	33.1	9989	24.2
1940–1949	1170	14.0	155	9.4	7913	19.1
1950–1959	680	8.1	70	4.2	5556	13.4
≥1960	285	3.4	23	1.4	3408	8.2
Year of hire						
<1948	204	2.4	74	4.5	1035	2.5
1948–1959	4048	48.4	973	58.9	12,038	29.1
1960–1969	2501	29.9	457	27.7	13,884	33.6
1970–1979	685	8.2	79	4.8	4215	10.2
1980–1989	797	9.5	68	4.1	8411	20.3
≥1990	137	1.6	0	0.0	1768	4.3
Year of termination						
<1960	16	0.2	8	0.5	51	0.1
1960–1969	4425	52.9	1025	62.1	18,694	45.2
1970–1979	1167	13.9	224	13.6	5026	12.2
1980–1989	1100	13.1	173	10.5	6103	14.8
1990–1999	1051	12.6	112	6.8	6748	16.3
Active (as of December 31, 1999)	613	7.3	109	6.6	4729	11.4
Duration of employment						
6 mos–<1 yr	366	4.4	76	4.6	2568	6.2
1–4 yr	2821	33.7	525	31.8	15,964	38.6
5–9 yr	1587	19.0	280	17.0	7799	18.9
10–14 yr	1367	16.3	282	17.1	5993	14.5
15–19 yr	690	8.2	148	9.0	3498	8.5
≥20 yr	1481	17.7	331	20.0	5313	12.8
Unknown	60	0.7	9	0.5	216	0.5
Years of follow up						
<1 yr	46	0.5	5	0.3	403	1.0
1–4 yr	264	3.2	13	0.8	1355	3.3
5–9 yr	344	4.1	30	1.8	1845	4.5
10–19 yr	1335	15.9	150	9.1	10,166	24.6
20–29 yr	1302	15.6	251	15.2	6363	15.4

(Continued)

Inspectors rarely came directly in contact with chemicals. Therefore, as a result of their high potential for exposure to chemicals, our analyses focus on the test stand mechanics.

Potential for Hydrazine Exposure. Most of the workers exposed to hydrazines were at particular test areas where hydrazines, predominantly monomethylhydrazines, were used for small engine tests from approximately 1961 to 1999. A small number of workers in the research area of the Advanced Propulsion Test Facility also worked with hydrazines. For relatively short periods of time and for a few limited engine programs, a small number of workers were potentially exposed to hydrazines at several of the large engine testing areas.

The potential for exposure to hydrazines could be assigned to 315 workers with some confidence based on the personnel listings (phone directories), medical records, job titles, and worker discussions. These workers were classified as having "likely" or probable exposure to hydrazines. During some calendar years, small engine tests involving hydrazines were conducted at large areas primarily engaged in testing large engines, and, infrequently, hydrazines were used in the testing of some large engines. For these circumstances, we were able to assign a worker to a large test area, but we were unable to distinguish workers potentially exposed to hydrazines from those who were not. Such workers ($n = 205$) were classified as "possible but unlikely" to have been exposed to hydrazines. Only approximately 20 (or 10%) of those classified as "possible but unlikely" were estimated to have had any hydrazine exposure. Analyses were conducted using both classifications.

Potential for Trichloroethylene Exposure. From approximately 1956 through 1994, 1111 (or 67.3%) of the test stand mechanics had potential exposure to TCE either when TCE was used in large volumes to "flush" (or clean) large engine parts or when

TABLE 1
Continued

Characteristic	SSFL Workers		Test Stand Mechanics		All Rocketdyne Workers	
	No.	Percent	No.	Percent	No.	Percent
30–39 yr	2872	34.3	566	34.3	13,961	33.8
40–49 yr	2177	26.0	628	38.0	7226	17.5
≥50 yr	32	0.4	8	0.5	32	0.1
Age at end of follow up						
<40 yr	392	4.7	43	2.6	3953	9.6
40–49 yr	850	10.2	115	7.0	6276	15.2
50–59 yr	1510	18.0	253	15.3	9214	22.3
60–69 yr	2958	35.3	609	36.9	11,252	27.2
70–79 yr	2033	24.3	479	29.0	7832	18.9
80–89 yr	587	7.0	146	8.8	2638	6.4
≥90 yr	42	0.5	6	0.4	186	0.4
Calendar year of death						
<1970	164	7.3	38	6.7	750	7.8
1970–1979	364	16.2	90	15.8	1621	16.8
1980–1989	678	30.1	181	31.7	2827	29.2
1990–1999	1045	46.4	262	45.9	4482	46.3
Vital status as of December 31, 1999						
Alive	6076	72.6	1074	65.1	31,443	76.0
Dead	2251	26.9	571	34.6	9680	23.4
Lost to follow up	45	0.5	6	0.4	228	0.6
Total	8372		1651		41,351	

*One hundred eighty-two test stand workers who were monitored for radiation are included.

SSFL indicates Santa Susana Field Laboratory.

TCE was used as a utility solvent. Engine flushing involved using TCE to remove hydrocarbon deposits left by kerosene in the fuel jackets and in the LOX (liquid oxygen) dome of large engines. Flush volumes ranged from 5 to 100 gallons and, in the early years, the TCE would drain out of the engine onto a concrete spillway and into holding ponds. Around 1961, catch pans that drained to a solvent recovery system were added. Individual test stands discontinued the use of TCE as a flush solvent at different times, depending on the particular engine programs in operation. Most test stands stopped flushing with TCE by the middle to late 1960s, although the Alfa test stand continued the procedure until 1994. The potential for exposure to large quantities of TCE was much greater during engine flush than when TCE was used as a utility solvent.

The date TCE was first introduced as a utility solvent is not precisely known, but workers reported seeing 55-gallon drums of TCE at the test stands a few years before the beginning of its use in the engine flush process. Generally, TCE use as a utility solvent was discontinued in 1974, except at the Bravo test stand where it was used until 1984. An "any TCE exposure" category includes both utility solvent and engine flush TCE exposures.

There was some overlap between TCE engine cleaning and the use of hydrazines at specific test stands. Hydrazines were mainly used in fuels in small engines at certain test areas, whereas TCE was used mainly to clean large engines at other areas. Overall, 21.9% (n = 315) of 1440 test stand mechanics for whom assignments could be made had potential exposure to hydrazines, 36.0% (n = 518) to TCE engine flush, 8.4% (n = 121) to both hydrazines and TCE engine flush, and 50% (n = 729) to neither. Analyses of possible hydrazine risk were adjusted for TCE and vice versa.

Other Exposures. "Years of work" at a test stand was taken as a measure of exposure to all the chemicals and substances present in the engine testing environment. In addition to hydrazines and TCE, a wide variety of fuels, propellants, oxidizers, and solvents were used over the years, including liquid oxygen, liquid nitrogen, kerosene, nitrogen tetroxide, peroxides, fluorine gas, chlorotrifluoride, pentaborane, benzene, carbon tetrachloride, alcohols, 1,1,1-trichloroethane (1,1,1 TCA), methylene chloride, toluene, xylene, and various freons. Most of these other substances were not specifically evaluated because the number of workers exposed was small or not identifiable, the potential for exposure was low, or the substance was not known to be carcinogenic or linked to other health problems associated with increased mortality. Asbestos was found in thermal system insulation materials in several locations at Atomics International where nuclear technology research was conducted. Small amounts of asbestos also were used at test stands in assorted materials such as gaskets and wiring insulation, but it was not extensively used in thermal system insulation. Beryllium powder was mixed with oxidizers for use in experimental rocket propellants in some research areas, and the thrust chamber of the Mars Orbiter Engine was made of beryllium metal. The number of workers potentially exposed to beryllium or asbestos appeared small and the potential exposures were apparently low. Although extensive research involving ionizing radiation was conducted at SSFL,[2] radiation workers were excluded from the study except for 182 who worked as test stand mechanics. Test stand mechanics spent only a limited amount of their careers as radiation workers as evidenced by their low cumulative occupational dose (average, 26.5 mSv) compared with their cumulative exposure to natural sources of radiation (approximately 210 mSv over 70 years).

Structured Worker Discussions. Nine structured discussion sessions were held over a 2-year period with groups of workers to understand more fully the potential for chemical exposures at particular test stands during specific years. Former and current workers still living near SSFL were sent letters inviting them to participate in a group discussion session. Invitees were then called by the study's industrial hygienist and personally invited to attend. Boeing officials did not participate in these sessions and were not involved in the selection of which workers to invite. When possible, workers were grouped by calendar year periods of employment to facilitate focused discussions. The discussions were complemented with photographs, charts, and other information obtained about the test areas. At least one long-term worker from each test area was identified beforehand and asked to escort the study investigators around the test stand while being asked questions about engine programs, job tasks, chemicals used, and respiratory protection.

Statistical Analysis

Four comparison groups were used in the analyses. External comparisons were made with the general populations of the State of California and the United States. Intracohort comparisons were made with SSFL workers and with all Rocketdyne workers (both SSFL and non-SSFL) who were not test stand mechanics.

External (standardized mortality ratio) Analyses. External comparisons contrasted the observed number of deaths with that expected in the general population of California and in the general population of the United States. Observed numbers of deaths from cancers and all other diseases were determined by race, gender, age, and calendar year for workers overall and for subgroups defined by time since first exposure, duration of employment, work location, job title, and potential exposure to hydrazines and TCE. Expected numbers of deaths were computed based on race-, age-, calendar-year, and gender-specific rates in the general population of California and the general population of the United States.

Person-years of follow up began 6 months after the date of first employment or July 1, 1948, depending on which came later. Follow up ended on the date of death, December 31, 1999, or age 95, whichever came first. Ratios of observed to expected deaths (or standardized mortality ratios [SMRs]) and 95% confidence intervals (95% CIs) were calculated using OCMAP software.[3] SMRs were calculated for total mortality and for over 40 causes of death. To account for the favorable mortality experience, primarily with respect to cardiovascular disease, seen among newly hired workers, SMR analyses were also conducted excluding the first 10 years of follow up after date of hire. For the 16% of workers with unknown race, a weighted approximation based on the racial proportions for the 84% of workers with known race was used to compute expected numbers.[3]

Intracohort Dose–Response Analyses. Internal comparisons were made to assess risk within the cohort over categories of duration of employment and potential exposure to chemicals. Intracohort comparisons would be expected to minimize biases that might exist when comparisons with the general population are made (eg, the healthy worker effect). Relative risks (RRs) were estimated by Cox proportional hazards models for categories of years worked at SSFL and years worked as a test stand mechanic.[4,5] RRs were also calculated for categories of years of potential exposure to hydrazines and TCE. Tests for linear trend (two-sided) were conducted by treating these measures as continuous variables in Cox models. The intracohort analyses focused on all SSFL workers and on male test stand mechanics. For these analyses, various referent groups were used: male hourly, nonadministrative Rocketdyne workers who were not test stand mechanics; male hourly, nonadministrative SSFL workers who were not test stand mechanics; and test stand mechanics classified as having no potential exposure to the chemical of interest. Regardless of the referent group chosen, results were similar. Analyses based on Rocketdyne workers are usually presented. Date of birth and date of hire were included as covariates in all models. Adjustment was made for potential exposure to TCE in models examining the risks of potential exposure to hydrazines and vice versa. Pay type (hourly, salary) was taken as an indicator of socioeconomic status and tobacco use and was included in the models when appropriate. The parameter estimates and standard errors for the exposure categories in the Cox models were used to obtain risk (or hazards) ratios and confidence intervals for death due to the cause under investigation compared with those in the referent group.

Guided by reports in the literature,[1,6–11] the outcomes of interest were cancers of all sites and cancers of the lung, kidney, liver, and non-Hodgkin lymphoma. For the "test stand environment" and hydrazine analyses, the exposure measure was taken as duration of employment in years. For the TCE "engine flush" analyses, the duration of potential exposure was weighted by the number of engine tests recorded for specific years accounting for the number of workers during the same period.

Results

Table 1 presents the demographic and occupational characteristics of the Rocketdyne study population. There were 41,351 Rocketdyne workers, 8372 SSFL workers, and 1651 test stand mechanics. Most Rocketdyne workers were male (77.0%), white (75.6%), hourly (63.7%), born before 1940 (59.3%), hired before 1970 (65.2%), terminated employment before 1980 (57.5%), employed for more than 5 years (55.2%), followed for more than 30 years (51.4%), and alive on December 31, 1999 (76.0%). Overall, 20.2% of the workers had worked at SSFL, and 19.7% of the SSFL workers had been test stand mechanics (4.0% of all workers). The test stand mechanics differed from the other SSFL workers in being older, hired earlier, terminated earlier, followed longer, and more likely to be male, hourly, and to have died. Overall, 23,970 (58.0%) of the Rocketdyne employees were classified as administrative/scientific workers, which included office, technical, clerical, scientific and engineering, and management personnel. Most (92.4%) of the 15,034 salaried workers fell into the administrative/scientific category, whereas only 38.3% of the 26,317 hourly workers were so classified. Only 0.6% (n = 228) of workers were lost to follow up.

Table 2 presents the SMRs for 42 cause of death categories by location of employment, ie, at SSFL or at the other nearby Rocketdyne facilities. Taken together, the entire Rocketdyne workforce had a significantly lower risk of death than the general population of California for all causes (SMR = 0.88; 95% CI = 0.86–0.90) and for all cancers (SMR = 0.93; 95% CI = 0.89–0.96). The overall SMR deficit was primarily due to diseases of the heart, cerebrovascular disease, cirrhosis of the liver, and external causes. No cancer was significantly elevated, and cancers of the mouth, colorectum, and liver occurred significantly below expectations. The SMR for cirrhosis of the liver also was significantly low. There were seven deaths due to mesothelioma or cancer of the pleura against 5.4 expected.

The overall patterns of death were similar between SSFL workers and the other Rocketdyne workers: the all-cause SMRs were 0.83 and 0.90, respectively, and the all cancer SMRs were 0.89 and 0.94, respectively. SMRs for smoking-related cancers were similar (0.92 vs 0.98) reflecting a nonsignificantly lower SMR for lung cancer (0.89 vs 1.02) among SSFL compared with other Rocketdyne workers and nonsignificantly higher SMRs for cancers of the esophagus (1.08 vs 0.74), larynx (1.41 vs 1.06), and bladder (0.93 vs 0.86). SMRs for nonmalignant respiratory disease were also similar (1.04 vs 0.95). SMRs for the lymphatic and hematopoietic cancers were similar between SSFL and the other Rocketdyne workers (0.94 and 0.91, respectively). Of the 30 SMRs presented for specific cancer sites, 14 were slightly higher among SSFL workers than the other Rocketdyne workers, 14 were slightly lower, and two were essentially the same, consistent with what might be expected by chance.

Among SSFL workers, the most common cancer deaths were of the lung (SMR = 0.89; n = 215), colon and rectum (SMR = 0.97; n = 70), and prostate (SMR = 0.94; n = 50). Observed deaths were not significantly different from expected numbers for cancer of the liver (SMR = 0.57; n = 11), non-Hodgkin lymphoma (SMR = 1.02; n = 29), leukemia (SMR = 0.84; n = 23), kidney cancer (SMR = 1.15; n = 21), and brain cancer (SMR = 0.91; n = 20). No cause of cancer death was significantly below or significantly above the number expected based on rates prevailing in the general population of California. Excluding the first 10 years of follow up from the analyses also failed to reveal any significantly raised SMRs for any cancer or any cause of death (data not shown).

The 8372 SSFL workers were also examined by time since first hire (<10 years, 10–29 years, and ≥30 years) (data not shown). All causes of death and all cancer deaths were, as anticipated, low in the first 10 years after hire and then approached population-expected numbers. The SMRs for all causes of death and all cancer deaths after 30 years from first hire were 0.87 and 0.92, respectively. No cause of death was significantly elevated for any follow-up period. Significant deficits after 30 years of follow up were seen for deaths from diabetes and heart disease.

Table 3 presents the SMRs for over 40 causes of death for the 8372 SSFL workers by duration of employment at SSFL. Because some workers were employed at both SSFL and at other Rocketdyne facilities, the numbers in Table 3 are slightly different from those in Table 1, which were for total length of employment at Rocketdyne and not just at SSFL. Workers employed for the longest time, ≥10 years, generally experienced slightly lower mortality risks than shorter-term employees (<5 years). For those employed ≥10 years, the overall SMR was 0.77 (95% CI = 0.70–0.84) and the overall cancer SMR was 0.82 (95% CI = 0.68–0.98). The SMR for cancer of the lung was 0.77 (95% CI = 0.54–1.05) for workers employed for 10 or more years (38 observed vs 49.7 expected). There were no significant elevations of any cause of death for any duration of employment period.

Table 4 presents intracohort dose–response analyses for all cancer combined and for specific cancers with at least 20 observed deaths over categories of years worked at SSFL. There were no significant increases seen for any of the 12 cancer outcomes examined. There was a suggested decrease in all cancer mortality with increasing years worked (P for trend = 0.09), and a suggested increase in esophageal cancer (P = 0.05), but the pattern over years worked was erratic. Long-term workers employed for 15 or more years were no more likely to die from lung cancer or leukemia than workers employed for shorter periods. SMRs for the cancers evaluated in Table 4 can be found in Table 3 or in Table 4 footnotes. SMRs based on rates in the general population of the United States are consistently lower than those based on the general population of California, but the patterns over years worked are similar. For example, for lung cancer the RRs for the four categories of years worked are 1.00, 1.04, 0.86, and 1.04; the

TABLE 2

Observed and Expected Numbers of Deaths and Standardized Mortality Ratios (SMRs) Based on California Population Rates for Rocketdyne Workers* Employed for At Least 6 Months, 1948–1999, and Followed Through 1999 by Work Location

Location / No. of Workers / Person-Years of Observation	Santa Susana Field Laboratory 8372 254,198				Other Rocketdyne Facilities 32,979 884,412				All Rocketdyne Facilities 41,351 1,138,610			
Cause of Death (ICD-9)	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI
All causes of death (001–999)	2251	2714.5	0.83	0.80–0.86	7429	8270.1	0.90	0.88–0.92	9680	10,984.3	0.88	0.86–0.90
All malignant neoplasms (140–208)	655	735.9	0.89	0.82–0.96	2086	2218.8	0.94	0.90–0.98	2741	2954.7	0.93	0.89–0.96
Buccal cavity and pharynx (140–149)	11	18.6	0.59	0.30–1.06	45	54.6	0.82	0.60–1.10	56	73.3	0.76	0.58–0.99
Esophagus (150)	21	19.4	1.08	0.67–1.65	40	54.4	0.74	0.53–1.00	61	73.8	0.83	0.63–1.06
Stomach (151)	23	25.6	0.90	0.57–1.35	66	76.4	0.86	0.67–1.10	89	102.0	0.87	0.70–1.07
Colorectal (153–154)	70	72.6	0.97	0.75–1.22	177	218.4	0.81	0.70–0.94	247	290.9	0.85	0.75–0.96
Biliary passages and liver (155, 156)	11	19.2	0.57	0.29–1.03	45	58.3	0.77	0.56–1.03	56	77.5	0.72	0.55–0.94
Pancreas (157)	36	38.2	0.94	0.66–1.31	112	113.8	0.98	0.81–1.18	148	152.0	0.97	0.82–1.14
Larynx (161)	11	7.8	1.41	0.71–2.53	23	21.6	1.06	0.67–1.59	34	29.4	1.16	0.80–1.61
Bronchus, trachea, and lung (162)	215	241.2	0.89	0.78–1.02	705	692.4	1.02	0.94–1.10	920	933.6	0.99	0.92–1.05
Breast (174, 175)	15	16.5	0.91	0.51–1.50	88	97.4	0.90	0.73–1.11	103	113.9	0.91	0.74–1.10
All uterine (179–182)	4	3.8	1.06	0.29–2.72	15	23.4	0.64	0.36–1.06	19	27.2	0.70	0.42–1.09
Cervix uteri (180)	2	1.9	1.07	0.13–3.85	5	12.0	0.42	0.14–0.97	7	13.9	0.50	0.20–1.04
Other female genital organs (183–184)	4	5.2	0.76	0.21–1.96	27	31.5	0.86	0.57–1.25	31	36.7	0.84	0.57–1.20
Prostate (185)	50	53.2	0.94	0.70–1.24	143	145.0	0.99	0.83–1.16	193	198.2	0.97	0.84–1.12
Testes and other male genital organs (186, 187)	2	2.3	0.88	0.11–3.19	3	6.2	0.48	0.10–1.41	5	8.5	0.59	0.19–1.37
Kidney (189.0–189.2)	21	18.3	1.15	0.71–1.76	53	51.5	1.03	0.77–1.35	74	69.8	1.06	0.83–1.33
Bladder and other urinary (188, 189.3–189.9)	16	17.2	0.93	0.53–1.51	42	48.9	0.86	0.62–1.16	58	66.1	0.88	0.67–1.13
Melanoma of skin (172)	13	14.2	0.92	0.49–1.57	34	40.4	0.84	0.58–1.18	47	54.6	0.86	0.63–1.15
Brain and central nervous system (191–192)	20	22.0	0.91	0.56–1.41	65	65.0	1.00	0.77–1.28	85	86.9	0.98	0.78–1.21
Thyroid and other endocrine glands (193–194)	2	2.4	0.82	0.10–2.97	11	7.5	1.47	0.73–2.62	13	9.9	1.31	0.70–2.24
Bone (170)	1	1.6	0.63	0.02–3.53	10	4.9	2.03	0.97–3.73	11	6.5	1.69	0.84–3.03
All lymphatic, hematopoietic tissue (200–208)	68	72.5	0.94	0.73–1.19	196	215.4	0.91	0.79–1.05	264	287.9	0.92	0.81–1.04
Non-Hodgkin lymphoma (200, 202)	29	28.3	1.02	0.69–1.47	75	84.1	0.89	0.70–1.12	104	112.4	0.93	0.76–1.12
Hodgkin lymphoma (201)	5	4.0	1.26	0.41–2.94	13	12.1	1.07	0.57–1.84	18	16.1	1.12	0.66–1.77
Leukemia and aleukemia (204–208)	23	27.3	0.84	0.53–1.26	76	81.0	0.94	0.74–1.18	99	108.3	0.91	0.74–1.11
Chronic lymphocytic leukemia (204.1)	3	4.9	0.61	0.13–1.79	15	13.9	1.08	0.60–1.78	18	18.8	0.96	0.57–1.52
Leukemia other than chronic lymphocytic leukemia	20	22.6	0.89	0.54–1.37	61	67.6	0.90	0.69–1.16	81	90.2	0.90	0.71–1.12
Multiple myeloma (203)	11	12.1	0.91	0.46–1.63	29	35.8	0.81	0.54–1.16	40	47.9	0.84	0.60–1.14
Pleura and peritoneum (158.8, 158.9, 163) and mesothelioma (ICD-10 C45)†	0	1.4	0.00	0.00–2.63	7	4.0	1.77	0.71–3.65	7	5.4	1.31	0.53–2.69
Smoking-related cancers (140–150, 161–162, 157, 188, 189)	331	360.8	0.92	0.82–1.02	1020	1037.2	0.98	0.92–1.05	1351	1397.9	0.97	0.92–1.02
AIDS (042–044, 795.8)	5	22.7	0.22	0.07–0.51	33	97.9	0.34	0.23–0.47	38	120.6	0.32	0.22–0.43
Diabetes (250)	30	46.6	0.64	0.43–0.92	127	143.1	0.89	0.74–1.06	157	189.7	0.83	0.70–0.97
Cerebrovascular disease (430–438)	102	138.2	0.74	0.60–0.90	386	445.3	0.87	0.78–0.96	488	583.5	0.84	0.76–0.91
All heart disease (390–398, 404, 410–429)	793	924.1	0.86	0.80–0.92	2557	2720.5	0.94	0.90–0.98	3350	3644.5	0.92	0.89–0.95

(Continued)

TABLE 2
Continued

Location / No. of Workers / Person-Years of Observation	Santa Susana Field Laboratory 8372 254,198				Other Rocketdyne Facilities 32,979 884,412				All Rocketdyne Facilities 41,351 1,138,610			
Cause of Death (ICD-9)	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI
Nonmalignant respiratory disease, excluding influenza and pneumonia (460–479, 488–519)	153	147.3	1.04	0.88–1.22	419	442.1	0.95	0.86–1.04	572	589.4	0.97	0.89–1.05
Emphysema (492)	32	33.3	0.96	0.66–1.36	89	100.2	0.89	0.71–1.09	121	133.5	0.91	0.75–1.08
Cirrhosis of the liver (571)	48	104.3	0.46	0.34–0.61	186	306.6	0.61	0.52–0.70	234	410.9	0.57	0.50–0.65
Nephritis and nephrosis (580–589)	13	14.7	0.88	0.47–1.51	45	46.0	0.98	0.71–1.31	58	60.7	0.96	0.73–1.24
All External causes of death (800–999)	160	237.5	0.67	0.57–0.79	516	773.1	0.67	0.61–0.73	676	1010.5	0.67	0.62–0.72
Accidents (850–949)	99	138.8	0.71	0.58–0.87	302	447.2	0.68	0.60–0.76	401	585.9	0.68	0.62–0.76
Suicides (950–959)	52	69.1	0.75	0.56–0.99	166	214.0	0.78	0.66–0.90	218	283.1	0.77	0.67–0.88
Unknown causes of death	50				205				255			

*One hundred eighty-two test stand workers who were monitored for radiation are included.

†Mesothelioma was not a codeable cause of death until 1999: ICD-10 (C45). Before 1999, cancers of the pleura and peritoneum (ICD-9 158.8, 158.9, 163) have been used to approximate mesothelioma mortality.

ICD-9 indicates International Classification of Diseases, 9th Revision; CI, confidence interval; ICD-10, International Classification of Diseases, 10th Revision.

SMRs based on California rates are 1.02, 0.91, 0.83, and 0.98; and the SMRs based on the U.S. rates are 0.89, 0.78, 073, and 0.84. Intracohort analyses conducted for hourly and salaried workers separately over categories of years worked at SSFL (data not shown) also revealed no significant findings and no differences in the patterns of risk.

Table 5 presents SMRs for over 40 cause of death categories for the 1642 male test stand mechanics by the number of years worked as a test stand mechanic (<5 years and ≥5 years). The overall all-cause SMR for test stand mechanics was 0.88. There were 174 cancer deaths versus 173.8 expected (SMR = 1.00). Lung cancer deaths occurred close to expectation (SMR = 1.07; 95% CI = 0.82–1.37). Nonmalignant respiratory disease was not significantly elevated (SMR = 1.22; 95% CI = 0.88–1.64). No significant differences were seen for cancer of the liver (four observed, 4.5 expected), kidney (eight observed, 4.5 expected), bladder (five observed, 4.4 expected), or non-Hodgkin lymphoma (six observed, 6.8 expected). No deaths due to mesothelioma or cancer of the pleura were found, although less than one case was expected based on population rates. There were 474 mechanics who worked 5 or more years on test stands. There were no appreciable differences seen by duration of test stand work: the SMRs for all causes of death were 0.90 and 0.83 for those who worked <5 years and those who worked ≥5 years, respectively. The SMRs for cancer deaths (SMR = 1.03 and SMR = 0.94) and lung cancer deaths (SMR = 1.07 and SMR = 1.06) for short- and longer-term work as a test stand mechanic were also similar. Kidney cancer was slightly elevated in both <5- and ≥5-year duration categories (SMR = 1.69, n = 5; SMR = 1.95, n = 3). Non-Hodgkin lymphoma was below expectation in both duration categories. Cancers of the esophagus and liver occurred close to expectation in both dura-

TABLE 3

Observed and Expected Numbers of Deaths and Standardized Mortality Ratios (SMRs) Based on California Population Rates for SSFL Workers* Employed for at Least 6 Months, 1948–1999, and Followed Through 1999 by Duration of Employment at SSFL

Duration of Employment at SSFL	<5 yr				5–9 yr				≥10 yr			
No. of workers	5661				1459				1252			
Person-yr of observation	180,497				44,554				29,157			
Cause of Death (ICD-9)	**Observed**	**Expected**	**SMR**	**95% CI**	**Observed**	**Expected**	**SMR**	**95% CI**	**Observed**	**Expected**	**SMR**	**95% CI**
All causes of death (001–999)	1366	1610.6	0.85	0.80–0.89	450	538.1	0.84	0.76–0.92	435	566.0	0.77	0.70–0.84
All malignant neoplasms (140–208)	403	438.2	0.92	0.83–1.01	129	147.2	0.88	0.73–1.04	123	150.5	0.82	0.68–0.98
Buccal cavity and pharynx (140–149)	9	11.3	0.80	0.36–1.51	0	3.7	0.00	0.00–1.00	2	3.6	0.55	0.07–1.98
Esophagus (150)	13	11.7	1.11	0.59–1.89	2	3.8	0.53	0.06–1.92	6	3.9	1.52	0.56–3.31
Stomach (151)	11	15.3	0.72	0.36–1.29	5	5.1	0.98	0.32–2.29	7	5.3	1.33	0.54–2.74
Colorectal (153–154)	37	42.4	0.87	0.61–1.20	16	14.6	1.10	0.63–1.78	17	15.6	1.09	0.64–1.75
Biliary passages and liver (155, 156)	10	11.7	0.85	0.41–1.57	0	3.7	0.00	0.00–1.00	1	3.8	0.26	0.01–1.47
Pancreas (157)	20	22.6	0.88	0.54–1.37	9	7.7	1.17	0.54–2.23	7	7.9	0.89	0.36–1.83
Larynx (161)	8	4.7	1.72	0.74–3.38	3	1.5	1.96	0.41–5.73	0	1.6	0.00	0.00–2.31
Bronchus, trachea, and lung (162)	131	143.5	0.91	0.76–1.08	46	48.0	0.96	0.70–1.28	38	49.7	0.77	0.54–1.05
Breast (174, 175)	10	10.3	0.97	0.47–1.79	3	4.2	0.72	0.15–2.10	2	2.0	0.99	0.12–3.57
All uterine (179–182)	2	2.3	0.86	0.10–3.10	2	1.0	2.05	0.25–7.40	0	0.5	0.00	0.00–7.85
Cervix uteri (180)	2	1.2	1.63	0.20–5.90	0	0.5	0.00	0.00–7.88	0	0.2	0.00	0.00–20.1
Other female genital organs (183–184)	2	3.2	0.63	0.08–2.27	1	1.4	0.73	0.02–4.06	1	0.7	1.46	0.04–8.16
Prostate (185)	30	28.8	1.04	0.70–1.49	4	10.5	0.38	0.10–0.98	16	13.9	1.15	0.66–1.87
Testes and other male genital organs (186, 187)	2	1.6	1.23	0.15–4.44	0	0.4	0.00	0.00–9.64	0	0.3	0.00	0.00–14.7
Kidney (189.0–189.2)	15	11.1	1.35	0.76–2.23	2	3.6	0.56	0.07–2.03	4	3.6	1.11	0.30–2.84
Bladder and other urinary (188, 189.3–189.9)	9	9.7	0.93	0.43–1.77	4	3.5	1.15	0.32–2.96	3	4.1	0.73	0.15–2.13
Melanoma of skin (172)	10	9.0	1.11	0.53–2.04	1	2.7	0.37	0.01–2.08	2	2.5	0.82	0.10–2.95
Brain and central nervous system (191–192)	11	13.9	0.79	0.40–1.41	6	4.3	1.41	0.52–3.07	3	3.8	0.79	0.16–2.31
Thyroid and other endocrine glands (193–194)	1	1.5	0.66	0.02–3.68	0	0.5	0.00	0.00–7.60	1	0.4	2.28	0.06–12.7
Bone (170)	1	1.0	1.00	0.03–5.55	0	0.3	0.00	0.00–12.2	0	0.3	0.00	0.00–13.4
All lymphatic, hematopoietic tissue (200–208)	44	44.0	1.00	0.73–1.34	14	14.2	0.99	0.54–1.65	10	14.3	0.70	0.34–1.29
Non-Hodgkin lymphoma (200, 202)	21	17.2	1.22	0.76–1.87	4	5.6	0.72	0.20–1.84	4	5.6	0.72	0.20–1.84
Hodgkin lymphoma (201)	1	2.7	0.37	0.01–2.06	3	0.7	4.03	0.83–11.8	1	0.5	1.90	0.05–10.6
Leukemia and aleukemia (204–208)	15	16.5	0.91	0.51–1.50	5	5.3	0.94	0.30–2.19	3	5.4	0.55	0.11–1.61
Chronic lymphocytic leukemia (204.1)	2	2.8	0.71	0.09–2.57	1	1.0	1.03	0.03–5.73	0	1.1	0.00	0.00–3.36
Leukemia other than chronic lymphocytic leukemia	13	13.8	0.94	0.50–1.61	4	4.4	0.91	0.25–2.33	3	4.4	0.69	0.14–2.01
Multiple myeloma (203)	7	7.1	0.98	0.40–2.03	2	2.4	0.83	0.10–3.00	2	2.5	0.78	0.10–2.83
Pleura and peritoneum (158.8, 158.9, 163) and mesothelioma (ICD-10 C45)†	0	0.8	0.00	0.00–4.45	0	0.3	0.00	0.00–13.3	0	0.3	0.00	0.00–12.4
Smoking-related cancers (140–150, 161–162, 157, 188, 189)	205	214.6	0.96	0.83–1.10	66	71.7	0.92	0.71–1.17	60	74.5	0.81	0.62–1.04
AIDS (042–044, 795.8)	5	17.2	0.29	0.10–0.68	0	3.2	0.00	0.00–1.14	0	2.3	0.00	0.00–1.58
Diabetes (250)	15	28.0	0.54	0.30–0.88	9	9.2	0.98	0.45–1.86	6	9.4	0.64	0.24–1.39

(Continued)

TABLE 3
Continued

Duration of Employment at SSFL	<5 yr				5–9 yr				≥10 yr			
No. of workers	5661				1459				1252			
Person-yr of observation	180,497				44,554				29,157			
Cause of Death (ICD-9)	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI
Cerebrovascular disease (430–438)	61	77.1	0.79	0.61–1.02	21	28.1	0.75	0.46–1.14	20	33.0	0.61	0.37–0.94
All heart disease (390–398, 404, 410–429)	469	530.1	0.89	0.81–0.97	165	186.6	0.88	0.75–1.03	159	207.4	0.77	0.65–0.90
Nonmalignant respiratory disease excluding flu/pneumonia (460–479, 488–519)	78	82.5	0.95	0.75–1.18	34	30.0	1.13	0.79–1.59	41	34.8	1.18	0.84–1.60
Emphysema (492)	19	18.4	1.03	0.62–1.61	6	7.0	0.86	0.32–1.87	7	7.9	0.88	0.35–1.81
Cirrhosis of the liver (571)	37	66.8	0.55	0.39–0.76	4	20.3	0.20	0.05–0.50	7	17.2	0.41	0.16–0.84
Nephritis and nephrosis (580–589)	6	8.6	0.70	0.26–1.52	3	3.0	1.02	0.21–2.97	4	3.2	1.24	0.34–3.18
All external causes of death (800–999)	111	164.7	0.67	0.55–0.81	33	42.1	0.78	0.54–1.10	16	30.7	0.52	0.30–0.85
Accidents (850–949)	65	96.1	0.68	0.52–0.86	21	24.7	0.85	0.53–1.30	13	17.9	0.73	0.39–1.24
Suicides (950–959)	38	46.5	0.82	0.58–1.12	11	12.8	0.86	0.43–1.53	3	9.8	0.31	0.06–0.90
Unknown causes of death	39				8				3			

*One hundred eighty-two test stand workers who were monitored for radiation are included.

†Mesothelioma was not a codeable cause of death until 1999: ICD-10 (C45). Before 1999, cancers of the pleura and peritoneum (ICD-9 158.8, 158.9, 163) have been used to approximate mesothelioma mortality.

SSFL indicates Santa Susana Field Laboratory; ICD-9, International Classification of Diseases, 9th Revision; CI, confidence interval; ICD-10, International Classification of Diseases, 10th Revision.

tion categories. There were no significant elevations of any cause of death. Heart disease and cirrhosis of the liver occurred significantly below expectation among those whose duration of work at a test stand was ≥5 years.

The 182 radiation workers included with the test stand mechanics had little influence on the SMR analyses. Only eight cancer deaths occurred against 12.1 expected. There were three deaths due to lung cancer and one each from cancer of the stomach, larynx, prostate and bladder, and non-Hodgkin lymphoma. When radiation workers were excluded, the all-cause SMR changed from 0.88 to 0.90, the all cancer SMR from 1.00 to 1.03, and the lung cancer SMR from 1.07 to 1.10.

Nearly 88% (or 1440) of the 1642 male test stand mechanics could be assigned to a test stand for which the potential for hydrazines or TCE exposure could be assessed. Overall, 1111 (or 77.2%) had potential exposure to TCE as a utility solvent or during engine flush, 518 (or 27.6%) to TCE during engine flush, and 315 (or 21.9%) to hydrazines. There were 307 (or 21.3%) test stand mechanics with no potential exposure to either TCE or hydrazines. There were 498 (or 34.6%) workers with potential exposure to both TCE and hydrazines and 121 (or 8.4%) with potential exposure to both TCE during engine flush and hydrazines. When intracohort analyses were done regarding a specific chemical, adjustment was made for the other.

Table 6 presents SMRs for 37 causes of deaths for male test stand mechanics with respect to their potential for exposure to either hydrazines or any TCE (either during engine flush or as a utility solvent). The all cancer SMRs were not significantly elevated for workers potentially exposed to hydrazines (n = 315) or any TCE (n = 1111): 1.09 and 1.00, respectively. Lung cancer SMRs were elevated but not significantly: 1.45 and 1.24, respectively. Smoking-related cancers (SMR =

TABLE 4

Intracohort Dose–Response and Relative Risk (RR)* Computations for All Cancers Combined and Other Causes of Death for SSFL Workers† Over Categories of Years Worked at SSFL (all Rocketdyne workers who were not test stand mechanics or monitored for radiation were used as referent)

	All Cancers				Lung Cancer			Nonmalignant Respiratory Disease		
Years Worked at SSFL	No.	Observed	RR‡	95% CI	Observed	RR§	95% CI	Observed	RR‖	95% CI
Referent (all Rocketdyne)	32,979	2086	1.00	Ref	705	1.00	Ref	419	1.00	Ref
<5 yr	5637	403	1.06	0.95–1.18	131	1.04	0.86–1.26	78	1.13	0.88–1.44
5–14 yr	2197	204	0.93	0.80–1.07	64	0.86	0.66–1.11	61	1.27	0.97–1.67
≥15 yr	538	48	0.86	0.65–1.15	20	1.04	0.66–1.62	14	1.08	0.63–1.85
			P for trend: 0.09			*P* for trend: 0.42			*P* for trend: 0.36	
Total for SSFL	8372	655			215			153		
	Esophageal Cancer				Stomach Cancer			Colorectal Cancer		
	No.	Observed	RR	95% CI	Observed	RR	95% CI	Observed	RR	95% CI
Referent (all Rocketdyne)	32,979	40	1.00	Ref	66	1.00	Ref	177	1.00	Ref
<5 yr	5637	13	1.50	0.80–2.83	11	0.89	0.47–1.69	37	1.10	0.77–1.58
5–9 yr	1480	2	0.74	0.18–3.09	5	1.19	0.48–2.97	16	1.46	0.87–2.44
≥10 yr	1255	6	1.81	0.75–4.32	7	1.32	0.60–2.92	17	1.26	0.76–2.09
			P for trend: 0.05			*P* for trend: 0.81			*P* for trend: 0.35	
Total for SSFL		21			23			70		
	Pancreas Cancer				Prostate Cancer			Kidney Cancer		
	No.	Observed	RR	95% CI	Observed	RR	95% CI	Observed	RR	95% CI
Referent (all Rocketdyne)	32,979	112	1.00	Ref	143	1.00	Ref	53	1.00	Ref
<5 yr	5637	20	0.94	0.58–1.53	30	1.13	0.76–1.68	15	1.47	0.82–2.63
5–9 yr	1480	9	1.33	0.67–2.64	4	0.41	0.15–1.12	2	0.64	0.16–2.65
≥10 yr	1255	7	0.89	0.41–1.93	16	1.14	0.68–1.93	4	1.11	0.40–3.13
			P for trend: 0.91			*P* for trend: 0.73			*P* for trend: 0.68	
Total for SSFL		36			50			21		
	Central Nervous System Cancer				Non-Hodgkin Lymphoma			Leukemia		
	No.	Observed	RR	95% CI	Observed	RR	95% CI	Observed	RR	95% CI
Referent (all Rocketdyne)	32,979	65	1.00	Ref	75	1.00	Ref	76	1.00	Ref
<5 yr	5637	11	0.85	0.45–1.63	21	1.44	0.88–2.36	15	0.96	0.55–1.69
5–9 yr	1480	6	1.59	0.68–3.70	4	0.84	0.31–2.31	5	0.97	0.39–2.41
≥10 yr	1255	3	0.73	0.23–2.35	4	0.73	0.26–2.00	3	0.46	0.14–1.47
			P for trend: 0.77			*P* for trend: 0.54			*P* for trend: 0.25	
Total for SSFL		20			29			23		

*RR (hazards ratio) from Cox proportional hazards model treating yr worked at SSFL as a time-dependent variable. All models adjusted for pay type, year of birth, year of hire, and gender. *P* for trend computed by treating yr worked as a continuous and time-dependent variable.

†One hundred eighty-two test stand workers who were monitored for radiation are included.

‡The corresponding all cancer SMRs for these categories based on California (and US) population rates are 0.94 (0.87), 0.92 (0.85), 0.86 (0.80), and 0.80 (0.74).

§The corresponding lung cancer SMRs for these categories based on California (and US) population rates are 1.02 (0.89), 0.91 (0.78), 0.83 (0.73), and 0.98 (0.84).

‖The corresponding nonmalignant respiratory disease SMRs for these categories based on California (and US) rates are 0.95 (0.90), 0.95 (0.88), 1.19 (1.12), and 1.02 (0.95).

SSFL indicates Santa Susana Field Laboratory; CI, confidence interval; SMRs, standardized mortality ratios.

1.36 and 1.20) and nonrespiratory lung disease (SMR = 1.16 and 1.19) were also elevated among workers exposed to hydrazines or TCE, respectively. Because all test stand mechanics were hourly workers, who have been consistently found to use tobacco products to a greater extent than men in the general population,[12] the slight increase in smoking-related sites observed may be due in part to increased smoking habits when comparisons are made with the general population.

For the 315 test stand mechanics with likely exposure to hydrazines, there were no significantly high or significantly low causes of death. Two deaths due to kidney cancer occurred and 0.8 were expected. No deaths from bladder cancer occurred (0.7 expected). Only one death due to leukemia was reported (1.2 expected). There were no material dif-

TABLE 5
Observed and Expected Numbers of Deaths and Standardized Mortality Ratios (SMRs) Based on California Population Rates for Male Hourly Test Stand Mechanics* by Duration of Employment as a Test Stand Mechanic

Duration of Work as a Test Stand Mechanics	<5 yr				≥5 yr				Total			
No. of Test Stand Mechanics	1168				474				1642			
Person-Years of Observation	39,416				16,870				56,286			
Cause of Death (ICD-9)	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI
All causes of death (001–999)	376	417.0	0.90	0.81–1.00	194	232.7	0.83	0.72–0.96	570	649.7	0.88	0.81–0.95
All malignant neoplasms (140–208)	116	112.1	1.03	0.86–1.24	58	61.7	0.94	0.71–1.22	174	173.8	1.00	0.86–1.16
Buccal cavity and pharynx (140–149)	3	3.0	1.01	0.21–2.94	2	1.6	1.25	0.15–4.51	5	4.6	1.09	0.35–2.54
Esophagus (150)	3	3.2	0.94	0.19–2.75	2	1.7	1.20	0.15–4.35	5	4.8	1.03	0.34–2.41
Stomach (151)	5	4.0	1.24	0.40–2.89	5	2.3	2.19	0.71–5.11	10	6.3	1.58	0.76–2.91
Colorectal (153–154)	11	11.0	1.00	0.50–1.79	8	6.3	1.27	0.55–2.51	19	17.3	1.10	0.66–1.71
Biliary passages and liver (155, 156)	3	3.0	1.01	0.21–2.94	1	1.5	0.66	0.02–3.67	4	4.5	0.89	0.24–2.28
Pancreas (157)	3	5.9	0.51	0.11–1.49	2	3.2	0.62	0.08–2.23	5	9.1	0.55	0.18–1.28
Larynx (161)	3	1.3	2.34	0.48–6.85	1	0.7	1.44	0.04–8.02	4	2.0	2.03	0.55–5.19
Bronchus, trachea, and lung (162)	41	38.2	1.07	0.77–1.46	22	20.8	1.06	0.66–1.60	63	59.0	1.07	0.82–1.37
Breast (175)	0	0.1	0.00	0.00–27.4	0	0.1	0.00	0.00–50.4	0	0.2	0.00	0.00–17.7
Prostate (185)	9	8.6	1.05	0.48–1.98	5	5.5	0.90	0.29–2.10	14	14.2	0.99	0.54–1.66
Testes and other male genital organs (186, 187)	1	0.4	2.40	0.06–13.4	0	0.2	0.00	0.00–19.6	1	0.6	1.66	0.04–9.22
Kidney (189.0–189.2)	5	3.0	1.69	0.55–3.95	3	1.5	1.95	0.40–5.71	8	4.5	1.78	0.77–3.51
Bladder and other urinary (188, 189.3–189.9)	5	2.7	1.85	0.60–4.32	0	1.7	0.00	0.00–2.21	5	4.4	1.14	0.37–2.67
Melanoma of skin (172)	2	2.3	0.86	0.10–3.10	0	1.1	0.00	0.00–3.33	2	3.4	0.58	0.07–2.10
Brain and central nervous system (191–192)	3	3.5	0.85	0.18–2.49	0	1.7	0.00	0.00–2.11	3	5.3	0.57	0.12–1.67
Thyroid and other endocrine glands (193–194)	0	0.4	0.00	0.00–10.0	0	0.2	0.00	0.00–19.3	0	0.6	0.00	0.00–6.61
Bone (170)	0	0.3	0.00	0.00–14.7	0	0.1	0.00	0.00–27.7	0	0.4	0.00	0.00–9.62
All lymphatic, hematopoietic tissue (200–208)	12	11.3	1.06	0.55–1.85	6	6.1	0.99	0.36–2.14	18	17.4	1.03	0.61–1.63
Non-Hodgkin lymphoma (200, 202)	4	4.4	0.90	0.25–2.31	2	2.3	0.86	0.10–3.10	6	6.8	0.89	0.33–1.93
Hodgkin lymphoma (201)	0	0.7	0.00	0.00–5.58	2	0.3	6.09	0.74–22.0	2	1.0	2.02	0.25–7.31
Leukemia and aleukemia (204–208)	6	4.3	1.40	0.52–3.05	2	2.3	0.86	0.10–3.10	8	6.6	1.21	0.52–2.39
Chronic lymphocytic leukemia (204.1)	1	0.8	1.31	0.03–7.30	0	0.5	0.00	0.00–8.17	1	1.2	0.82	0.02–4.59
Leukemia other than chronic lymphocytic leukemia	5	3.5	1.41	0.46–3.29	2	1.9	1.06	0.13–3.82	7	5.4	1.29	0.52–2.65
Multiple myeloma (203)	2	1.9	1.08	0.13–3.89	0	1.0	0.00	0.00–3.59	2	2.9	0.69	0.08–2.50
Pleura and peritoneum (158.8, 158.9, 163) and mesothelioma (ICD-10 C45)†	0	0.2	0.00	0.00–16.5	0	0.1	0.00	0.00–30.5	0	0.3	0.00	0.00–10.7
Smoking-related cancers (140–150, 161–162, 157, 188, 189)	63	57.2	1.10	0.85–1.41	32	31.2	1.03	0.70–1.45	95	88.4	1.07	0.87–1.31
AIDS (042–044, 795.8)	0	3.6	0.00	0.00–1.02	0	1.0	0.00	0.00–3.52	0	4.7	0.00	0.00–0.79
Diabetes (250)	7	7.0	1.00	0.40–2.07	2	3.7	0.54	0.07–1.96	9	10.7	0.84	0.39–1.60
Cerebrovascular disease (430–438)	14	19.5	0.72	0.39–1.21	12	12.3	0.98	0.50–1.71	26	31.8	0.82	0.54–1.20
All heart disease (390–398, 404, 410–429)	124	143.4	0.87	0.72–1.03	63	84.9	0.74	0.57–0.95	187	228.3	0.82	0.71–0.95
Nonmalignant respiratory disease, excluding influenza and pneumonia (460–479, 488–519)	26	21.9	1.19	0.77–1.74	17	13.4	1.26	0.74–2.03	43	35.4	1.22	0.88–1.64
Emphysema (492)	4	4.9	0.81	0.22–2.08	3	3.2	0.94	0.19–2.75	7	8.1	0.86	0.35–1.78
Cirrhosis of the liver (571)	8	17.3	0.46	0.20–0.91	2	8.2	0.24	0.03–0.88	10	25.5	0.39	0.19–0.72
Nephritis and nephrosis (580–589)	2	2.2	0.91	0.11–3.28	3	1.3	2.33	0.48–6.80	5	3.5	1.43	0.47–3.34
All external causes of death (800–999)	30	39.3	0.76	0.51–1.09	8	16.9	0.47	0.20–0.93	38	56.2	0.68	0.48–0.93
Accidents (850–949)	17	23.1	0.74	0.43–1.18	6	10.0	0.60	0.22–1.31	23	33.0	0.70	0.44–1.05

(Continued)

TABLE 5
Continued

Duration of Work as a Test Stand Mechanics	<5 yr				≥5 yr				Total			
No. of Test Stand Mechanics	1168				474				1642			
Person-Years of Observation	39,416				16,870				56,286			
Cause of Death (ICD-9)	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI
Suicides (950–959)	12	11.5	1.04	0.54–1.82	1	5.2	0.19	0.01–1.08	13	16.6	0.78	0.42–1.34
Unknown causes of death	7				4				11			

*One hundred eighty-two test stand workers who were monitored for radiation are included.

†Mesothelioma was not a codeable cause of death until 1999: ICD-10 (C45). Before 1999, cancers of the pleura and peritoneum (ICD-9 158.8, 158.9, 163) have been used to approximate mesothelioma mortality.

ICD-9 indicates International Classification of Diseases, 9th Revision; CI, confidence interval; ICD-10, International Classification of Diseases, 10th Revision.

ferences between the 315 workers with likely and the 205 workers with "possible but not likely" hydrazine exposure, although the latter group tended to have higher SMRs (data not shown).

For the 1111 test stand mechanics with potential exposure to TCE, either from engine flush or use as a utility solvent, there also were no significantly high or significantly low SMRs. Non-Hodgkin lymphoma occurred slightly below expectation (one observed and 4.7 expected) and liver cancer slightly above (four observed and 3.1 expected). Kidney cancer was elevated based on seven observed deaths (SMR = 2.22; 95% CI = 0.89–4.57).

Table 7 presents intracohort analyses for test stand mechanics by years of work as a test stand mechanic, years of potential exposure to hydrazines, and years of potential exposure to TCE for all cancers taken together, lung cancer and kidney cancer, and other cancers with at least 10 observed deaths. Corresponding SMRs for the analyses are presented in footnotes. Analyses using several different referent groups were conducted including Rocketdyne workers and SSFL workers.

Over categories of years worked as a test stand mechanic, no significant elevations or trends were observed for all cancers combined or for any specific cancer. Slight decreases in relative risk (RR) with increased years worked were suggested for all cancers combined, lung cancer, and prostate cancer. Slight increases in RR were seen for cancers of the kidney, stomach, and colorectum, but the patterns were erratic. The trend for stomach cancer was of borderline significance ($P = 0.06$). Based on a total of eight kidney cancers, the RRs for years worked of <1 year, 1 to 4 years, and ≥5 years were 1.27, 2.13, and 2.12, respectively, but the trend was not significant ($P = 0.32$).

Four categories of potential exposure to hydrazines were used in the analyses: test stand mechanics who did not work at a test stand with potential hydrazine exposure ($n = 920$), test stand mechanics with "possible but not likely" exposure to hydrazines ($n = 205$), test stand mechanics with likely exposure to hydrazines for less than 1.5 years ($n = 156$), and test stand mechanics with likely exposure to hydrazines for greater than or equal to 1.5 years ($n = 159$). The 1.5-year cutoff was chosen to have equal numbers of workers in each category of years worked. No significant trends were seen. For lung cancer, 15 deaths occurred among those with likely exposure to hydrazines, and all of the RRs were below 1.0, including those who worked more than 1.5 years (RR = 0.70; 95% CI = 0.24–2.05). If the 1598 SSFL hourly workers were used as referent instead of all Rocketdyne hourly workers, the patterns and trends remained the same, eg, the lung cancer RRs are 1.00, 0.52, 0.96, 0.79, and 0.76 ($P = 0.63$) in contrast to 1.00, 0.47, 0.89, 0.74, and 0.70 ($P = 0.80$). The SMRs based on California rates for these categories are 1.30, 0.84, 0.81, 1.45, and 1.45. Lung cancer SMRs were higher than the intracohort RRs, likely reflecting in part differences between hourly workers and the general population in smoking histories that could not be adjusted for in the SMR analyses. Kidney cancer was elevated for all comparisons but no significant trends were seen. Only two deaths due to kidney cancer occurred among the 315 workers with likely exposure to hydrazines.

Table 7 also presents the relative risks for the 1111 test stand mechanics with potential exposure to TCE. No significant trends or significant RRs were seen for any category of years of potential exposure to any TCE (engine flush and/or utility solvent) for all cancers taken together, lung cancer, or kidney cancer. Similarly, there were no significant trends for these cancers among the 518 workers with potential TCE exposure during the flushing or cleaning of engines using the weighted mea-

TABLE 6
Observed and Expected Numbers of Deaths and Standardized Mortality Ratios (SMRs) for Male Hourly Test Stand Mechanics* by Potential Exposure to Hydrazines and Trichloroethylene (TCE)

Potential Chemical Exposure	Hydrazines (likely)				Any TCE (either utility or engine flush)			
No. of Test Stand Mechanics Person-Years of Observation	315 10,717				1111 39,687			
Cause of Death (ICD-9)	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI
All causes of death (001–999)	101	114.0	0.89	0.72–1.08	391	451.2	0.87	0.78–0.96
All malignant neoplasms (140–208)	33	30.4	1.09	0.75–1.52	121	121.2	1.00	0.83–1.19
Buccal cavity and pharynx (140–149)	2	0.8	2.48	0.30–8.96	4	3.2	1.25	0.34–3.21
Esophagus (150)	0	0.9	0.00	0.00–4.31	3	3.4	0.88	0.18–2.58
Stomach (151)	1	1.1	0.91	0.02–5.09	6	4.4	1.37	0.50–2.99
Colorectal (153–154)	5	3.0	1.67	0.54–3.89	13	12.0	1.08	0.58–1.85
Biliary passages and liver (155,156)	0	0.8	0.00	0.00–4.61	4	3.1	1.28	0.35–3.27
Pancreas (157)	1	1.6	0.63	0.02–3.49	2	6.4	0.32	0.04–1.14
Larynx (161)	1	0.3	2.90	0.07–16.2	2	1.4	1.45	0.18–5.25
Bronchus, trachea, and lung (162)	15	10.3	1.45	0.81–2.39	51	41.2	1.24	0.92–1.63
Prostate (185)	3	2.4	1.26	0.26–3.68	8	9.7	0.82	0.36–1.62
Testes and other male genital organs (186, 187)	0	0.1	0.00	0.00–32.7	0	0.4	0.00	0.00–8.53
Kidney (189.0–189.2)	2	0.8	2.51	0.30–9.08	7	3.2	2.22	0.89–4.57
Bladder and other urinary (188, 189.3–189.9)	0	0.7	0.00	0.00–4.97	5	3.0	1.66	0.54–3.87
Melanoma of skin (172)	0	0.6	0.00	0.00–5.87	0	2.4	0.00	0.00–1.51
Brain and central nervous system (191–192)	0	1.0	0.00	0.00–3.88	3	3.7	0.81	0.17–2.36
Thyroid and other endocrine glands (193–194)	0	0.1	0.00	0.00–37.0	0	0.4	0.00	0.00–9.39
Bone (170)	0	0.1	0.00	0.00–54.0	0	0.3	0.00	0.00–13.8
All lymphatic, hematopoietic tissue (200–208)	2	3.1	0.65	0.08–2.34	9	12.2	0.74	0.34–1.40
Non-Hodgkin lymphoma (200, 202)	0	1.2	0.00	0.00–3.07	1	4.7	0.21	0.01–1.18
Hodgkin lymphoma (201)	0	0.2	0.00	0.00–20.5	2	0.7	2.86	0.35–10.3
Leukemia and aleukemia (204–208)	1	1.2	0.86	0.02–4.78	5	4.6	1.08	0.35–2.53
Chronic lymphocytic leukemia (204.1)	0	0.2	0.00	0.00–17.7	1	0.8	1.19	0.03–6.61
Leukemia other than chronic lymphocytic leukemia	1	1.0	1.04	0.03–5.77	4	3.8	1.05	0.29–2.69
Multiple myeloma (203)	1	0.5	1.98	0.05–11.1	1	2.0	0.50	0.01–2.77
Smoking-related cancers (140–150, 161–162, 157, 188, 189)	21	15.5	1.36	0.84–2.08	74	61.7	1.20	0.94–1.51
AIDS (042–044, 795.8)	0	1.0	0.00	0.00–3.74	0	3.0	0.00	0.00–1.23
Diabetes (250)	0	1.9	0.00	0.00–1.95	5	7.5	0.67	0.22–1.56
Cerebrovascular disease (430–438)	3	5.4	0.56	0.12–1.64	16	21.8	0.73	0.42–1.19
All heart disease (390–398, 404, 410–429)	41	39.3	1.04	0.75–1.42	131	158.0	0.83	0.69–0.98
Nonmalignant respiratory disease, excluding influenza and pneumonia (460–479, 488–519)	7	6.0	1.16	0.47–2.38	29	24.4	1.19	0.80–1.71
Emphysema (492)	1	1.4	0.74	0.02–4.12	5	5.5	0.90	0.29–2.11
Cirrhosis of the liver (571)	2	4.7	0.43	0.05–1.54	7	18.1	0.39	0.16–0.80
Nephritis and nephrosis (580–589)	0	0.6	0.00	0.00–6.09	5	2.4	2.07	0.67–4.82

(Continued)

TABLE 6
Continued

Potential Chemical Exposure	Hydrazines (likely)				Any TCE (either utility or engine flush)			
No. of Test Stand Mechanics Person-Years of Observation	315 10,717				1111 39,687			
Cause of Death (ICD-9)	Observed	Expected	SMR	95% CI	Observed	Expected	SMR	95% CI
All external causes of death (800–999)	8	10.8	0.74	0.32–1.46	25	39.7	0.63	0.41–0.93
Accidents (850–949)	5	6.3	0.79	0.26–1.84	14	23.4	0.60	0.33–1.01
Suicides (950–959)	3	3.1	0.96	0.20–2.79	10	11.8	0.85	0.41–1.56
Unknown causes of death	0				6			

*One hundred eighty-two test stand workers who were monitored for radiation are included.
ICD-9 indicates International Classification of Diseases, 9th Revision; CI, confidence interval.

sure of exposure that takes into account the number of tests performed during a specific year at a specific test area and the number of workers assigned to that same area. There was a suggestion of a positive dose–response for kidney cancer, but it was not significant and based on only four deaths among those with potential exposure to TCE during engine flush. We examined whether these four workers who died of kidney cancer had a common work environment and found that they each had worked at a different test stand.

TCE analyses of the two other malignancies most frequently reported to be elevated in studies of TCE exposure (ie, cancers of the liver and non-Hodgkin lymphoma) also failed to indicate significantly increased risks.

Additional SMR and intracohort analyses were conducted for SSFL workers and the other Rocketdyne workers by pay type (data not shown). Hourly workers generally had higher SMRs than salaried workers for most causes of death. Differences in death due to lung cancer, nonmalignant respiratory disease, and heart disease were especially pronounced between hourly and salaried workers at both SSFL and the other Rocketdyne facilities, suggesting, again, the likelihood that tobacco use was more frequent among hourly workers. There were no trends in lung cancer among SSFL or non-SSFL workers over categories of years worked for hourly or salaried workers.

Table 8 presents risks of all cancers combined and lung cancer by decade of employment for male workers employed as test stand mechanics. The RRs presented contrast working more than 3 years as a test stand mechanic during a certain decade with working less than 3 years during that same decade. There were no significant RRs for any decade of employment nor were there any significant trends. Nonsignificant increased risks were seen for 1980 to 1999 employment for all cancers combined (RR = 1.47) and for 1960 to 1969 employment for lung cancer (RR = 1.40). Nonsignificant decreased risks were seen for 1970 to 1979 employment for all cancers combined (RR = 0.65) and for lung cancer (RR = 0.80). Although employment before 1970 appeared associated with an increased risk of lung cancer, this was not the case for all cancers combined. These inconsistent results by decade of employment provide little evidence for increased cancer risk overall or for certain decades for which exposures may have been more intense than others.

Discussion

There is little consistent evidence for increased cancer mortality among workers at SSFL who were potentially exposed to a wide range of chemicals in the course of testing rocket engines over a 50-year period. In particular, test stand mechanics who had the greatest exposure potential to rocket engine fuels such as hydrazines or industrial solvents such as TCE were not found to be at significantly increased risk of death from cancers of the lung, liver, bladder, esophagus, kidney, or non-Hodgkin lymphoma. Although actual exposure to hydrazines or TCE could only be inferred from a worker's job history at a specific test area where these chemicals were used, employment as a test stand mechanic would encompass all possible exposures to a "test stand environment," and analyses by duration of employment also failed to reveal any excess cancer mortality. These findings are perhaps not surprising given that exposures at rocket engine testing areas were outdoors and episodic and thus generally less intense than possible within enclosed facilities.

Hydrazines are white or colorless liquids with an ammonia-like odor that are used in rocket fuels, chemical manufacturing, and as an oxygen scavenger in the treatment of boiler water. The National Research Council recently concluded that the potential cancer risk from inhalation exposures to hydrazines cannot be determined from available human studies.[13] Hydrazines are suspected as possible human carcinogens, however, because they have produced liver, mammary, and lung tumors in rodents after inhalation or oral administration.[10,14,15] Although there is sufficient evidence that hydrazines can cause cancer in experimental animals, the human evidence is inadequate.[10] A cohort of 427 men occupationally exposed to hydrazines between 1945 and 1971 experienced no increase in death due to cancers of the lung (eight observed versus 12.1 expected), digestive system, or any cause.[16] The previous study of Rocketdyne workers assumed that all test stand mechanics were exposed to hydrazines and reported a significant association between hydrazines and lung cancer.[1,17] Based on a more precise exposure assessment, we identified a much smaller number of workers within this cohort (n = 315) with likely exposure to hydrazines and followed them for an average of 34.0 years. Lung cancer (n = 15) was increased in comparison with the general population (SMR = 1.45; 95% CI = 0.81–2.39), but the increase may reflect in part differences in tobacco use between hourly test stand workers and the population in general. The intracohort comparisons with other Rocketdyne workers did not find lung cancer risk to increase with years of potential exposure to hydrazines. The 159 test stand mechanics who worked the longest, ie, more than 1.5 years at test stands where hydrazines were used as a rocket engine propellant, were not at increased risk of lung cancer (RR = 0.70). The 205 workers who were "possibly but not likely" exposed to hydrazines had similar but slightly higher mortality risks for lung cancer as the 315 workers who were likely to have been exposed, providing lit-

TABLE 7

Intracohort Dose–Response and Relative Risk (RR)* Computations for All Cancers Combined and Cancers of the Lung, Kidney, Stomach, Colorectum, and Prostate for Test Stand Mechanics† Over Categories of Years Worked as a Test Stand Mechanic, Cumulative Potential Exposure to Hydrazines (likely and possible),‡ and Cumulative Potential Exposure to Trichloroethylene (TCE; any and engine flush)§ (all Rocketdyne workers who were not test stand mechanics or monitored for radiation were used as referent)

		All Cancers			Lung Cancer			Kidney Cancer		
	No.	Observed	RR	95% CI	Observed	RR	95% CI	Observed	RR	95% CI
Years worked as a test stand mechanic										
Referent¶	13,342	1168	1.00	Ref	474	1.00	Ref	28	1.00	Ref
<1 yr	368	35	1.05	0.75–1.47	10	0.74	0.39–1.38	1	1.27	0.17–9.34
1–4 yr	800	81	1.01	0.80–1.26	31	0.94	0.65–1.36	4	2.13	0.74–6.16
≥5 yr	474	58	0.93	0.71–1.22	22	0.86	0.56–1.33	3	2.12	0.63–7.11
			P for trend: 0.72			*P* for trend: 0.82			*P* for trend: 0.32	
Total test stand mechanics	1642	174			63			8		
Potential hydrazine exposure‡										
Referent**	13,342	1168	1.00	Ref	474	1.00	Ref	28	1.00	Ref
No hydrazine exposure	920	92	0.79	0.54–1.15	30	0.47	0.22–1.00	4	1.66	0.57–4.83
Possible (not likely) Hydrazine exposure	205	24	0.97	0.54–1.76	13	0.89	0.33–2.43	1	2.01	0.27–14.8
Likely hydrazine exposure <1.5 yr	156	17	1.05	0.56–1.99	7	0.74	0.25–2.23	2‖	2.79	0.66–11.8
Likely hydrazine exposure ≥1.5 yr	159	16	0.82	0.43–1.57	8	0.70	0.24–2.05			
			P for trend: 0.99			*P* for trend: 0.80			*P* for trend: 0.09	
Total likely hydrazine exposure	315	33			15			2		
Years worked with potential exposure to any TCE§										
Referent	13,342	1168	1.00	Ref	474	1.00	Ref	28	Model does not converge	
0	329	28	0.79	0.54–1.14	7	0.47	0.22–1.00	0		
<4 yr	695	69	0.93	0.71–1.23	27	0.80	0.50–1.26	4		
≥4 yr	416	52	0.87	0.61–1.24	24	0.80	0.46–1.41	3		
			P for trend: 0.56			*P* for trend: 0.69				
Total TCE (any)	1111	121			51			7		
Potential exposure to TCE (engine flush)§										
Referent	13,342	1168	1.00	Ref	474	1.00	Ref	28	1.00	Ref
0	922	89	0.82	0.65–1.04	35	0.68	0.46–1.01	3	1.21	0.33–4.35
<4 test-yr	179	18	1.07	0.64–1.79	6	0.64	0.26–1.57	1	2.51	0.27–23.5
≥4 test-yr	339	42	0.99	0.70–1.42	17	0.76	0.42–1.36	3	3.13	0.74–13.2
			P for trend: 0.48			*P* for trend: 0.69			*P* for trend: 0.59	
Total TCE flush	518	60			23			4		

(Continued)

TABLE 7
Continued

		Stomach Cancer			Colorectal Cancer			Prostate Cancer		
	No.	Observed	RR	95% CI	Observed	RR	95% CI	Observed	RR	95% CI
Years worked as a test stand mechanic										
Referent¶	13,342	44	1.00	Ref	99	1.00	Ref	102	1.00	Ref
<1 yr	368	2	1.65	0.40–6.82	4	1.48	0.54–4.03	5	2.00	0.81–4.93
1–4 yr	800	3	1.00	0.31–3.25	7	1.08	0.50–2.34	4	0.62	0.23–1.70
≥ 5 yr	474	5	2.10	0.82–5.38	8	1.60	0.77–3.33	5	0.86	0.35–2.14
			P for trend: 0.06			*P* for trend: 0.16			*P* for trend: 0.91	
Total test stand mechanics	1642	10			19			14		

*RR (hazards ratio) from Cox proportional hazards model. All models adjusted for year of birth and year of hire. Because all test stand mechanics were hourly nonadministrative workers, the referent group is comprised only of hourly nonadministrative workers at SSFL and the nearby facilities. Models for hydrazine are additionally adjusted for potential exposure to TCE. Models for TCE are additionally adjusted for potential exposure to hydrazine.

†Two hundred two test stand mechanics who could not be assigned to a test stand are excluded from the hydrazine and TCE analyses.

‡Potential exposure to hydrazine could only be inferred from working at specific rocket engine test stands where hydrazines were used. For some test stands, hydrazines were used throughout and thus the potential for exposure was "likely." For other test stands, hydrazines were used specifically or only at one of several areas and thus the potential for exposure was "possible" but unlikely.

§"Any TCE" exposure potential includes possible use of TCE as a utility solvent and working at a rocket engine test stand where engines were cleaned by flushing with TCE. The yr of potential exposure to TCE during engine cleaning (ie, flush) are weighted by the number of engine tests performed during specific calendar yr and the number of workers during those yr (see "Methods").

‖The "likely: hydrazine categories of >0–1.4 yr and ≥ 1.5 yr had to be combined for model convergence.

¶Different referent groups for the analyses of "yr worked as a test stand mechanic" were evaluated with little difference in the patterns of risk. For example, if the 1598 SSFL hourly workers were used as referent instead of all Rocketdyne hourly workers, the all cancer RRs are 1.00, 1.09, 1.05, and 0.99 ($P = 0.95$); the lung cancer RRs are 1.00, 0.80, 1.02, and 0.96 ($P = 0.64$); and the kidney cancer RRs are 1.00, 1.02, and 1.61 ($P = 0.88$). The corresponding SMRs based on California population rates for all cancer are 1.07, 0.88, 1.02, and 0.94; the lung cancer SMRs are 1.30, 0.91, 1.14, and 1.06; the kidney cancer SMRs are 1.03, 1.15, 1.91, and 1.95; the stomach cancer SMRs are 1.71, 1.05, and 2.19; the colorectal cancer SMRs are 1.29, 0.89, and 1.29; and the prostate SMRs are 2.09, 0.64, and 0.90.

**Different referent groups for the analyses of "potential hydrazine exposure" were evaluated with little difference in the patterns of risk. For example, if the 1598 SSFL hourly workers were used as referent instead of all Rocketdyne hourly workers, the all cancer RRs are 1.00, 0.82, 1.01, 1.08, and 0.86 ($P = 0.86$); the lung cancer RRs are 1.00, 0.52, 0.96, 0.79, and 0.76 ($P = 0.63$); and the kidney cancer RRs are 1.00, 1.20, 1.63, and 2.13 ($P = 0.36$). The corresponding SMRs based on California population rates for all cancer are 1.07, 1.05, 1.14, 0.98, and 1.20; the lung cancer SMRs are 1.30, 0.84, 1.81, 1.45, and 1.45; and the kidney cancer SMRs are 1.03, 1.58, 1.80, and 2.58.

CI indicates confidence interval; SSFL, Santa Susana Field Laboratory; SMRs, standardized mortality ratios; Ref, referrant.

TABLE 8
Relative Risk (RR)* Computations for All Cancer Combined and Lung Cancer for Test Stand Mechanics† by Decade of Employment (exposure is defined as 3 or more years as a test stand mechanic compared with <3 yr during each decade‡)

	All Cancers				Lung Cancer		
Time Period	No.‡	Observed‡	RR	95% CI	Observed‡	RR	95% CI
Pre-1960	984	123	1.08	0.75–1.57	43	1.29	0.70–2.40
1960–1969	1454	167	0.99	0.69–1.43	61	1.40	0.80–2.47
1970–1979	530	58	0.65	0.28–1.51	25	0.80	0.23–2.83
1980–1999	387	25	1.47	0.56–3.91	11	0.45	0.05–3.82
Total	1642	174			63		

*RR (hazards ratio) from Cox proportional hazards model with adjustment for year of birth and year of hire.

†One hundred eighty-two test stand mechanics who were monitored for radiation are included.

‡Workers and cancers can appear in more than one category if test sand mechanic worked in more than one time period.

CI indicates confidence interval.

tle support for an association between hydrazines and lung cancer. Nonetheless, a small increase in lung cancer cannot be completely ruled out and should be evaluated further in any additional follow up of the SSFL population.

TCE is a colorless and sweet-smelling liquid that was widely used after World War II as a solvent to remove grease from metal parts. In animal experiments, TCE has been shown to induce cancers of the kidney, liver, lung, testis, and lymph nodes.[18,19] The IARC in 1995 classified TCE as a probable human carcinogen based on experimental animal data and the limited evidence from epidemiologic studies.[18] There have been three cohort studies of workers in the aerospace industry that assessed TCE exposure at the individual level, but no consistent patterns were seen.[6–8] A recent review concluded that the strongest evidence in humans was for cancers of the kidney and liver.[20] For the 1111 male test stand workers in our study with potential for TCE exposure, either from use as a utility solvent to clean small metal parts or in the course of engine cleaning with relatively large volumes of TCE, cancers suspected to be caused by TCE, ie, cancers of the esophagus, liver, bladder, kidney, and lymphoma, were not significantly increased in any analyses. Cancer of the lung (SMR = 1.24; 95% CI = 0.92–1.63) was increased in comparison with the general population, but there was no increase seen when intracohort comparisons were made with other Rocketdyne workers. There was no evidence of a dose–response over categories of years of potential TCE exposure, and the RR among lung cancer for workers with 4 or more years of potential TCE exposure was 0.80.

Cancer of the kidney was increased compared with the general population (SMR = 2.22; 95% 0.89–4.57) based on seven deaths, and there was a suggestion of a dose–response, relation. Kidney cancer has been inconsistently associated with TCE exposures in epidemiologic studies,[11,21,22] although there have been increases reported in several case–control and cluster evaluations.[20] Arguments favoring a causal interpretation in our series include the magnitude of the increase risk, slightly over twofold, the suggestion of a dose–response, and the consistency with animal evidence. Arguments against a causal interpretation include the small numbers of observed cases (ie, no association was statistically significant), the absence of any increased risk for other cancers such as lymphoma thought to be inducible by TCE, the role of chance due to multiple comparisons, and possible exposure assessment inaccuracies. Although the test stands were outdoors and exposure was much less concentrated than in an enclosed environment, the finding should be evaluated further in any additional follow up of the Rocketdyne population.

Interestingly, there also was a suggestion of a dose–response relation between kidney cancer and estimated radiation dose in the study of radiation workers at the Rocketdyne facilities.[2] However, there was no overlap. None of the 182 test stand mechanics who also had been radiation workers had died from kidney cancer, and their cumulative occupational radiation dose was very low, only 26.5 mSv, so that a radiation effect was improbable. In comparison, the cumulative lifetime exposure to natural sources of radiation is of the order of 210 mSv.

Strengths and Limitations

Strengths of our investigation include the nearly complete follow up of the workforce (over 99%), the ability to assign workers to specific engine test stands where hydrazines and TCE were used, the availability of a large group of workers in nearby facilities owned by Rocketdyne to serve as an additional comparison group, and the consistency of results using different analytic approaches. The follow up was for up to 50 years (27.5 years on average), providing ample time to detect an increase in cancer deaths had there been any. The potential for exposure to chemicals associated with the testing of rocket engines could be evaluated because of the existence of detailed job history work records and personnel listings (specialized phone directories) that placed workers at specific test stands during specific times when specific chemicals, ie, hydrazines and TCE, were used.

Comparisons were made with the general populations of California and the United States and also with SSFL workers and Rocketdyne workers at nearby facilities. Although the exposure assessment of Rocketdyne workers was not as comprehensive as that for the test stand mechanics, the non-SSFL workers were similar to SSFL workers with regard to socioeconomic characteristics, place of residence, and access to medical care. It was reassuring that results did not differ appreciably by choice of referent, ie, general population, SSFL workers, or all Rocketdyne workers.

Limitations of our investigation include the use of test stand work as a surrogate or proxy measure of actual chemical exposure, the relatively small number of workers potentially exposed to hydrazines or TCE at test areas, the minimal exposure assessment afforded workers at the Rocketdyne facilities near the SSFL, and the lack of complete information on tobacco use. The exposure metrics used were limited, because only the potential or likelihood for exposure to hydrazines or TCE could be studied, ie, personal measurements of specific chemicals were not made in the early years of engine testing. We were able, however, to use the number of engine tests conducted per year by test stand to estimate exposure intensity to TCE during engine flush. There was also little uncertainty in the broad evaluations of the "test stand environment" for which years worked as a test stand mechanic was used as a measure of all chemical and physical hazards experienced while testing rocket engines. Any trends of cancer risk by years worked as a test stand mechanic would have implicated aspects of this work, although the causal exposure(s) might not be clearly identifiable. No significant trends, however, were observed for all cancers taken together or for any specific cancer, including lung cancer or kidney cancer.

Exposure Assessment of Rocketdyne Comparison Groups. The exposure assessment for non-SSFL workers was not as comprehensive as that for the test stand mechanics, but exposure to hydrazine was unlikely and exposure to TCE was not as widespread or as intense as among test stand mechanics involved with engine flush. The non-SSFL workers were mainly involved in manufacturing and assembly, which are generally associated with lower level chemical exposures than at an engine testing facility. We also found little evidence for noncomparability as evidenced by the similarities in results, ie, the patterns of risk were the same whether comparisons were based on all Rocketdyne workers, SSFL workers, or the general populations of California or the United States. This is not to say that non-SSFL workers had "zero" exposure to TCE, just "low exposure" compared with the quantities used for engine flush at a rocket engine test stand. Other occupations were included among non-SSFL workers, eg, machinists. However, there is little evidence that they are at increased risk of cancer based on occupational exposures in the aerospace industry in nearby California areas; ie, among 8,027 machinists evaluated from 1960 to 1996, there were 225 lung cancer deaths (SMR = 0.94).[6] Furthermore, there was little evidence for increased cancer risks among non-SSFL workers compared with either the population of California or the United States. The non-SSFL comparison group had the advantage of being comparable to the SSFL workers with regard to demographic characteristics, socioeconomic status, residential locations, and medical care. We preferred to present the total Rocketdyne worker population as the referent because the increased numbers added statistical precision in the analyses and provided a stronger benchmark for those analyses based on small numbers of individual cancers.

Changing Exposure Levels. Consideration was given to applying a subjective multiplying factor to account for possible changing levels of exposures over the years as well as the increasing use of respiratory protection and other engineering controls to reduce worker exposures. Although there was anecdotal information obtained in the discussions with long-term employees to support this concept, there were no data on which to construct a meaningful multiplier. The absence of historical air sampling information before the early 1980s also limited our ability to assign meaningful exposure levels to individuals, particularly because most exposures were outdoors. The primary exposure measure was then taken as the specific jobs with exposure potential, eg, test stand mechanic, and the length of time in these jobs. We were able to provide a better estimate of the potential for exposure to TCE during engine cleanings by taking into account the number of rocket engine tests conducted at specific test stands during specific calendar years. Assuming also that there would be more persons working on test stands that had frequent engine tests because of shift work, we adjusted the number of tests by the number of mechanics at specific sites during specific calendar years. Thus, the exposure metric was "tests per mechanic-years" as the measure of potential exposure to TCE. Based on the "tests per mechanic-years" metric, the weighting for potential TCE exposure ranged from one to 12. Information on the number of tests for the predominantly small engines using hydrazines was not available and was not considered as informative as those for the larger engines requiring TCE flushing. Although exposure levels may have changed over time, there was no consistent evidence that risk varied by decade of employment. It seems plausible that exposures occurring outdoors were sufficiently diluted to minimize any overall impact on cancer mortality. Nonetheless, only crude indicators of possible chemical exposures in outdoor ambient air were available and actual estimates of exposure to individuals were not possible.

Smoking Information. The lack of detailed smoking information is a study limitation and indirect methods were used to evaluate and adjust for possible confounding. Pay type was a predictor of cancer risk with somewhat higher risks of cancers of the lung and other smoking-related sites found for hourly compared with salaried workers. Such a difference is often seen in occupational studies and has been attributed to higher prevalences of tobacco use by blue collar (hourly) compared with white collar (salaried) workers.[23,24] During the last 2 decades, the prevalence of cigarette smoking has declined faster in the general population and among salaried workers than among hourly workers. Hourly workers continue to smoke in large numbers[12,25] and at a rate twice that of salaried workers.[24,26] The nonsignificant increases in lung cancer among test stand mechanics in comparison with the general population conceivably reflect in part this noncomparability in tobacco use because all test stand mechanics were hourly workers. We controlled for pay type in the intracohort analyses to account for possible differences in socioeconomic and demographic characteristics of hourly and salaried workers and thus indirectly adjusted for smoking.

Smoking Survey. To provide some support for the assumption that hourly workers used tobacco products to a greater extent than salaried workers at Rocketdyne, we conducted a small smoking survey. Three hundred hourly and 300 salaried workers known to be alive on December 31, 1999, were randomly selected. Current addresses were found for 145 hourly and 147 salaried workers of whom 47% and 48% responded to a mailed questionnaire, respectively. Compared with salaried workers, hourly workers were significantly more likely to have smoked cigarettes (61% vs 41%), to be current smokers (9% vs 0%), to have started smoking at a younger age, to have quit at an older age, to smoke for more years (31.4 years vs 21.1 years), and to have consumed more cigarettes during their lifetime as measured in "pack-years." Although limited by the small numbers, low response rate, and inclusion of only living workers, the findings are consistent with information obtained from a sample of over 120 medical records of test stand workers, which indicated that just over 60% of the hourly workers were current or former smokers based on responses to a questionnaire administered in the 1960s. These findings indicate the importance of controlling for pay type in the analyses as a surrogate measure of smoking.

Interestingly, the prevalences of current smokers in our survey of male workers (median age, 71 years) were generally similar to recent national and California population estimates, adding some support for the general validity of the survey findings.[24,27] We found 9% of hourly workers reporting current smoking, and none of the salaried workers. The national prevalence of smoking in 2002 (the latest year for which estimates are available) were 10% at ages 65+, and smoking prevalence of California males over the age of 70 years is estimated to be below 7%.

Smoking Habits of Test Stand Mechanics. Because test stand mechanics worked with flammable substances at the test area, we investigated the possibility that they were less likely to smoke cigarettes than other hourly workers. Decreased smoking rates, however, were not reported during our interviews with current and retired workers or apparent from medical record abstractions. The test stand areas were outdoors, there were no restrictions in general against smoking, and there were frequent smoking breaks. Test stand mechanics interviewed were asked whether they smoked more or less than other workers and they responded "about the same." Furthermore, there was no indication that lung cancer rates were lower among test stand mechanics than other hourly workers at SSFL, ie, the SMRs were 1.07 and 1.15, respectively, and not significantly different. Thus, although hourly workers appear more likely to smoke cigarettes than the general population, there was little indication that test stand mechanics smoked significantly less (or significantly more) than other hourly workers at Rocketdyne.

The previous investigation also evaluated medical records of over 1000 workers to learn whether smoking information might be available and whether smoking status might vary over categories of estimated hydrazine exposure (essentially among test stand workers). There was little evidence that smoking was a confounder, because smoking prevalences were similar among the test stand workers and other workers.[17] The available medical records were limited, however, in that most medical records for workers who terminated employment before approximately 1970 (ie, for over 66% of the test stand workers) had been destroyed and were thus not available for review in the 1990s. In addition, the questionnaires available in existing medical records had for the most part been administered in the 1960s and changes in smoking habits over the years could not be evaluated.

Pay Type Classification. Imperfect categorization of pay type is another possible study limitation. We classified anyone who held an hourly job for at least 20% of his or her career as an hourly worker and any misclassification could result in inadequate control for potential confounding factors such as cigarette smoking associated with pay type. The numbers of workers actually affected by this classification, however, is small, eg, only 4% of workers held an hourly job for 20% to 49% of his or her career. The classification by pay type also differed from the previous study in which only 11.3% of SSFL workers were classified as hourly compared with our percentage of 62.6%. This difference may explain, in part, the increase in lung cancer reported previously in an internal analysis of test stand mechanics that used all other SSFL workers as the referent.[17] Although pay type was adjusted for in this previous study, all test stand mechanics were hourly workers, whereas the majority of workers in the referent category were salaried workers by our classification. Conceivably, the increase in lung cancer previously reported may have been confounded due to inadequate control for pay type taken as a surrogate measure of smoking.

Standardized Mortality Ratio Analyses Based on California Rates. Because of the mobility of the workforce, use of California rates to compute expected numbers of deaths likely overestimated the SMRs. Many workers after terminating employment left California and spent substantial portions of their lives living in other states. Approximately 24% of the nearly 10,000 deaths occurred outside the state of California. Because California rates of mortality are generally lower than for the United States as a whole, the computed expected numbers accordingly would be lower and the SMRs higher than if based on comparisons with the United States. SMRs based on U.S. population rates were significantly low for all cancer, lung cancer, leukemia, and other causes of death. A "true" SMR is likely somewhere between that computed using California rates and that computed using U.S. rates.

Comparison With Previous Study

For completion, we discuss the similarities and differences between the current and previous studies of SSFL workers.[1,17] The previous investigators acknowledged the small size of the population studied and noted that their findings would have to be confirmed by other studies and/or further follow up of the Rocketdyne workforce.[17,28] Differences in findings between the two studies are likely related to differences in study design, exposure assessment, classification of hourly workers, and years of follow up. We included all workers who were hired up to 1999, whereas the previous cohort included only men and accrual stopped in 1980. In addition, we included 182 test stand mechanics who had been monitored for radiation, whereas all radiation workers had been previously excluded. We also included workers employed for at least 6 months at SSFL, whereas the previous investigation required that a worker spend at least 2 years at any Rocketdyne/Rockwell division with apparently no minimum time restriction for work at SSFL.

These different criteria for worker selection and eligibility resulted in our cohort of 8372 SSFL workers being larger than the previous study population by 2265 (or 37.1%). The expanded numbers and longer follow up (254,198 person-years vs approximately 171,100) resulted in an additional 860 deaths from all causes (a 62% increase), an additional 251 cancer deaths (a 62% increase), and an additional 69 deaths from lung cancer (a 47% increase) among SSFL workers. Another difference was that the previous investigation assumed that all rocket test stand workers were exposed to hydrazines, whereas we found that hydrazines were limited to certain test areas during certain calendar years and only approximately 19 to at most 31% of test stand mechanics were potentially exposed to hydrazines. We also were able to estimate and adjust for the potential for exposure to TCE at the test stands, which was not done previously. Finally, we did not limit our investigation only to workers at SSFL, but included 32,979 workers employed at nearby Rocketdyne facilities as an additional referent group, enhancing the statistical power of the analyses. Our intracohort analysis of lung cancer among test stand mechanics using hourly SSFL workers as referent is perhaps compatible with the previous analyses that assumed all test stand mechanics were exposed to hydrazines. However, our analyses provided no evidence for an association between lung cancer and years worked as a test stand mechanic: RRs being 1.00, 0.80, 1.02, and 0.46 ($P = 0.64$ for trend). As mentioned earlier, the previous study reported that hourly workers comprised only 11.3% (or 690) of the 6107 SSFL workers evaluated, whereas we found that 62.6% (or 5241) of the 8372 SSFL workers evaluated were hourly. Our percentage of hourly workers is also similar to that reported for Rocketdyne radiation workers.[2,17] Conceivably, differential misclassification of pay type may have been responsible in part for the prior findings of an increased risk for lung cancer.

Limitations of the previous study had been summarized by the National Research Council[13] to include collapsing heterogeneous cancers by organ systems, estimating exposure based on job title, not accounting for possible exposure to solvents, and the inability to control completely for tobacco smoking. The current study did not combine heterogeneous cancers, refines the assessment of exposure to particular chemicals used at specific test areas, and adjusted for TCE solvent use within hydrazine analyses. Other than adjusting for pay type as a surrogate for tobacco use, however, we were not able to control completely for cigarette smoking.

Conclusions

No consistent associations between cancer and chemical exposures associated with the testing of rocket engines were found within the Rocketdyne workforce followed for up to 50 years. A nonsignificant increase in lung cancer mortality based on comparisons with the general population was not supported by analyses using internal comparisons with other Rocketdyne workers not involved in rocket engine testing. A small risk of lung cancer associated with potential exposures to hydrazines, however, could not be completely ruled out. An increase in kidney cancer associated with TCE was observed and, although not statistically significant, may be worthy of additional study in any further follow up. A nonsignificant increase of stomach cancer with years worked as a test stand mechanic may be a chance observation due to the large number of associations evaluated. Differences between the current study and the previous one likely reflect differences in study design and size, the additional 5 years of follow up, and a more accurate assessment of pay type and exposure to hydrazines and TCE.

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