

FOLLOW-ON ROCKETDYNE WORKER HEALTH STUDY

Science Committee Summary

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March 19, 2005

Background

In 1999, investigators from the University of California at Los Angeles (UCLA) reported results of a cohort study of mortality among workers at Rocketdyne/Atomics International facilities in California. They found a significantly elevated risk of lung cancer among workers employed in 'rocket-engine testing jobs' among workers employed at the Santa Susana Field Laboratory (SSFL), and significant associations with radiation dose among workers monitored for radiation exposure (Ritz et al 1999a, 1999b; Morgenstern et al 2000, 2001). This study had a number of limitations, including a relatively small size and short period of follow up, and the assessment of both chemical exposures and radiation dose to individuals in the cohort was approximate. It was recognized at the time that it would be important to confirm these findings with additional follow up and study of Rocketdyne workers.

The following year a committee of six external scientists was formed (referred to hereafter as the Science Committee) to advise Boeing Rocketdyne management on the design and conduct of an expanded study. A Request for Proposals was developed and the Science Committee reviewed four proposals submitted in response to it. The committee recommended that a contract be awarded to the International Epidemiology Institute (IEI) to conduct an expanded cohort mortality study. The new study was designed to focus on individuals employed in either nuclear technology development or in rocket engine testing since 1948 at the Santa Susana Field Laboratory and nearby facilities at Canoga Park and DeSoto Avenue. The key improvements in the study were to: 1) extend the observation period; 2) consider additional comparison populations; 3) expand approaches to determining vital status; 4) ascertain and consider pre- and post-Rocketdyne radiation exposures; 5) estimate internal radiation doses; and 6) assess chemical exposure information for individuals in a more comprehensive and detailed manner.

Overview of Study Design

Three nearly mutually exclusive populations were included in the study: 5,801 workers monitored for radiation exposure, 8,190 workers at SSFL (including 1,469 test stand mechanics who had the greatest potential exposure to chemicals, in particular hydrazine and trichloroethylene), and 32,979 workers employed at the other Rocketdyne facilities. The populations were identified from Kardex work histories cards, electronic personnel files, transfer lists, medical record index cards, phone directories, medical records and radiation dosimetry records. Workers were classified by job title, pay type (hourly or salary) and whether they held an administrative/scientific position.

Organ-specific radiation doses from lifetime occupational exposures and radionuclide intakes were estimated for the workers monitored for radiation and employed for more than six months between 1948-1999 from company records of external and internal exposures and linkages with national dosimetry datasets. Bioassay data were evaluated using current ICRP biokinetic models to estimate annual doses for 16 organs or tissues, taking into account time of exposure, type of radionuclide, and excretion patterns.

The potential for chemical exposures at SSFL from 1948 until 1999 was estimated from job histories and work at specific test stands. Potential exposure to a mixture of substances at rocket engine test areas was evaluated according to years of employment at a test stand. Patterns of potential exposure to specific chemicals were identified based on the quantity used and the number of workers exposed. Individual test stand mechanics were placed at specific test stands during specific calendar years to estimate their potential for exposure using historical phone books. Confirmation of these assignments was based on visits to operating and closed test stands with knowledgeable personnel, discussions with over 100 long-term employees, and existing medical records.

The mortality experience of all workers through 1999 was determined by examination of national, state and company records. Standardized mortality ratios (SMR) were calculated comparing the observed numbers of deaths among workers with those expected in the general

population of California adjusting for age, gender, race and calendar year. Dose-response analyses were conducted using Cox proportional hazard models to evaluate trends over categories of cumulative radiation dose and over years of potential exposure to chemicals.

The Science Committee closely monitored the conduct of the study and provided advice and oversight throughout. The committee was provided quarterly progress reports by IEI and met regularly with the IEI study team, UAW representatives, and Boeing management. The Science Committee has been greatly impressed with the very careful and comprehensive manner in which the work has been carried out, and the responsiveness of the IEI team to numerous requests and recommendations. We believe the study has been done as well as is possible, and that state-of-the-art approaches and methods have been used to collect data and conduct statistical analyses. Particularly noteworthy achievements and aspects of this study include the following:

1. Multiple sources of information were extensively exploited to identify workers to form the two cohorts for study. It is unlikely that many individuals were missed.
2. Vital status was determined for 99.2% of the worker population.
3. Cause of death was ascertained for 97.6% of the 11,118 workers who had died.
4. External radiation dose was determined in a more comprehensive manner than the previous study through the use of numerous sources of radiation dosimetry records.
5. Radiation dose received both prior to and after employment at Rocketdyne was determined.
6. Extensive efforts were made to estimate internal radiation dose for persons with bioassay data available.

7. Extensive efforts were made to better characterize the chemical exposure environment at specific test stands over time, and to place individuals at specific test stands at specific points in time in order to better characterize their potential chemical exposure.
8. A number of alternative analyses were conducted to better understand the mortality experience of the worker populations. These included: a) analyses limited to white males; b) SMR analyses based on three different comparison populations (United States, California, Los Angeles and Ventura counties); c) dose-response analyses comparing mortality within the study cohorts over categories of radiation dose or years worked with potential chemical exposures; d) radiation dose analyses with a lag period of two years for leukemia and ten years for solid cancer (i.e., excluding radiation exposure during these periods prior to the diagnosis or end of follow up); e) analyses restricted to workers monitored for radiation only at Rocketdyne; and f) analyses separating hourly and salaried workers.
9. A small survey was conducted to ascertain smoking habits of hourly and salaried workers.

Summarized below are the study methods for the two principal components of the study (the Radiation Cohort and the Chemical Cohort), and the principal findings of the study, organized according to the four worker populations studied.

Summary of Study Methods and Principal Results

I. All Rocketdyne workers (N = 46,970)

Overall, the Rocketdyne workforce had a much lower total mortality rate than the rate observed in the California population. Rocketdyne workers had somewhat lower total cancer mortality rates than the California population, and for most specific types of cancer, such as lung cancer, the Rocketdyne rates were very similar to the rates in the California population. Thus, overall,

there is no evidence that working conditions at Rocketdyne caused increased mortality in the workforce.

II. Rocketdyne workers who did not work at SSFL and who were not monitored for radiation (N = 32,979)

Salaried workers in this group (approximately 12,000) had much lower rates of mortality overall, as well as from almost all types of cancer, including lung cancer, compared with rates observed in the California population. In contrast, the overall mortality rate among hourly workers in this group (approximately 21,000) was similar to that seen in the California population, and consequently substantially higher than that of salaried workers. While total cancer mortality rate in hourly workers was not high, the rate of lung cancer was about 20% higher than in California and about double than in salaried workers. This type of mortality pattern for lung cancer is often seen when comparing 'blue collar' with 'white collar' workers, and is often attributed to the fact that 'blue collar' populations smoke more than 'white collar' populations, and that there are other lifestyle factors related to lower socioeconomic status that are associated with some risk of lung cancer. This may well explain the observed excess of lung cancer in this study among the hourly workers. It is also possible that some of the excess lung cancer risk is related to occupational exposure to lung carcinogens. The study was not specifically designed to explore this possibility. At this time, it is not possible to determine whether the apparent excess risk of lung cancer among the hourly workers was entirely due to the effects of social or lifestyle factors, such as smoking, or whether occupational carcinogens may have played a role.

III. The Radiation Cohort: Mortality Among Rocketdyne/Atomics International Workers Monitored For Radiation 1948 – 1999 (N = 5801)

The prior study conducted by UCLA investigators of radiation exposure among Rocketdyne workers found a significant three-fold increased risk of all cancers among workers exposed to greater than 200 mSv from external radiation, based on four cancer deaths, and a significant

four-fold increase of lung cancer at >200 mSv, based on two deaths (Ritz and Morgenstern 1999). A significant trend was also reported for all lymphatic and hematopoietic malignancies considered together, excluding chronic lymphocytic leukemia (CLL), based on 28 deaths. The UCLA study also reported high risks at cumulative lung doses greater than 30 mSv from inhaled radionuclides for lymphopoietic cancers excluding CLL and for upper aerodigestive tract cancers (i.e., cancers of the mouth, esophagus and stomach) but not for lung cancer (Morgenstern and Ritz 2000).

The expanded radiation study conducted by IEI comprised all workers who were monitored for radiation and employed on or after January 1, 1948 for at least six months at Rocketdyne. To be included in the radiation cohort required evidence of radiation monitoring and confirmation of employment at Rocketdyne. After excluding 350 radiation workers employed for less than six months and 524 workers with insufficient identifying information, 5,801 remained eligible for study and comprised the Radiation Cohort. This cohort differs in several ways from the previous study: 1) it includes all workers (men and women) who were hired up to 1999 and followed through December 31, 1999; the previous cohort accrual stopped December 31, 1993 and follow-up was through December 31, 1994; 2) it includes workers employed for at least six months at Rocketdyne, whereas the previous investigation included anyone monitored for radiation, including short-term workers; and 3) it excludes contract workers and visitors. The current radiation cohort is larger than the previous study by 1,194 workers (25.9%).

External radiation doses were derived from the Rocketdyne/Atomics International files and linkages with a number of national radiation dosimetry databases. Neutron exposures and organ doses from the intake of radionuclides were also determined. Organ doses were estimated for each worker taking into account the external (both photon and neutron) and the internal exposures.

Paycode (hourly/salary) was used as a measure of socio-economic status (SES) and was controlled for in the dose-response analyses conducted within the cohort. Workers who held hourly jobs for at least 20% of their career were classified as hourly workers. Workers were also classified by calendar years of employment and length of employment. A total of 182 (3.1%) of

the 5,801 workers monitored for radiation also held jobs associated with work on rocket engine test stands. Work as a test stand mechanic (yes/no) was included as a covariate in the dose-response analyses.

Overall (Table 2.1), the Rocketdyne workforce had a significantly lower risk of death than the general population for all causes (SMR 0.79; 95% CI 0.75-0.83) and for all cancers (SMR 0.90; 95% CI 0.82-0.99). There were no significantly elevated SMRs for any site. Leukemia was slightly elevated, but not significantly (SMR 1.33, n=25), and the SMR for chronic lymphocytic leukemia, which has not been shown to be associated with radiation exposure, was higher (SMR 2.04) than the SMR for the other leukemias (SMR 1.16). Lung cancer was not increased (SMR 0.89; 95% CI 0.76-1.05). In an analysis of observed and expected numbers of deaths for 36 specific causes over seven categories of external radiation dose that included all workers ever monitored for radiation at Rocketdyne, and that excluded the first ten years of follow up for solid cancers and the first two years of follow up for leukemia, there were no significantly increased trends in total cancer deaths, leukemia or any specific cancer, except for kidney cancer based on 12 observed deaths and only 2 occurring over 100 mSv (Table 3.1). Among the 335 workers who accumulated more than 50 mSv, 33 cancer deaths occurred and 33.2 were expected. Few workers (69) had cumulative doses greater than 200 mSv and only seven cancer deaths (vs 6.3 expected) occurred among these workers.

Dose-response analyses were conducted within the cohort across seven categories of radiation dose using the Cox Proportional Hazards model. There was no evidence of an increased risk of mortality with increasing radiation dose for all cancers, all cancers excluding leukemia, or lung cancer (Table 5.2). Lagging radiation dose did not materially change the results. In contrast, the risk of leukemia tended to increase with increasing radiation dose, although in the results presented no trends were statistically significant. The most informative results are found in Table 6.1 and Figure 3. Doses used in these analyses were the sum of all external exposures plus any bone marrow doses from the intake of radionuclides, were lagged by two years, and the model included an adjustment for pay type. Relative risks in the highest dose category (≥ 50 mSv) relative to workers not monitored were: all leukemia (RR=2.84; 95% CI 0.75-10.81); leukemia excluding CLL (RR=2.64; 0.53-13.21); and CLL (RR=3.82; 0.33-43.8). The risk estimates

across seven dose categories are imprecise, however, due to the small number of leukemia deaths (25 total; 18 excluding CLL). Combining the upper dose categories as either ≥ 5 mSv or ≥ 10 mSv provides a degree of stability to the dose-response, but doesn't materially alter the results.

Dose-response analyses revealed no significant trends of increasing risk over categories of organ dose for colorectal cancer or cancer of the stomach, prostate, bladder and pancreas. In contrast to the SMR analyses, the trend for kidney cancer was no longer significant. A number of analyses were conducted to assess the impact of the choice of analytical strategy on the estimate of risk for all cancers (excluding leukemia), lung cancer and leukemia (excluding CLL). The choice of referent population did not have an effect on the estimate of risk, i.e., the RR was similar whether all Rocketdyne workers, all SSFL workers or only monitored workers were used as referent. Restricting the analysis to workers who received only external exposure reduced the estimate of risk but not significantly. No appreciable changes in the RR were seen when adjustment for any of the following factors was not made: socio-economic status, duration of employment, gender, age, calendar year and potential exposure to chemicals. Relative Risk estimates at 100 mSv were small and not significant for all cancers (excluding leukemia), lung cancer and leukemia (excluding CLL): 1.04 (95% CI 0.86-1.26), 1.00 (95% CI 0.89-1.12) and 1.32 (95% CI 0.71-2.45), respectively. No significant differences were observed in relative risk estimates at 100 mSv over categories of attained age, age at exposure or time since last exposure. For leukemia excluding CLL, the RR at 100 mSv was highest at the youngest ages at exposure but the differences were not significant. The RR at 100 mSv was seen to decrease with increasing lag intervals but not significantly.

The cohort mortality study conducted by IEI expands and extends a previous investigation in the same worker population conducted by UCLA. The expanded numbers (larger than the previous study by 1,194 or 25.9%), and longer follow-up (161,605 person-years vs. about 119,100) resulted in an additional 593 deaths from all causes (a 67.8% increase) and an additional 198 deaths from all cancers (a 76.7% increase). Other important differences from the previous study are that the IEI study determined and accounted for the occupational doses accumulated by nearly 28% of the workers at places of employment other than at Rocketdyne, and computed radiation doses from the intake of radionuclides for specific organs. Overall, the cohort had a

significantly lower risk of death than the general population for all causes (SMR 0.79; 95% CI 0.75-0.83) and for all cancers (SMR 0.90; 95% CI 0.82-0.99). The study did not confirm the key findings reported from the UCLA study: no significant elevation of all cancers among workers exposed to greater than 200 mSv external radiation (RR 1.25; 95% 0.6-2.7) and no evidence of a dose-response ($p=0.50$); no significant increase of lung cancer at >200 mSv (RR 1.39; 95% CI 0.5-3.6) and no evidence of a dose-response ($p = 0.98$); no significant increase of all lymphatic and hematopoietic malignancies taken together, excluding CLL, and no evidence of a dose-response ($p=0.25$); and no significant increase of upper aerodigestive tract cancers and no evidence of a dose-response ($p=0.49$). There was some evidence of an increase in all leukemia and leukemia excluding CLL, and an indication of a trend of increasing risk with increasing dose, although not statistically significant. The RR at 100 mSv for all leukemia excluding CLL was estimated as 1.32 (95% CI 0.71 - 2.45), which is consistent with predictions from other radiation studies. However, an even greater increase was seen for CLL, which is not thought to be induced by radiation. An association between radiation dose and kidney cancer was seen in the SMR analysis but not in the dose-response analysis. The absence of any clear radiation associations likely reflects the relatively low doses experienced by the workers (mean 14 mSv, maximum 1000 mSv) and the relatively small number of deaths from specific types of cancer. Only 69 workers had career doses from external radiation greater than 200 mSv, and only 111 workers had lung doses greater than 200 mSv when internal doses were considered. The Science Committee agrees that there is no clear evidence from this study of a significant increase in cancer risk associated with radiation exposure in the Radiation Cohort, but believes that additional follow up of this cohort may be helpful in clarifying the suggestive findings regarding a possible increase of leukemia.

IV. The Chemical Cohort: Mortality Among Rocketdyne Workers Who Tested Rocket Engines, 1948 – 1999 (N = 8190)

A prior cohort mortality study by Ritz et al. (1999) among workers employed at the Santa Susana Field Laboratory (SSFL) found a significantly elevated risk of lung cancer among workers employed in ‘rocket-engine testing jobs’. For these analyses, Ritz et al. used occupational

groups to define qualitative hydrazine exposures as ‘high’ (propulsion/test mechanics or propulsion/test technicians for a minimum of 6 or 24 months), ‘medium’ (propulsion/text inspector, test engineer, and instrument mechanic), and ‘low’ (flight-line mechanics and groups who may have been present during engine test firings but without direct work with hydrazine). The unexposed group included all workers who did not qualify for any of the exposed categories. Logistic regression modeling using the risk-set approach to account for time-dependent covariates found significantly ($p < 0.05$) elevated risk of lung cancer for workers in the ‘high’ exposure category for hydrazine (RR = 1.68 to 2.10). Ritz et al. were unable to link workers with job locations such as specific test stands.

Researchers at the International Epidemiology Institute (IEI) conducted an expanded retrospective cohort mortality study of the SSFL population. This study included workers employed at least six months at Rocketdyne facilities in California, including SSFL, on or after January 1, 1948 with cohort follow-up through 1999. Age, race, gender, and calendar time specific death rates for California and the United States were used to calculate standardized mortality ratios (SMRs) for the total cohort as well as for subgroups defined by potential for exposures to hydrazines or TCE. Jobs titles and annual Rocketdyne telephone directories were used to assign workers to qualitative exposure categories associated with test-stand work. Like the study by Ritz et al., test stand mechanics and technicians were combined into a single category ‘test stand mechanics’, thought to have the highest potential for chemical exposures (hydrazines and TCE). The potential for hydrazine exposures at each Rocketdyne test stand was assessed by review of history of each test stand. Using several data sources (job titles, medical records, phone books, and worker discussions, 315 workers were classified as having ‘likely’ exposures to hydrazines and an additional 205 workers were classified as having ‘possible’ hydrazine exposures. Internal cohort analyses using Cox regression methods compared risks by years of work as test stand mechanics and for years of potential exposure to hydrazines and TCE at SSFL.

The all cause mortality among SSFL workers combined was significantly less than expected using California general population death rates (SMR=0.83; 95% CI. 80-.86). All cancer mortality also was significantly less than expected for the total cohort (SMR=0.89; 95% CI 0.82-

0.96). In the overall cohort, no cause of death was significantly elevated; however, non-malignant respiratory diseases (excluding influenza and pneumonia) were significantly elevated among SSFL hourly workers (SMR=1.27; 95% CI 1.06-1.51). Among the population of all male 'test stand mechanics' (n=1642), no cause of death was significantly increased in the SMR analyses. Stratification by duration of employment as a test stand mechanic (<5 years and > 5 years) did not detect significantly increased mortality. When test stand mechanics were further stratified by hydrazine exposure groups, workers who were 'likely' exposed were found to have a lung cancer SMR of 1.45 (95% CI 0.81-2.39) and workers 'potentially' exposed to hydrazine had a lung cancer SMR of 1.81 (95% CI 0.96-3.09). Thus workers 'likely' or 'potentially' exposed to hydrazine (combined) had a significant excess of lung cancer (SMR= 1.60; 95% CI 1.06-2.31), assuming a Poisson distribution for the observed cases. Among the 1111 workers potentially exposed to TCE, no excess mortality was observed for all causes (SMR=0.87; 95% CI 0.78-0.96) or all cancers (SMR=1.00; 95% CI 0.83-1.19). Cancer of the kidney was elevated based on 7 deaths but this excess was not statistically significant (SMR=2.22; 95% CI 0.89-4.57) and no other cause of death was significantly elevated. Use of U.S. deaths rates resulted in similar patterns of mortality for all cohort and sub-cohort analyses.

Internal cohort analyses were used to further explore risks associated with potential exposure to hydrazines and TCE among test stand mechanics. In these analyses, several groups were used as the 'referent' for purposes of calculating relative risks (RR) in the Cox models. Using all hourly SSFL workers who were not test stand mechanics as the referent, no lung cancer or kidney cancer excess was observed by duration of test stand work and no significant trends by work duration were apparent. Stratification of workers by qualitative exposure category (none, possible, and likely) did not demonstrate elevated risks for lung cancer or kidney cancer using all Rocketdyne hourly workers as the referent. However, internal analyses comparing test stand mechanics with no hydrazine exposure with those 'possible' or 'likely' exposed to hydrazine combined demonstrated an excess risk among those exposed (RR=1.62; 95% CI 1.08-2.34), with the confidence interval being calculated assuming a Poisson distribution for the observed. No significant trend was observed in the lung cancer risk by duration of likely or potential hydrazine exposure. There was a suggestion of a dose response over years of potential TCE exposure, although the trend was not statistically significant.

The ICI analyses have updated and expanded the analyses of cancer risks among test stand mechanics in several important areas. First, the cohort has been expanded and the follow-up period extended by five years. Secondly, the assessment of exposures to hydrazines and TCE has been improved by detailed review of test stand activities, including their use of hydrazine and TCE, and use of annual telephone directories to assign workers to specific test stands. However, even with these improvements in the assessments of exposures, the potential for exposure misclassification still persists. Thus, while the analysis of disease risk trends by exposure status is informative, the Science Committee is cautious in placing too much emphasis on these results. Overall, the SSFL cohort experienced favorable mortality for all causes and all cancers. Only when the cohort is stratified by hydrazine and TCE qualitative exposure status does any excess emerge. The Science Committee observed that both the SMR analyses and the internal Cox regression analyses found an association with ‘likely’ or ‘potential’ hydrazine exposures and the risk of lung cancer when these groups were combined. While confounding by smoking might partially explain the excess in the SMR analyses, where test stand workers are compared to the general population of California or the U.S., the magnitude of this excess (SMR=1.6) is too large to be easily explained through confounding by smoking [Kriebel D, Zeka A, Eisen E, Wegman D (2002). Quantitative evaluation of the effects of uncontrolled confounding by alcohol and tobacco in occupational cancer studies. *Int J. Epid.* 33:1040-1045, 2004]. Additionally, the internal analyses observed a similar elevated risk when test stand mechanics were compared among themselves by exposure status. These internal comparisons should have less potential for confounding by smoking. The Science Committee thus concludes that the small number of observed lung cancer cases among test stand mechanics produces results which can not rule out the possibility of a small increase in the risk of lung cancer among test stand mechanics with likely or potential hydrazine exposure. The Science Committee agrees with IEI’s interpretation of the data with regard to kidney cancer risk. Additional follow-up may help to clarify the lung cancer risk among hydrazine exposed test stand mechanics and the association of kidney cancer with TCE exposures.

Summary and Conclusions

A. Overall Experience of the Rocketdyne Workforce

- The Rocketdyne workforce had a much lower overall mortality rate than the rate observed in the California population.
- The Rocketdyne workforce had somewhat lower total cancer mortality rates than the California population, and for most specific types of cancer, such as lung cancer, the Rocketdyne mortality rates were very similar to the rates in the California population.
- There is no evidence that working conditions caused increased mortality in the Rocketdyne workforce.

B. Rocketdyne workers who did not work at SSFL and were not monitored for radiation

- Salaried workers had much lower rates of mortality overall and from almost all types of cancer, including lung cancer, compared with mortality rates in the California population.
- Hourly workers had an overall mortality rate similar to that of the California population, and consequently substantially higher than that of salaried workers.
- It is not possible to determine whether the apparent excess risk of lung cancer among the hourly workers was entirely due to the effects of social or lifestyle factors, such as smoking, or whether occupational carcinogens may have played a role.

C. The Radiation Cohort: Rocketdyne workers monitored for radiation

- Workers in this cohort had much lower rates of mortality overall, and from almost all types of cancer, compared with mortality rates in the California population.
- Salaried workers had much lower mortality rates than hourly workers, and the rates for the hourly radiation-monitored workers were similar to those in the California population.
- For the vast majority of radiation-monitored workers, there was no evidence of excess risk of all cancers combined, lung cancer or leukemia.
- In the most highly exposed radiation-monitored workers (N = 132) with exposures over 10 mSv, there was a hint of excess risk of leukemia; however this could well have been due to chance. Cases of chronic lymphocytic leukemia (CLL) are not likely to be related to radiation exposure and thus only leukemia excluding CLL is plausibly linked to radiation.

- A small excess risk of leukemia excluding CLL at the exposure levels found in this study is consistent with existing knowledge regarding radiation-induced leukemia. However, at most a few cases of leukemia excluding CLL may be attributable to such exposure in the entire cohort.

D. The Chemical Cohort: Rocketdyne workers who worked at SSFL who were not monitored for radiation

- Workers in this cohort had much lower rates of mortality overall, and from almost all types of cancer, compared with mortality rates in the California population.
- Salaried workers had much lower mortality rates than hourly workers, and the rates for the hourly workers were similar to those in the California population.
- For SSFL workers who did not work on test stands (N = 6721), there was no evidence of excess risk of all cancers combined, or for any specific type of cancer, including lung cancer.
- For test stand mechanics who were not exposed to hydrazine (N = 941), there was no evidence of excess risk of all cancers combined or any specific type of cancer, including lung cancer.
- For test stand mechanics who were possibly or likely exposed to TCE (N = 1111), there was no excess of total mortality or total cancer mortality, or mortality from any specific type of cancer.
- For test stand mechanics who were possibly or likely exposed to hydrazine (N = 520), there was no excess of total mortality or of total cancer mortality. However, there were hints of some excess risk of lung cancer based on 28 observed cases. This excess was not statistically significant; it could be due to chance, but it may also reflect a real risk. For no other type of cancer, including kidney cancer, does the evidence support a plausible causal association.

E. Overall Conclusion:

- There was no convincing evidence that any workers at Rocketdyne experienced excess risk of cancer mortality as a result of working at Rocketdyne. There are four qualifications to this overall conclusion:
 - Salaried workers had much lower mortality rates than hourly workers, and the rates for the hourly workers were similar to those in the California population.

- Hourly workers experienced some excess risk of lung cancer, and while it is plausible that their smoking patterns explain this entirely, there might be other factors involved;
- The most highly exposed radiation-monitored workers may have experienced a small excess risk of leukemia, perhaps accounting for a handful of cases;
- The hydrazine-exposed test stand workers may have experienced a small excess risk of lung cancer (Based on a total of 28 observed cases in this group).