ROCKETDYNE WORKER HEALTH STUDY

INTERNATIONAL EPIDEMIOLOGY INSTITUTE

IEI EXECUTIVE SUMMARY

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<u>STATEMENT OF WORK</u>

The overall objectives outlined in the Statement of Work (12/14/00) were as follows:

> “A retrospective cohort mortality study will focus on individuals employed in either nuclear technology development or in rocket engine testing since 1950 at the following Boeing (Rocketdyne) facilities: Santa Susana Field Laboratory (SSFL) in the Simi Hills area of Ventura County, California, Canoga Park and De Soto Avenue. The study will determine whether mortality rates of cancer and other diseases are elevated among these workers, and whether mortality varies as a function of length of employment, place of employment (and or job title) or work with specific chemicals or radiation. Nested case-control studies shall be conducted for any type of cancer that appears to show an excess risk in the cohort (e.g. lung, leukemia or lymphoma).”
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> “The published reports on Rocketdyne workers (UCLA studies) have recognized deficiencies, many acknowledged by the authors, and this extended study will incorporate a more comprehensive and rigorous approach. The observation period shall be extended, more appropriate comparison populations shall be sought, approaches to determining vital status shall be expanded, pre- and post-Rocketdyne radiation exposures shall be ascertained, internal radiation doses shall be determined in a comprehensive manner, and complete and detailed chemical exposure information shall be sought. Further, the seller will provide an experienced and highly credible research team committed to making this project their highest priority during the next five years.”

The objectives in the Statement of Work (12/14/00) were addressed during the four years of study. Results are summarized in this Executive Summary, in nine booklets prepared for the seven meetings of the Scientific Committee, and in four manuscripts prepared for publication. The Executive Summary begins with an Overall Summary and then continues with brief summaries of specific study activities and issues including Institutional Reviews, Population Identification, Population Tracing, External and Internal Radiation Dosimetry, Chemical Exposure Assessment, Study Findings, Auxiliary Analyses, Comparisons with the Previous UCLA Study, and Final Comments. The PowerPoint presentation for the worker meetings 6-8 April 2005 is included at the end of the Executive Summary.

<u>OVERALL SUMMARY</u>. A retrospective cohort mortality study was conducted of 46,970 Rocketdyne workers employed for at least 6 months in either nuclear technology development or in rocket engine testing since 1948 at the Santa Susana Field Laboratory (SSFL) and at nearby facilities, including Canoga Park and De Soto Avenue in California. The Rocketdyne workers were grouped into three populations: those monitored for radiation (Radiation Cohort), those who worked at SSFL (Chemical Cohort) and those who worked at all other facilities (Comparison Cohort). The Radiation Cohort consisted of 5,801 workers monitored for radiation of whom 2,232 were also monitored for internal radionuclide uptake. The Chemical Cohort consisted of 8,372 workers at SSFL of whom 1,651 were test stand mechanics assumed to have the greatest potential for exposure to chemicals such as hydrazines and trichloroethylene (TCE). The Comparison Cohort consisted of 32,979 workers employed at the other Rocketdyne facilities. There were 182 workers who during their career at Rocketdyne had been monitored for radiation and also had worked as test stand mechanics. These workers, 30 of whom were found to have died, are included in both the Radiation and the Chemical Cohorts.

Methods. The Rocketdyne population was identified from Kardex work history cards, electronic personnel files and radiation dosimetry records. Other personnel records evaluated included worker transfer lists, medical record index cards, medical records, and personnel lists (phone directories). Workers were classified by work location, job title, pay type (hourly or salary), and whether they were monitored for radiation or held an administrative/scientific position. Lifetime occupational radiation doses were derived from company records of external and internal exposures and record linkages with national dosimetry datasets. Bioassay data were evaluated using current International Commission of Radiation Protection (ICRP) biokinetic models to estimate annual radiation doses for 16 organs or tissues. The estimation of internal radiation doses accounted for the type of radionuclides taken into the body and their likely chemical forms, time of exposure, and excretion patterns. The mortality experience of all workers through 1999 was determined by examination of national, state and company records. Observed numbers of deaths were compared with the number expected in the general population of California adjusting for age, gender, race and calendar year. Internal cohort dose-response analyses using Cox proportional hazards models were conducted to evaluate trends over categories of cumulative radiation dose and over years of potential exposure to chemicals. For the Radiation Cohort the comparison group for the internal cohort dose-response analyses was in most cases Rocketdyne workers who were not monitored for radiation. For the Chemical Cohort the comparison group for the internal cohort dose-response analyses was in most cases Rocketdyne workers who did not work at SSFL and who were not monitored for radiation. However, various other referent groups were used in the analyses and any differences were noted.

Overall Results. Overall, the 46,970 Rocketdyne workers (including both radiation and chemical cohorts together) accrued 1.3 million person-years of observation (average 27.6 years). Vital status was determined for 99.2% of the workers: 11,118 (23.7%) had died and only 368 (0.8%) were lost to follow-up. Cause of death was determined for all but 280 (2.5%) of those who had died. The overall mortality experience among all Rocketdyne workers was lower than that of the general population of California, i.e., the ratio of observed to expected numbers of deaths (the Standardized Mortality Ratio, or SMR) was less than 1.0 (SMR 0.87; 95% CI 0.85-0.88). Low overall mortality was seen among radiation workers (SMR 0.79; 95% CI 0.75-0.83; n=1,468 deaths), SSFL workers (SMR 0.83; 95% CI 0.80-0.86; n=2,251 deaths) and among the other

Rocketdyne workers (SMR 0.90; 95% CI 0.88-0.92; n=7,429). The observed numbers of cancer deaths also were slightly below population expectation for all workers (SMR 0.93; 95% CI 0.89-0.96; n=3,189 deaths), radiation workers (SMR 0.90; 95% CI 0.82-0.99; n=456 deaths), SSFL workers (SMR 0.89; 95% CI 0.82-0.96; n=655) and the other Rocketdyne workers (SMR 0.94; 95% CI 0.90-0.98). The ratios of observed to expected deaths (SMRs) computed using United States rates were lower than those computed using California rates, whereas county rates (combined Los Angeles and Ventura Counties) were similar to those computed using California rates. No cause of death was significantly elevated. There were no notable increases in cancer deaths over time since first hire, or by duration of employment at SSFL or at the other Rocketdyne facilities.

Overall Radiation Results. Among the 5,801 radiation workers, the mean dose from external radiation was 13.6 mSv (maximum 1,000 mSv); the mean lung dose from external and internal radiation combined was 19.1 mSv (maximum 3,600 mSv). 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. Deaths from all cancers taken together (SMR 0.90; 95% CI 0.82-0.99 , n = 456), all leukemia excluding chronic lymphocytic leukemia (CLL) (SMR 1.16; 95% CI 0.69-1.84; n = 18), and lung cancer (SMR = 0.89; 95% CI 0.76-1.05; n = 151) were not significantly elevated. Internal cohort dose-response analyses revealed no significant trends over categories of increasing radiation dose for all cancers taken together, leukemia, lung cancer or any other cancer. There were no significant associations found among the 2,232 workers who were monitored for internal radionuclide intakes. For all cancers excluding leukemia, the RR at 100 mSv was estimated as 1.04 (95% CI 0.86 - 1.26) and for all leukemia excluding CLL it was 1.32 (95% CI 0.71 - 2.45).

Overall Chemical Results. Overall, 1,651 test stand mechanics were identified and assumed to have the greatest potential exposure to chemicals associated with the testing of rocket engines. Compared with the general population of California, test stand mechanics had a lower risk of dying overall (SMR 0.90; 95% CI 0.82-0.98) and a similar risk of dying from cancer (SMR 1.03; 95% CI 0.88-1.20). The mortality experience of the other male hourly workers at SSFL was similar to that of the test stand mechanics for all causes (SMR 0.97; 95% CI 0.91-1.03), all cancers (SMR 0.93; 95% CI 0.82-1.06), and all specific cancers. No cancer of *a priori* interest among test stand mechanics was significantly increased: lung (SMR 1.07; 95% CI 0.8-1.4), esophagus (SMR 1.03; 95% CI 0.3-2.4), kidney (SMR 1.78; 95% CI 0.8-3.5), bladder (SMR 0.98; 95% CI 0.3-2.5), liver (SMR 0.97; 95% CI 0.3-2.5), and non-Hodgkin's lymphoma (SMR 0.80; 95% CI 0.3-1.9). Among the 315 male test stand mechanics with likely exposure to hydrazines, there were no significant increases for any cancer and, based on internal cohort analyses, no evidence of a dose response over years of potential exposure for all causes of death (SMR 0.89, n=101), all cancers taken together (SMR 1.09, n= 33), lung cancer mortality (SMR 1.45, n=15), or any specific cancer. Among the 1,114 workers potentially exposed to TCE, there were no significant increases for all causes of death (SMR 0.87; 95% CI 0.78-0.96), all cancers taken together (SMR 1.00; 95% CI 0.83-1.19) or any specific cancer. Based on internal cohort analyses, there was no significant dose response over years of potential exposure to TCE for all cancers combined, lung cancer or any other cancer. Cancer of the kidney was elevated based on 7 deaths (SMR 2.22; 95% CI 0.89-4.57) and there was a suggestion of a dose response over years of potential TCE exposure, although the trend was not significant. For the three malignancies most frequently found to be elevated in studies of TCE exposure (i.e., cancers of the kidney and liver and non-Hodgkins lymphoma), the combined SMR based on 12 deaths was not significantly increased (SMR 1.09; 95% CI 0.56, 1.90).

Questionnaire Survey. A questionnaire survey of 139 workers indicated that hourly workers (n=66) were significantly more likely than salaried workers (n=71) to have smoked cigarettes (61% vs 41%; p=0.02). The smoking prevalences of hourly workers who responded to this survey were also greater than smoking prevalences in the general population of California, and indicate the need for caution when interpreting comparisons with the general population for these subgroups because of the likely differences in tobacco use. All test stand mechanics were hourly workers. National surveys also indicate that blue collar workers smoke cigarettes to a greater extent than both white collar workers and people in the general population (Lee et al. 2004; Howard 2004; CDC 2004a, 2004b).

Overall Conclusions. The Rocketdyne workforce overall, including those monitored for radiation, those employed at SSFL and test stand mechanics potentially exposed to hydrazines or TCE, did not experience a statistically significant increased mortality for any cancer, including lung cancer, that could be linked to radiation dose, years of employment at SSFL, years of employment as a test stand mechanic, or years of potential exposure to hydrazines or TCE. No statistically significant internal cohort dose-response relationship was seen for leukemia, lymphoma, or cancers of the esophagus, liver, bladder, kidney or any other cancer over categories of radiation dose or years of potential chemical exposure. We conclude that radiation exposure has not caused a detectable increase in cancer deaths in this population and that work at the SSFL rocket engine test facility or as a test stand mechanic is not associated with a statistically significant increase in cancer mortality overall or for any specific cancer. A slight non-significant increase in leukemia (excluding CLL) was seen among radiation workers, although a similar non-significant increase in CLL (a malignancy not associated with radiation) was also observed. A slight non-significant increase in kidney cancer and a slight non-significant decrease in bladder cancer was also seen among radiation workers. Additional follow-up would be needed to clarify the inconsistent finding with regard to radiation and kidney cancer (a cancer not generally found increased in radiation exposed populations) as well as the non-significant association observed for kidney cancer and potential TCE exposure. Additional follow-up might also clarify the non-significant elevated risk of lung cancer among workers potentially exposed to hydrazines when compared with the general population.

SPECIFIC STUDY APPROACHES AND ISSUES

The following sections provide summary details of study approaches, methods and issues, including those raised by the Science Committee during the conduct of the study.

1. Institutional Review Board (IRB) and other Approvals. To conduct a study involving human subjects it was necessary to receive approval from a number of IRBs and other Human Subjects Review committees. Applications were prepared and approvals were received from the Boeing Company, Vanderbilt University, Oak Ridge National Laboratory, National Center for Health Statistics (National Death Index), Social Security Administration, Health Care Financing Administration (now Centers for Medicare & Medicaid Services), University of Southern

California (Cancer Surveillance Program), Nuclear Regulatory Commission, Department of Energy, and U.S. Air Force.

2. Identification of the Worker Population. Sources to identify workers and obtain exposure information included Kardex job history cards, an electronic personnel file, Radiation Safety folders, personnel listings (phone directories), medical index cards, medical records, and transfer lists. Excluded from study were those who had worked less than 6 months (6,601) and those who were not Rocketdyne employees or who had insufficient identifying information for tracing (813). A cohort of 46,970 eligible workers was developed (Figure 1). There were 5,801 workers monitored for radiation, 8,372 workers at SSFL (including 1,651 test stand mechanics of whom 182 were also monitored for radiation) and 32,979 workers at other Rocketdyne facilities.

3. Population Tracing. Vital status was determined for 99.2% of the worker population. Mortality information was received from the Social Security Administration, California Surveillance Program, Health Care Financing Administration (CMS), Compserv Inc., PBI, Rocketdyne records, state vital statistics departments, and the National Death Index. Individuals were confirmed alive (35,458, 76%) from Rocketdyne personnel and retirement records, the Social Security Administration and the Health Care Financing Administration (CMS) databases. There were 11,144 (23.9%) study subjects who were found to have died. Only 368 workers were lost to follow-up, i.e., 0.8% of all workers (Figure 1).

4. Cause of Death Determination. Cause of death was sought for all 11,118 workers who were found to have died in the United States and all but 265 (2.4%) were obtained. Sources of cause of death information included death certificates available from the Rocketdyne personnel files, the California Death Tape, the California Surveillance Program, the National Death Index and death certificates obtained from individual state departments of vital statistics.

5. Radiation Dosimetry (Figure 2, Figure 3, Figure 4). Organ-specific doses from lifetime occupational exposure to external radiation and radionuclide intakes were estimated for the 5,801 Rocketdyne/Atomics International workers monitored for radiation and employed for more than 6 months between 1948-1999. Radiation-related activities included the operation of ten nuclear reactors and seven criticality test facilities, nuclear fuel fabrication, reactor disassembly, spent nuclear fuel decladding, laboratory work and storage of nuclear material. The radiation workforce was identified from the over 14,000 radiation record folders in the Radiation Safety (Health Physics) offices. Information in the radiation folders was scanned into machine-readable images and sent to a central location for abstraction and dose assessment. To obtain prior and subsequent occupational exposure information, the roster of all workers, including those not known to be radiation workers, was matched against nationwide dosimetry files after permissions were received from the Department of Energy, the Nuclear Regulatory Commission, the Landauer Dosimetry Company, the U.S. Army, and the U.S. Air Force. Requests were also made to investigators of other worker studies to match their dosimetry files against our roster of Rocketdyne workers. Computation of organ doses from radionuclide intakes was complicated by the diversity of bioassay data collected over a 40 year period (urine and fecal samples, lung counts, whole-body counts, nasal smears, and wound and incident reports) and the variety of radionuclides with documented intake including isotopes of uranium, plutonium, americium, calcium, cesium, cerium, zirconium, thorium, polonium, promethium, iodine, zinc, strontium,

and hydrogen (tritium). Over 30,000 individual bioassay measurements, recorded on 11 different bioassay forms, were abstracted. The 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. A modification of the ICRP respiratory model for relatively insoluble material was applied to uranium aluminide, and proposed ICRP models were used for promethium and cerium. Detailed internal exposure scenarios were developed and annual internal doses were derived on a case-by-case basis for workers with committed equivalent doses indicated by screening criteria to be greater than 10 mSv to the organ with the highest internal dose.

The mean cumulative external dose based only on exposures received while employed by Rocketdyne was 10.0 mSv and the dose distribution was highly skewed (maximum 500 mSv) (Figure 2). Only 45 workers received greater than 200 mSv while employed at Rocketdyne. However, 1,833 (or 32%) of the Rocketdyne radiation workers had been monitored for radiation at other nuclear facilities and incorporation of these doses increased the mean dose to 13.6 mSv (maximum 1,005 mSv) and the number of workers with >200 mSv to 69 (Figure 4). For a small number of workers (n=292), lung doses from internal radionuclide intakes were relatively high (mean 106 mSv; maximum 3,560 mSv), and increased the overall population mean dose to lung from 13.6 mSv to 19.1 mSv and the number of workers with lung dose >200 mSv to 111. Nearly 10% of the radiation workers (587) were monitored for neutron exposures (mean 1.2 mSv) at Rocketdyne and another 2% were monitored for neutron exposures elsewhere. These cumulative neutron dose levels were small in comparison with other external and internal radiation doses. Without considering all sources of occupational exposure, however, an incorrect characterization of worker exposure would have occurred with the potential to bias results. For 604 (10%) of the Rocketdyne workers, the doses received at other facilities both prior to and after employment at Rocketdyne were greater than the doses received at Rocketdyne. Similarly, a small number of workers monitored for internal radionuclides contributed disproportionately to the number of workers with high lung doses. A manuscript describing the dosimetry approach has been submitted for publication. Another manuscript describing the unique aspects of internal exposure to uranium aluminide has also been submitted for publication.

6. Chemical Exposure Assessment (Figure 5). The potential for chemical exposures at SSFL from 1948 until 1999 was estimated from job history records and work at specific test stands. The workforce, particularly the test stand mechanics, were potentially exposed to a wide range of rocket fuels, oxidizers, exhaust gases, solvents and other chemicals. This potential exposure to a mixture of substances at rocket engine test areas was evaluated in terms of years of employment at a test stand. Several patterns of potential exposure to specific chemicals were identified based on the quantity used and the number of workers exposed. These patterns included hydrazines used as a fuel in some rocket engines, trichloroethylene (TCE) used to clean ("flush") engines and TCE as a utility solvent to clean small metal parts. Since these patterns of exposure existed only at certain test stands during certain rocket engine tests, individual test stand mechanics had to be placed at specific test stands during specific calendar years to estimate their potential for exposure. Because the work history information available on Kardex cards was not specific enough to do this, historical personnel listings (phone books) were relied upon to make this placement. Confirmation of these assignments was based on information gleaned from walkthrough surveys at operating and closed test stands with knowledgeable personnel who

were involved with specific engine tests over the years, discussions with over 100 long-term employees (both retired and active), and existing medical records which often listed the specific test stands and specific chemicals that the employees worked with.

Overall, 1,651 test stand mechanics were identified within the SSFL workforce of 8,372 (Figure 5). There were 315 test stand mechanics with likely exposure to hydrazines and 205 with possible exposure to hydrazines. The terms “likely” and “possible but unlikely” were used to distinguish two levels of potential exposures to hydrazines: “likely” meant we were able to assign an individual to a test area where hydrazines were used throughout the year whereas “possible but unlikely” meant that hydrazines were used only in one of several areas within a large test area and we were unable to distinguish which test stand mechanics worked in those areas where hydrazines were used from those who worked in areas where hydrazines were not used. We estimate that less than about 10% of the 205 workers classified as “possible but unlikely” actually worked with hydrazine and had potential for exposure. There were 1,114 workers with potential exposure to TCE. There were 182 test stand mechanics who also had been monitored for radiation. The approach to chemical exposure assessment is included in the draft manuscript on the mortality experience of Rocketdyne workers who tested rocket engines.

7. <u>Study Findings.</u>

The entire workforce of 46,970 workers had a lower risk of death from all causes compared to the general population of California (SMR 0.87; 95% CI 0.85-0.88) (Figure 6).

a. Radiation Cohort (Figures 3, 4, 6-8). Overall, 5,801 workers were monitored for radiation, including 2,232 monitored for radionuclide intakes (Figure 3). The mean dose from external radiation was 13.6 mSv (maximum 1,000 mSv); the mean lung dose from external and internal radiation combined was 19.1 mSv (maximum 3,600 mSv). 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 external uptakes were considered. Vital status was known for 97.6% of the workers of whom 25.3% (n = 1,473) had died. The average period of observation was 27.6 years. Radiation workers had a lower risk of death form all causes (SMR 0.79) than the general population of California (Figure 7). All cancers taken together (SMR 0.90, n = 456) and all leukemia excluding chronic lymphocytic leukemia (CLL) (SMR 1.16, n = 18) were not significantly elevated. The most frequent cancer deaths were of the lung (SMR = 0.89, n = 151), colon (SMR = 1.17, n = 47) and prostate (SMR = 0.93, n = 37). Internal cohort dose-response analyses revealed no significant trends for all cancers taken together (Figure 8), leukemia (Figure 9), lung cancer or any other cancer over categories of increasing radiation dose. Slight positive dose-response trends were seen for kidney cancer and slight negative trends were seen for bladder cancer and for cirrhosis of the liver based on the internal dose-response analyses. For all cancers excluding leukemia, the RR at 100 mSv was estimated as 1.04 (95% CI 0.86 - 1.26) and for all leukemia excluding CLL it was 1.32 (95% CI 0.71 - 2.45). There were no significant modifications in the estimates of radiation risk over categories of attained age, age at exposure, or time since exposure.

b. Chemical Cohort (Figures 5, 10-20). The Chemical Cohort consisted of 8,372 workers at SSFL of whom 1,651 were test stand mechanics with the greatest potential for chemical exposures, including 182 test stand mechanics who also were monitored for radiation (Figure 5). The all cause mortality among SSFL workers (SMR 0.83; 95% CI 0.80-0.86; n=2,251 deaths) and among the other Rocketdyne workers (SMR 0.90; 95% CI 0.88-0.92; n=7,429) were lower than the general population (Figure 10, Figure 11). The all cancer mortality SMRs were similar among SSFL workers (SMR 0.89; 95% CI 0.82-0.96) and the other Rocketdyne workers (SMR 0.94; 95% CI 0.90-0.98). No cause of death was significantly elevated. There were no notable increases over time since first hire or duration of employment at SSFL. Test stand mechanics had a lower risk of dying overall (SMR 0.88; 95% CI 0.81-0.95) and a similar risk of dying from cancer (SMR 1.00; 95% CI 0.86-1.16) compared with the general population (Figure 12). No cancer was significantly increased (Figure 13, Figure 14). The SMRs for cancers of *a priori* interest among test stand mechanics were: lung (SMR 1.07; 95% CI 0.8-1.4), esophagus (SMR 1.03; 95% CI 0.3-2.4), kidney (SMR 1.78; 95% CI 0.8-3.5), bladder (SMR 1.14; 95% CI 0.4-2.7), liver (SMR 0.89; 95% CI 0.2-2.3), and non-Hodgkin's lymphoma (SMR 0.89; 95% CI 0.3-1.9). There were no significant increases for any cancer among the 474 male test stand mechanics who worked more than 5 years on a test stand. Among the 315 male test stand mechanics with likely exposure to hydrazines, there were no significant increases for any cancer and no evidence of a dose response over years of potential exposure for all causes of death (SMR 0.89, n=101), all cancers taken together (SMR 1.09, n= 33), lung cancer mortality (SMR 1.45, n=15) or any specific cancer (Figures 15-17). For those who worked less than or more than 1.5 years with likely hydrazine exposure, the RRs of lung cancer were 0.74 and 0.70, respectively (Figure 18). It is noted that the RR of lung cancer for test stand mechanics not exposed to hydrazines was lower than for those with potential hydrazines exposure, although the difference is not statistically significant. Among the 1,114 workers potentially exposed to TCE, there were no significant increases for any cause of death (overall SMR 0.87; 95% CI 0.78-0.96) or for all cancers taken together (SMR 1.00; 95% CI 0.83-1.19) (Figure 19). There was no significant dose response over years of potential exposure to TCE for all cancers taken together, lung cancer or any other cancer (Figure 20, Figure 21). Cancer of the kidney was elevated based on 7 deaths (SMR 2.22; 95% CI 0.89-4.57), although the increase was not statistically significant. Non-Hodgkins lymphoma and cancers of the kidney and liver, combined, were not elevated based on 12 deaths (SMR 1.09; 95% CI 0.56-1.90), and there was no evidence of a dose-response (Figure 22). These three cancers are those most frequently found to be elevated in studies of TCE-exposed populations.

8. <u>Other Analyses and Evaluation</u>.

Additional analyses and evaluations were conducted and are summarized below.

a. White Males. Analyses limited only to white males were conducted for all Rocketdyne workers, the radiation workers and the chemical (SSFL) workers. The observed to expected ratios for all 43 causes of death evaluated did not differ from those computed for the entire population, including women and non-white races. White males constitute the majority (nearly 75%) of all Rocketdyne workers.

b. External Comparison Populations. Although internal cohort dose-response analyses based on radiation dose or based on years worked with potential exposure to chemicals was the primary focus of the evaluation of health risks among Rocketdyne employees, external comparisons with the general population were also made to evaluate patterns of risk over time and by duration of employment. There were three general populations that could be used for comparison purposes: the population of California (which we used), the population of the United States (which was used by the previous investigators from UCLA) and the population of persons residing in Los Angeles and Ventura Counties. Many Rocketdyne workers had been born in states other than California and moved to Los Angeles or Ventura County for employment. Many Rocketdyne workers also left California for employment elsewhere (e.g., Washington State, Missouri, Idaho) or for retirement (e.g., Florida). Approximately 25% of deaths occurred outside of California, 50% in Los Angeles or Ventura Counties and 25% in other California counties. It is not known where the majority of workers are currently residing or whether or when they left California. The observed to expected ratios of deaths (i.e., the SMRs), were similar when comparisons were made with the general populations of California or with Los Angeles and Ventura Counties. The SMRs were consistently lower when comparisons were made with the general population of the United States. None of the external populations is ideal and there are unknown factors such as differences between workers and the general population in health, occupational exposures and confounding factors (e.g., tobacco use) that cannot be accounted for in the analyses. However, patterns of risk over time and by duration of employment can be informative with regard to revealing the presence of any occupational risks. The most comparable general population to the Rocketdyne Workforce probably lies midway between the California and United States populations. However, internal comparisons, described below, are more appropriate when making inferences about workplace exposures and effects.

c. Internal Comparison Populations. Internal cohort dose-response analyses did not rely upon an external population but rather compared various groups of Rocketdyne workers over categories of radiation dose or over categories of years worked with potential exposure to chemicals. All analyses included adjustments for gender, race, age, pay type (hourly or salary), and most analyses included an adjustment for duration of employment. These internal cohort analyses are preferred for causal inferences. There were no internal cohort analyses for which the test for trend in increasing risks over the categories of exposure were statistically significant, i.e., no trend p-value was <0.05. For most internal cohort dose-response analyses, all Rocketdyne workers not monitored for radiation were used as the referent category, but other groups were used as well. For example, dose-response analyses for the Radiation Cohort used monitored workers with no measured dose as the referent; none of these analyses produced a significant trend, although slightly lower relative risks at the highest dose categories were seen. Similarly for the Chemical Cohort, the different referent groups evaluated included all Rocketdyne workers not monitored for radiation, and all SSFL workers not monitored for radiation. For test stand mechanics potentially exposed to hydrazines (or TCE), test stand workers with no known potential exposure to the chemical being evaluated were also used as referent. None of these analyses produced a significant trend. Using either the Rocketdyne or SSFL groups as referent produced essentially the same relative risks at the highest dose categories of years worked with potential exposure to the chemical/s of interest. Using as referent the relatively small number of test stand mechanics with no years of exposure to the chemical/s of interest produced no statistically significant trends and all the confidence limits about the relative risk estimates became wider. The lung cancer risk among the 205 workers with “possibly but unlikely” exposure to hydrazine was greater than the lung cancer risk among the 315 workers with "likely" exposure potential.

d. Healthy Worker Effect. The healthy worker effect usually refers to a type of bias that results from using a general population for comparison with an occupational group. The general population differs from a working population in ways that are likely to affect the risk of dying. The bias is related to selection processes that are in force when a worker enters the workforce and to the health characteristics that enable a worker to continue on the job for many years. Workers in general are healthier than the general population and as such are less likely to die at a young age. These selection factors, however, usually diminish over time, especially for deaths due to cancer. Analyses were conducted excluding the first 10 years of follow-up after a worker was hired and, while the SMRs rose in general, none was statistically significant and no different patterns of risk were seen. Similarly, internal cohort dose-response analyses were conducted excluding the first 10 years of follow-up and no significant trends were seen over categories of exposure for any cancer or groups of cancers. To learn whether short-term workers had different patterns of risk over time than workers of longer duration, SMR analyses were conducted. There were no material differences in the patterns of risk over time whether a worker had been employed at Rocketdyne for less than 5 years or whether he had been employed for more than 10 years.

e. Radiation Dose Lagging. There is a certain period of time before damaged cells can develop and be diagnosed as a leukemia or as a cancer. This minimum latency period is usually taken as 2 years for leukemia and 10 years for solid cancer, i.e., cancers occurring shortly after radiation exposure are not likely related to the radiation exposure but to other causes. Analyses were conducted lagging the dose for two years for leukemia and 10 years for solid cancers, i.e., any exposures occurring in these time periods before the diagnosis of cancer or end of follow-up are excluded. Because most of the high doses occurred in the 1950s and 1960s, lagging doses in the analyses had little effect on the computations of risk over categories of radiation organ dose or on the significance of the trend tests.

f. Workers Monitored for Radiation Only at Rocketdyne. To evaluate whether radiation received while employed at Rocketdyne resulted in any adverse health effects, analyses were restricted to the 3,968 workers who were monitored for radiation only at Rocketdyne and at no other place of employment. There were no significant elevations in cancer risk or significant dose-response relations found. The previous investigation did not exclude workers who where monitored for radiation elsewhere but did exclude the doses received elsewhere. Not including the relatively large contribution to radiation dose received by the 1,776 (31%) workers who were monitored for radiation other than at Rocketdyne could be misleading, as 604 (10%) had received greater doses elsewhere than at Rocketdyne (Figure 4).

g. Smoking Evaluation. To learn more about the smoking habits of hourly and salaried workers, a brief questionnaire survey was conducted in 2004. A sample of living workers was selected and approximately half of those mailed a questionnaire responded (68 hourly and 71 salaried workers). Compared to 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 yr vs 21.1 yr) and to have smoked more cigarettes during their lifetime as measured in terms of "pack-years". The number of cigarettes smoked each day and the use of other tobacco products, such as cigars, did not differ significantly between the two groups. The value of the survey is limited because only survivors are included and the response rate was only 50%. Distinctions between SSFL workers and the workers at other facilities by pay type were not informative because of the small numbers, e.g., there were only 29 salaried workers overall who had smoked cigarettes. Nonetheless, these distributions are consistent with information obtained from a sample of over 120 medical records of test stand workers; smoking information was available for over 60 who had completed questionnaires in the 1960s which included queries on cigarette smoking habits, i.e., just over 60% of the hourly workers were current or former smokers. National surveys of smoking habits among hourly (blue collar) and salaried (white collar) workers also indicate a significantly higher prevalence of tobacco use among hourly workers compared to salaried workers and hourly workers compared to the general population. These evaluations indicate that caution should be exercised when interpreting comparisons in cancer risk between hourly workers and salaried workers and between hourly workers and the general population because of the differences in smoking habits. This is seen in the SMR analyses in that hourly workers in general had higher rates of death from lung cancer and other smoking related causes of death such as heart disease and non-malignant respiratory diseases such as emphysema. It has been suggested that smoking prevention programs should be considered for blue collar workers (Howard 2004). While patterns of risk in the observed and expected ratios can be informative, the internal cohort dose-response analyses comparing hourly workers to hourly workers and salaried workers to salaried workers over categories of exposure are the most informative with regard to investigating causal associations.

h. Hourly and Salary Workers. The risk of death is usually found to be different between hourly and salaried workers in occupational studies. As such, all internal dose-response analyses included an adjustment for pay type, except for those analyses where only specific pay types were evaluated. Comparisons with the general population were made for hourly workers and SMRs were generally higher than 1.0 for smoking-related causes of death in comparison with the general population of California, whereas there were few elevations when comparisons were made with the general population of the United States. Salaried workers on the other hand generally had low SMRs for most causes of death. As indicated above in (g), these differences may be related to differences in the use of tobacco products, although there may be other reasons. Because the general population differs in many ways from a worker population, use of internal comparisons is the more appropriate way to evaluate the exposures of interest. There was no evidence in these analyses that the risk of death from all cancers taken together or for any specific cancer among hourly workers (or salaried workers) increased with increasing numbers of years worked at SSFL, or with increasing level of radiation dose, or with increasing numbers of years with potential exposure to hydrazines, TCE or work as a rocket engine test stand mechanic.

i. Radiation Dose Response by Pay Type. Several analyses were conducted with regard to possible radiation associations and pay type classification. One internal cohort dose-response analysis evaluated the effect of not controlling for pay type and another evaluated the dose-response over hourly and salaried workers separately. Similar to the overall analyses, not adjusting for pay type did not change the pattern of cancer risk over categories of radiation dose and there were no discernible differences in the internal cohort dose-response analyses that were restricted to either hourly or salaried workers.

j. Chemical Cohort Tables Excluding Radiation Workers. To be consistent with the previous investigation conducted by UCLA, analyses for the chemical cohort were conducted excluding the workers who were monitored for radiation. No material difference was seen, in large part because the number excluded, only 182, was small.

k. Time and Duration Analyses for SSFL and the Other Rocketdyne Workers. SMR analyses using California rates as referent were conducted for three durations of employment (<5 years, 5-9 years and > 10 years) by three intervals of follow-up after first hire (< 10 years, 10-29 years, and > 30 years) for selected causes of death. For the SSFL hourly male workers, there were no noticeable patterns. For the other Rocketdyne hourly male workers, there also were no apparent patterns although lung cancer and non-respiratory lung disease were significantly elevated in several subgroups and heart disease was generally elevated. When U.S. rates were used for comparison, there were no significant elevations for any cause of death within any subgroup. As discussed previously, caution in interpreting the SMR analyses is warranted when hourly workers, who apparently smoke more than the general population, are evaluated. The more valid comparisons are the internal cohort evaluations. Internal cohort dose-response analyses based on years worked at SSFL or years worked at the other Rocketdyne facilities did not indicate any increasing trends over categories of years worked.

l. Figures. Graphical representations of many of the internal cohort dose-response analyses for radiation and chemical exposure are presented in addition to the tabular data found throughout the study documents. These figures provide a visual representation of the number of cases involved in the analyses as well as variations in the estimates of relative risk. Several of these figures have been added to this Executive Summary as were the figures presented at the 6-8 April 2005 worker meetings.

m. Test Stand Workers. Although test stand mechanics were assumed to have the greatest potential for exposure to chemicals during the testing of rocket engines, there were other workers at test stands who had some, but much lower, potential for exposure. These included inspectors, engineers, and instrument mechanics. Analyses were conducted to see whether elevated cancer rates were apparent among all test stand workers and among test stand workers excluding the test stand mechanics. There were no discernible differences and no significant findings. While all test stand mechanics were hourly workers, many of the other test stand "workers" were salaried workers. Further, it seems likely that the chemical exposures received outdoors at a test stand were lower than for indoor circumstances because of the dilution and dispersion that occurs in the open air.

n. Special Groupings of Cancer Sites. For the radiation analyses, groupings of cancer sites were made to be similar to the previous UCLA investigation, i.e., aerodigestive sites and all leukemia and lymphomas combined. These groupings, however, are not typical based on etiologic considerations, i.e., the causes of leukemia differ from the causes of lymphoma. The National Cancer Institute SEER (Surveillance Epidemiology and End Results) cancer registries also do not use such categories. A recent exchange of letters on the issue of lumping leukemias and lymphomas together appeared in the January 2005 issue of the American Journal of Epidemiology (Poole et al. 2005; Lee et al. 2005). Regardless, there were no associations with radiation dose based on internal cohort dose-response analyses for any of these groupings.

o. Asbestos. There was no evidence of significant/heavy excessive exposure to asbestos for any of the worker cohorts. Observed numbers of mesothelioma deaths and deaths due to cancer of the pleura and peritoneum did not differ from the expected numbers of deaths in these categories.

p. Beryllium. There was no evidence of excessive exposure to beryllium for any of the worker cohorts. Only one death certificate had mention of berylliosis.

q. Trend Tests. Trend tests for all internal cohort radiation dose-response analyses were conducted by entering the individual cumulative radiation dose as a continuous measure into a Cox proportional hazards model along with the exact same set of covariates used in the corresponding categorical dose analysis. This continuous measure of dose was the actual radiation dose value received by each individual worker. From the Cox model, a single estimate of risk was calculated for this continuous measure and the p-value from a Wald chi-square test was presented in the tables as the ‘p for linear trend.’ Thus, the individual dose values and not group values are used to calculate the trend test. Trend tests were conducted in similar manner described above for the internal cohort dose-response analyses with years worked taken as the continuous variable of exposure. However, there was one exception. For the tables with hydrazines exposure broken down by “potential” and “possible but unlikely”, ordinal values were used for the independent variable. The ordering was based on a logical ranking of the potential for hydrazine exposure among workers in each category. Linear trend tests are used in most of the evaluations and point and interval estimates are also presented for each category in each interval dose-response table. Use of a linear trend test in radiation studies is standard procedure, especially in studies of low dose exposures.

9. Comparisons with UCLA Study.

a. Radiation Cohort. Our radiation cohort differs in several ways from the earlier UCLA study (Ritz et al. 1999b, 2000; Morgenstern and Ritz, 2001). We included 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. The current study included workers employed for at least six months at Rocketdyne whereas the previous investigation included anyone monitored for radiation, including short-term workers. We excluded workers not employed at Rocketdyne, i.e., contract workers and visitors. For 617 workers with only a radiation folder and not a Kardex or electronic job history, we were able to include 332 workers who had both a Rocketdyne serial number and sufficient identifying information for tracing. Additional data sources that we used to confirm and obtain employment histories included over 50,000 medical index cards, detailed dosimetry files, worker transfer lists and employment personnel listings (telephone directories). The previous investigation excluded workers without a personnel work history or identifying information. These differences resulted in our radiation cohort being larger by 1,194 (25.9%) workers than the previous study, i.e., 5,801 workers compared to 4,607 workers (Morgenstern and Ritz 2001).

Our study expanded and extended the previous UCLA investigation by five years and did not find significant associations with radiation dose for lung cancer hemato- and lymphopoietic cancers or aerodigestive cancers (Morgenstern and Ritz 2001; Ritz et al. 1999b, 2000). The previous investigators recognized the small size of the population studied and the low occupational doses received and concluded that their findings would have to be confirmed by other studies and/or further follow-up of the Rocketdyne workforce (Morgenstern and Ritz 2001; ATSDR 1999). The differences in findings between the two studies are likely related to the additional years of follow-up, coupled with differences in study design and the approach to dose assessment. The number of workers monitored for internal radiation (2,232 vs. 2,297) was similar but the number of externally monitored workers (5,743 vs 4,563) was appreciably larger in our investigation. The expanded numbers and longer follow-up (161,605 person-years vs about 119,100 person-years) 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). Another difference was that the previous investigation was not able to include the occupational doses accumulated by 1,776 (31%) of the workers at places of employment other than at Rocketdyne. The dose received elsewhere by 604 (10.4%) workers was greater than the dose received at Rocketdyne. Further, we were able to compute radiation doses from the intake of radionuclides for specific organs and did not use lung dose as a surrogate for dose to all organs. Finally, different analytical methods were used in that the previous analyses used logistic regression whereas we used Cox proportional hazards methods (Callas et al. 1999).

b. Chemical Cohort. Our SSFL cohort also differs in several ways from the one previously reported (Ritz et al. 1999a; Morgenstern and Ritz, 2001). We included all workers (men and women) who were hired up to 1999, whereas the previous cohort included only men and accrual stopped in 1980. We included test stand workers who worked on the Peacekeeper missile system from 1979 to about 1999 and who had potential exposure to hydrazines as well as other chemicals. We included 182 test stand workers who were also monitored for radiation whereas they were excluded in the previous investigation. We identified additional workers for study from transfer lists, personnel listings (phone books) and medical record index cards, and then sought their Kardex work histories. The current study included workers employed for at least six months at SSFL whereas the previous investigation required that a worker spend at least two years at any Rocketdyne/Rockwell division with apparently no minimum time restriction for work at SSFL. These differences resulted in our cohort of SSFL workers being 37.1% larger than the previous cohort, i.e., 8,372 workers compared with 6,107. In addition, the previous study did not estimate potential exposure to TCE and assumed all test stand mechanics were potentially exposed to hydrazines. We were able to make more refined estimates of exposure potential to both TCE and hydrazines. We determined that the percentage of test stand mechanics with potential exposure to hydrazines was between 19-33%, depending on how we classified the workers with regard to likely or "possible not unlikely" exposure potential. Over 65% of the test stand mechanics were unlikely to have been exposed to hydrazines to any appreciable degree.

Our study, expanded with a larger population and 5-year increase in follow-up, did not find a significant association between lung cancer and exposure to hydrazines as previously reported (Morgenstern and Ritz 2001; Ritz et al. 1999a). The previous investigators recognized the small size of the hydrazine-exposed population studied and concluded that their findings would have to be confirmed by other studies and/or further follow-up of the Rocketdyne workforce (Morgenstern and Ritz 2001; ATSDR 1999). Our larger numbers of workers and longer follow-up (248,849 person-years vs about 171,100 person-years) resulted in an additional

830 deaths from all causes (a 59.6% increase), an additional 243 cancer deaths (a 60.1% increase), and an additional 66 deaths from lung cancer (a 45.2 % increase) among SSFL workers. We found little evidence that work as a test stand mechanic during the 1960s was related to an increased risk of lung cancer. Finally, we did not limit our investigation only to workers at SSFL, but included the 32,979 workers employed at nearby Rocketdyne facilities as an additional comparison or referent group, enhancing the statistical power of the internal dose-response analyses.

The previous investigation also reported an association between hydrazines and all lymphatic and hematopoietic malignancies taken together (including CLL) based on 41 deaths which was not seen in our extended follow-up with 67 deaths. Such an aggregated category, as discussed above in (n), is not generally examined because the component malignancies, i.e., Hodgkin's disease, non-Hodgkin's lymphoma, multiple myeloma, and myelogenous leukemia, have such different etiologies (Poole et al. 2005; Lee et al. 2005).

10. <u>Final Comments.</u>

Every epidemiologic study has strengths and weaknesses and the Rocketdyne Health Study is not an exception. The limitations of the study include the relatively low exposures to radiation and chemicals which limits the ability to detect increased risks. The number of cancer deaths can determine whether a study has the ability to detect a statistically significant increase. Studies involving small numbers are not as powerful as studies with large numbers. Small numbers result in estimates of risk that are very imprecise which means that chance often cannot be ruled out as an explanation for the findings. This does not mean that there was no increase in risk, just that the ability of the study to detect the risk was limited. Mortality and not incidence or illness was evaluated. Chemical exposure could be evaluated only as "potential" since few measurements were made in the early years. Lifestyle factors such as diet and tobacco use were also not known.

On the other hand the study has several strengths. Multiple data sources were used to identify the worker population of whom 99.2% were located. Radiation exposure assessment was comprehensive and included obtaining doses before and after Rocketdyne tenure. The assessment of organ doses from internal intakes of radionuclides used state-of-the-art methodologies. Chemical exposure assessment was facilitated by knowledge of test stand assignment and chemical use which enabled a more accurate assessment of hydrazines and TCE. Auxiliary analyses were conducted to augment and support the main analyses, including comparisons with other workers at Canoga Park and other local Rocketdyne facilities.

The radiation dose distribution for workers is relatively low and much lower than in other studies where effects are clearly evident. The numbers exposed to "high" doses of radiation are small, as are the numbers of workers "potentially" exposed to hazardous test stand chemicals. The exposure assessment problem for the chemicals is recognized, which necessitates having to use "years worked" as a surrogate for actual exposure. Further, chemical exposures at a test stand occurred outdoors where concentrations were likely diluted. Attempts to improve the exposure assessment to radiation or to chemicals are unlikely to yield an appreciable improvement. Additional investigation of potential confounding influences, such as tobacco use, would likely be unproductive because of the absence of any significant increases over categories of radiation dose to lung or over categories of years worked as a test stand mechanic. Further, obtaining accurate and valid smoking information would be difficult for those who have died, where surrogate responses from spouses or children many years after the fact would have to be obtained. Finally, the number of cancers for some sites of potential interest, such as kidney, are small and generally less than 10 and not amenable for meaningful case-control evaluation. Thus, the small numbers of workers in the study, the relatively low exposures to radiation and test stand chemicals, and the absence of any significant or consistent excesses argues at this time against the need for a nested case-control investigation.

The Rocketdyne workers are an aging population with the median age in 1999 being just over 60 years overall and nearly 70 years for test stand mechanics. Through 1999, 23.7% (11,118) of the Rocketdyne workforce had died. Based on age and current mortality patterns, an additional 5,000 workers would be expected to die by the end of 2005, including approximately 700 radiation workers and 1,000 SSFL workers. An additional mortality follow-up through 2005 would result in a much more powerful evaluation of the potential risk from work in nuclear technology development and work at rocket engine test facilities. Any inconsistencies in the current data could be resolved with further follow-up and suggestive patterns could be clarified, such as the non-significant increase in leukemia among radiation workers, the non-significant increase in lung cancer among hydrazine-exposed workers, and the non-significant increase in kidney cancer among TCE-exposed workers. Because there were no significant increases seen in the cohort internal dose-response evaluations, however, there seems little justification to consider nested case-control studies at this time.

11. <u>Manuscripts.</u>

Dosimetry Paper

Boice JD Jr, Leggett RW, Dupree BE, Wallace P, Mumma M, Cohen SS, Brill AB, Chadda B, Boecker B, Yoder RC, Eckerman KF. A comprehensive dose reconstruction methodology for former radiation workers. <u>Health Phys</u> (Submitted)

Uranium Aluminide Paper

Leggett RW, Eckerman KF, Boice JD Jr. A respiratory model for uranium aluminide based on occupational data. <u>J Radiol Prot</u> (Submitted)

Radiation Epidemiology Paper

Boice JD Jr, Cohen SS, Mumma MT, Dupree Ellis E, Eckerman KF, Leggett RW, Boecker BB, Brill AB, Henderson B. Mortality among Rocketdyne/Atomics International workers monitored for radiation 1948-1999. (In Draft)

SSFL / Chemical Epidemiology Paper

Boice JD Jr, Marano D, Cohen SS, Mumma MT, Blot WJ, Brill AB, McLaughlin JK, Henderson B. Mortality among Rocketdyne workers who tested rocket engines, 1948-1999. (In Draft)

12. Papers Cited.

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Ritz B, Morgenstern H, Crawford-Brown D, Young B. The effects of internal radiation exposure on cancer mortality in nuclear workers at Rocketdyne/Atomics International. Environ Health Perspect 108:743-751, 2000.

13. Summary Charts and Figures

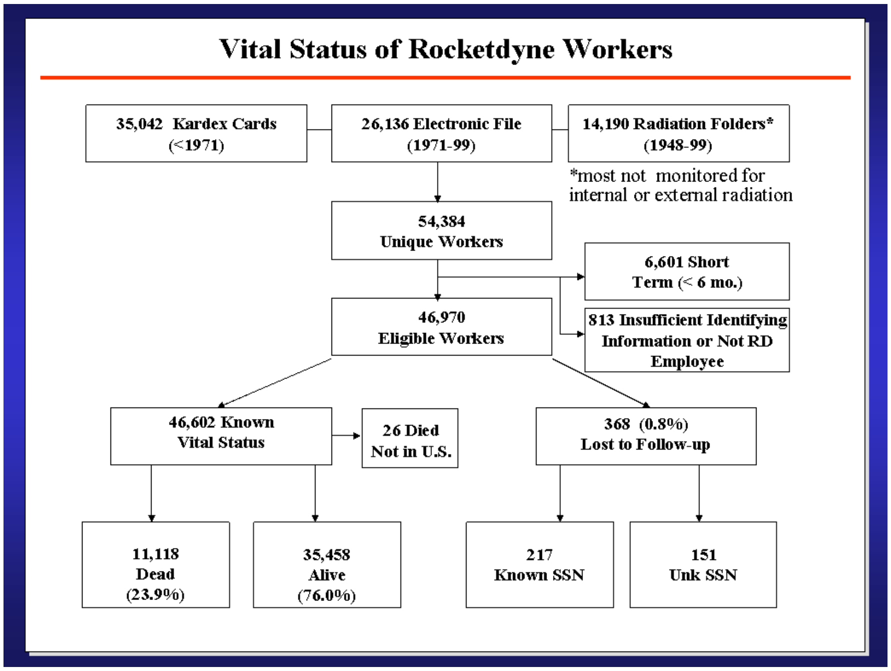


Figure 1

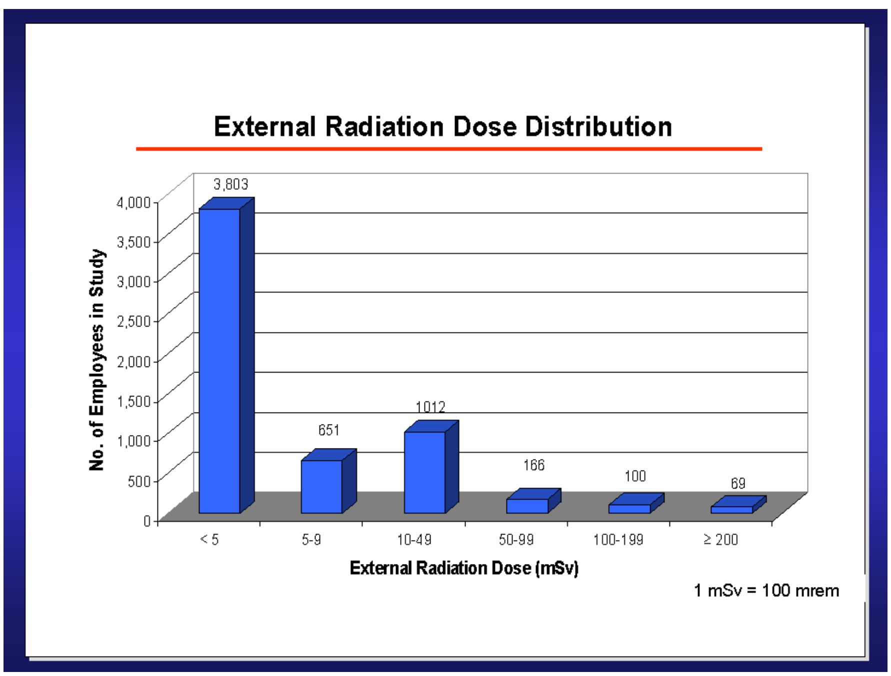
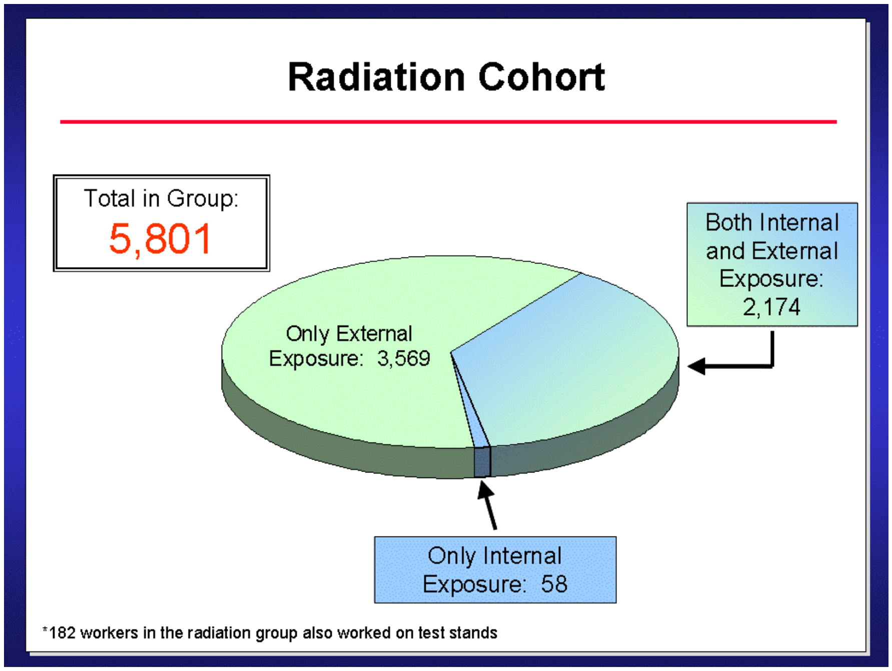


Figure 2



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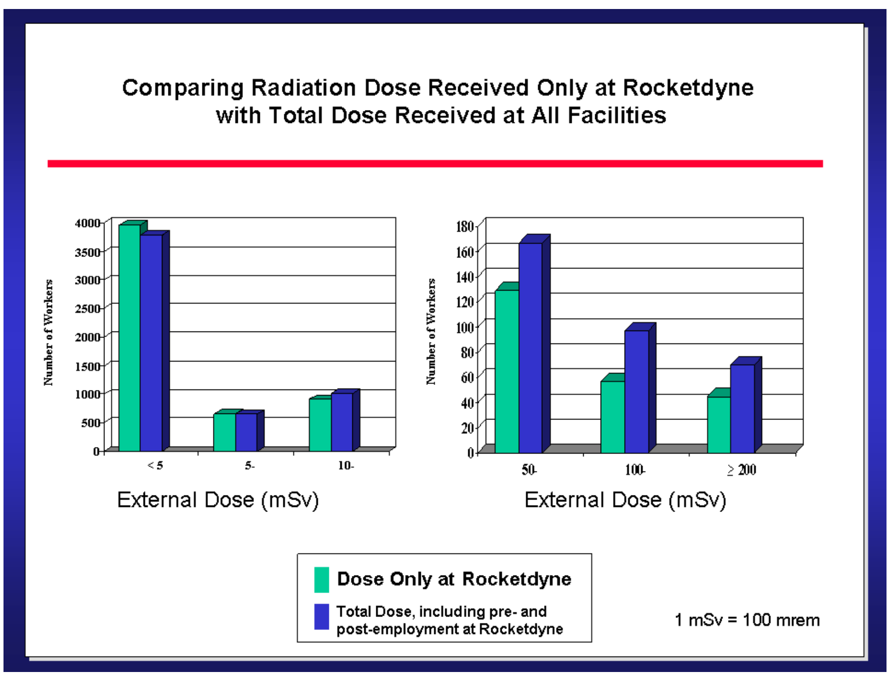

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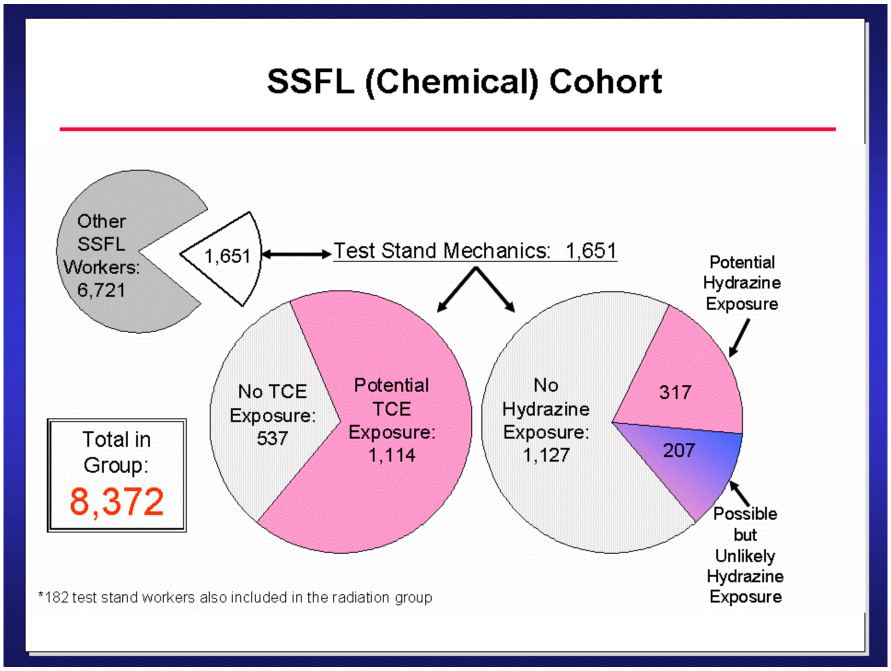

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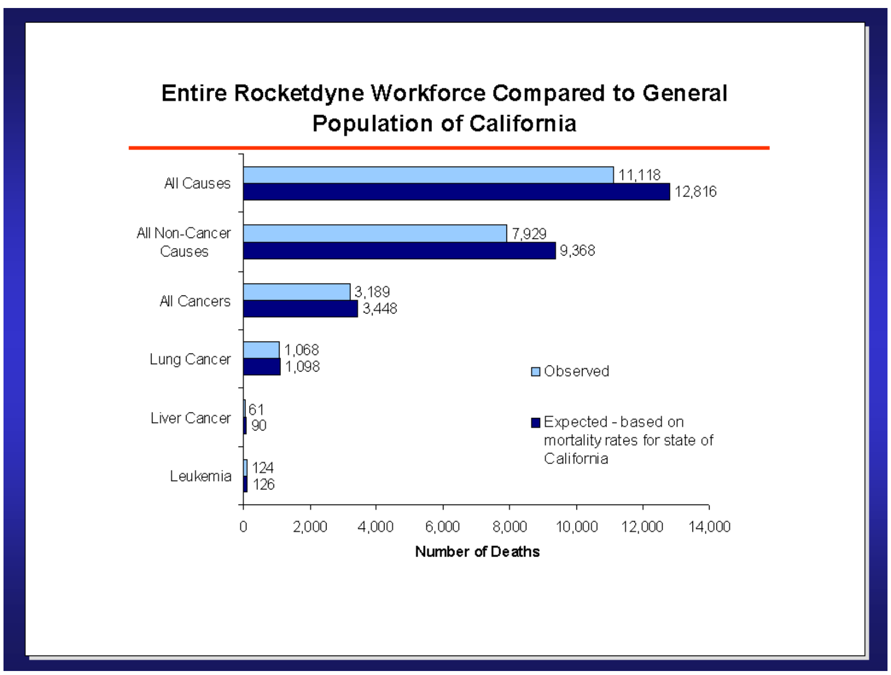

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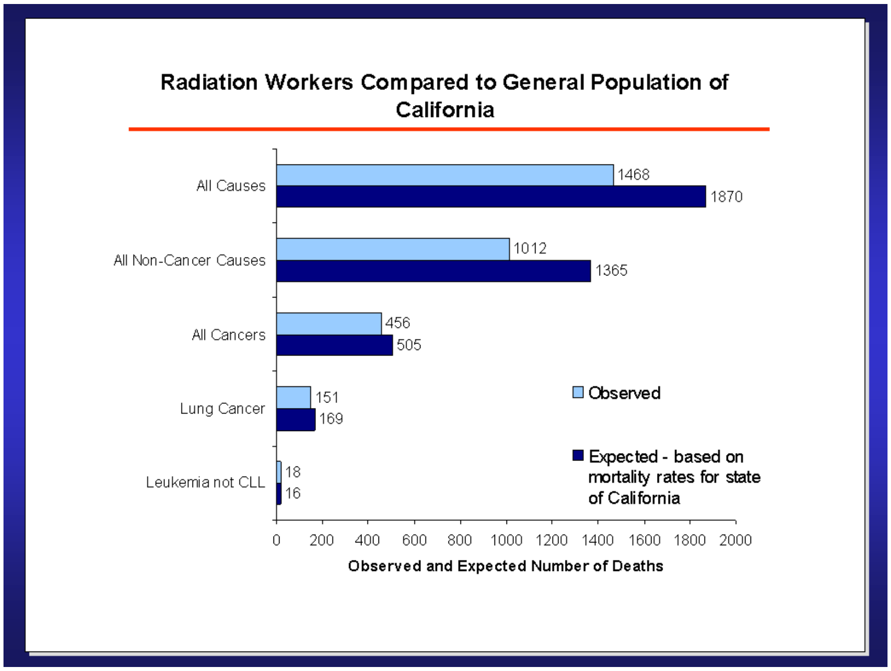

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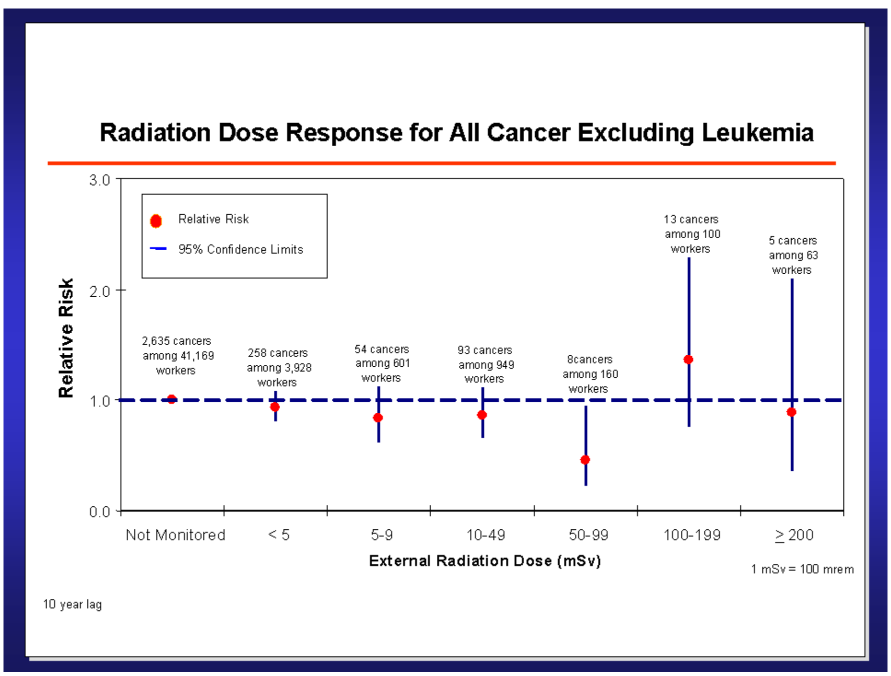

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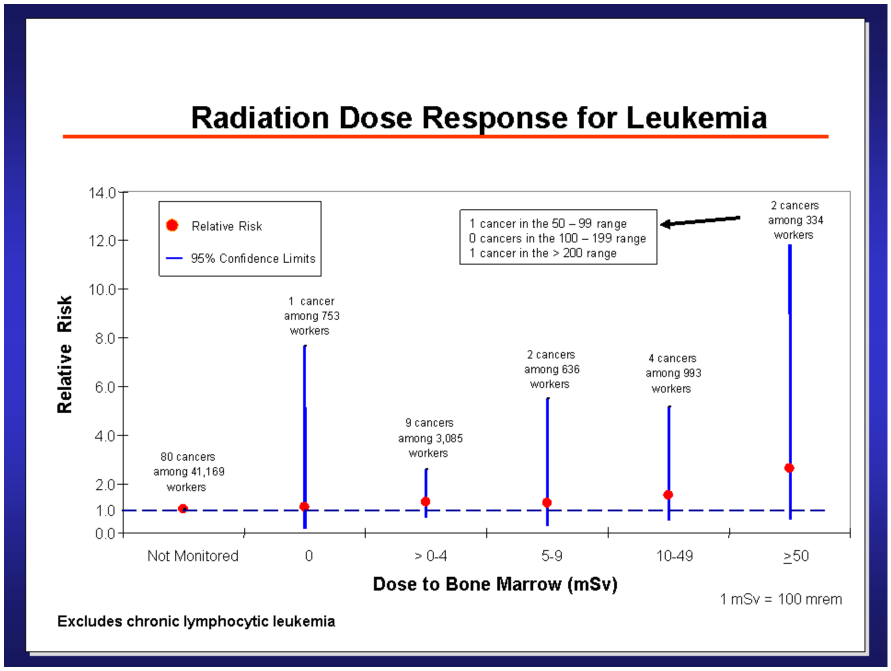

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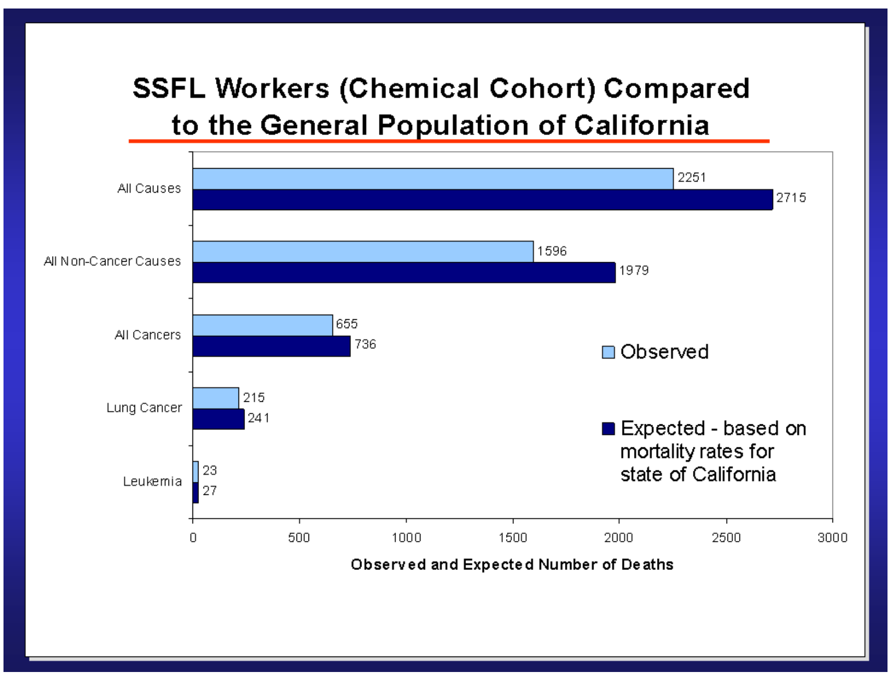

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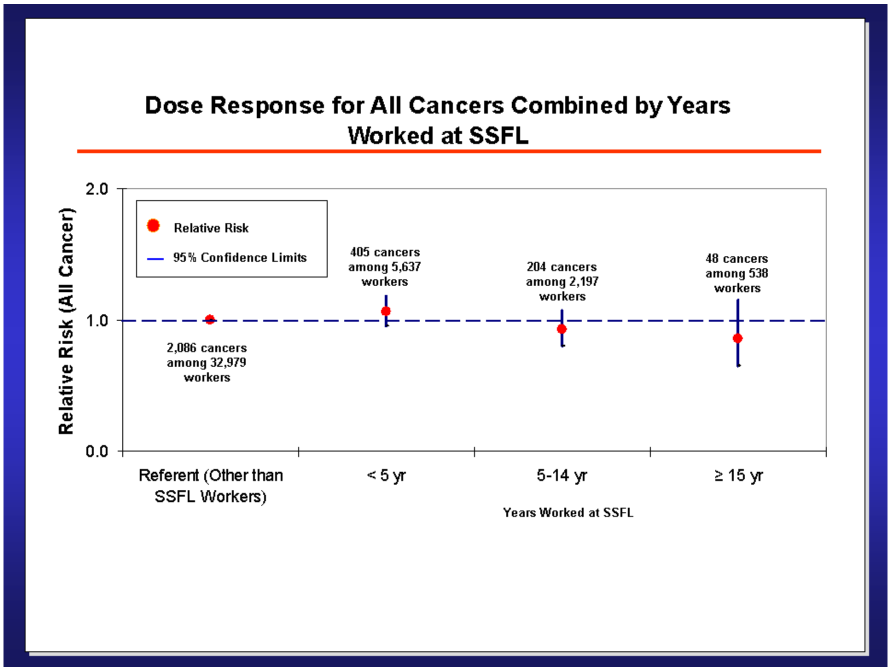

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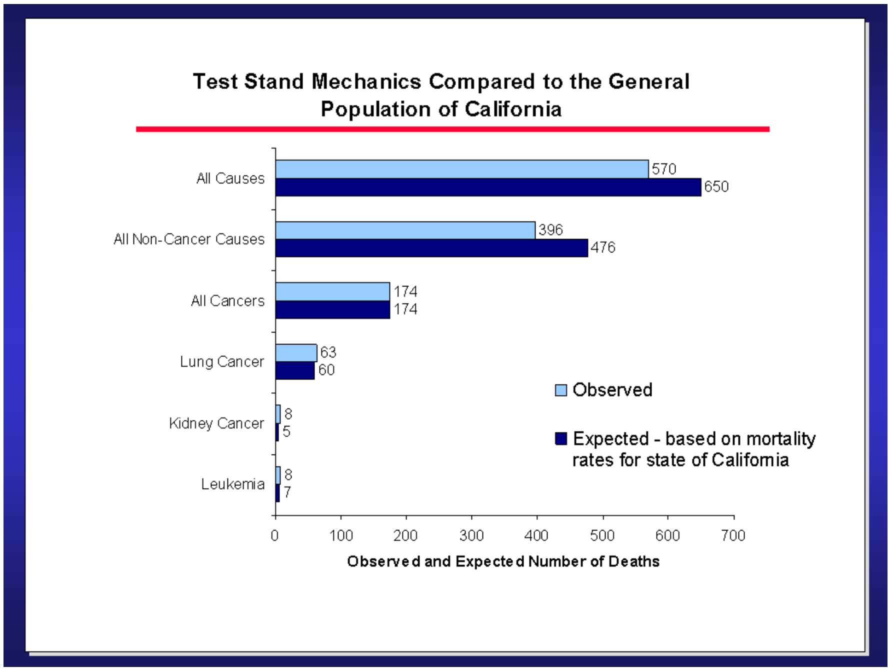

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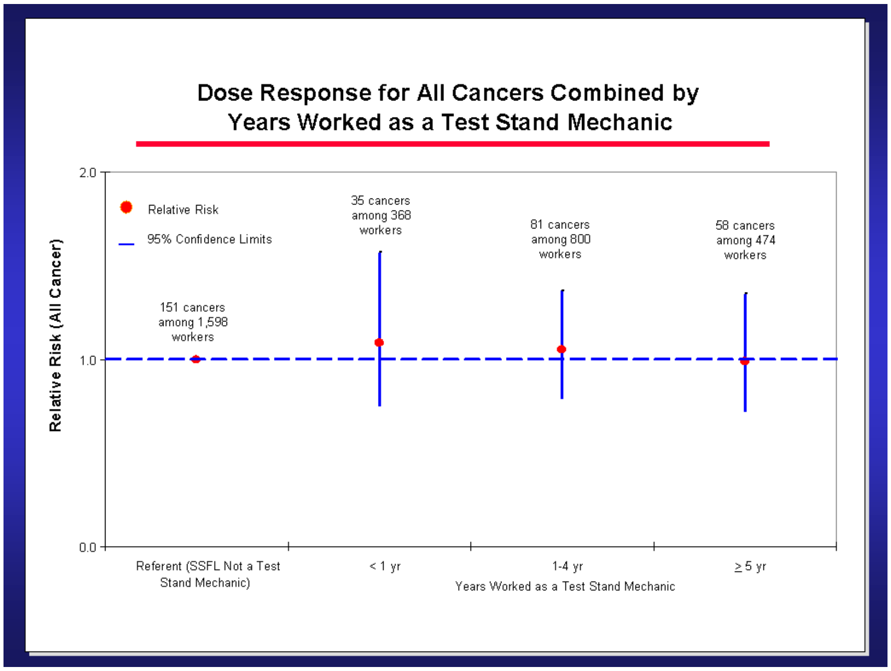

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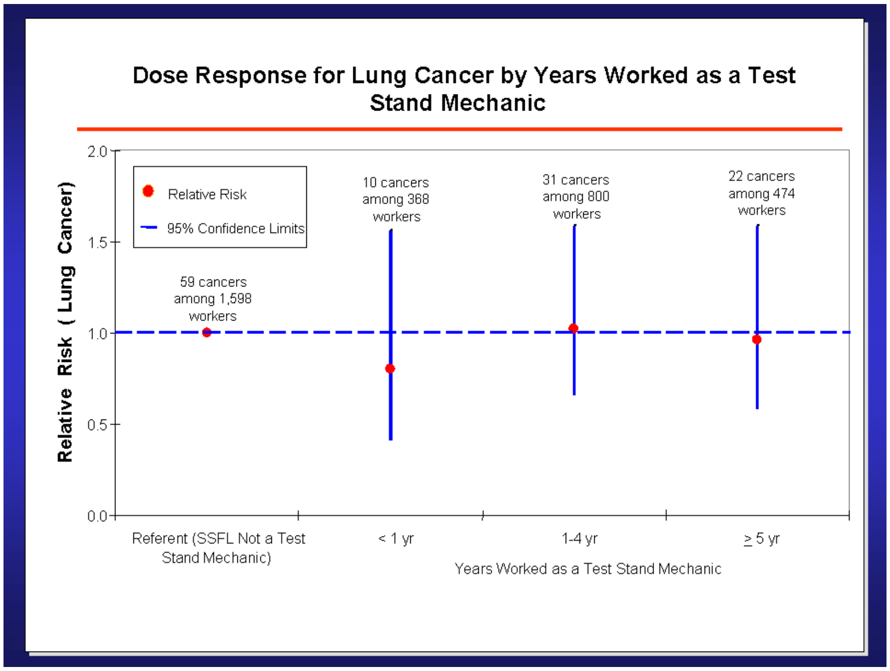

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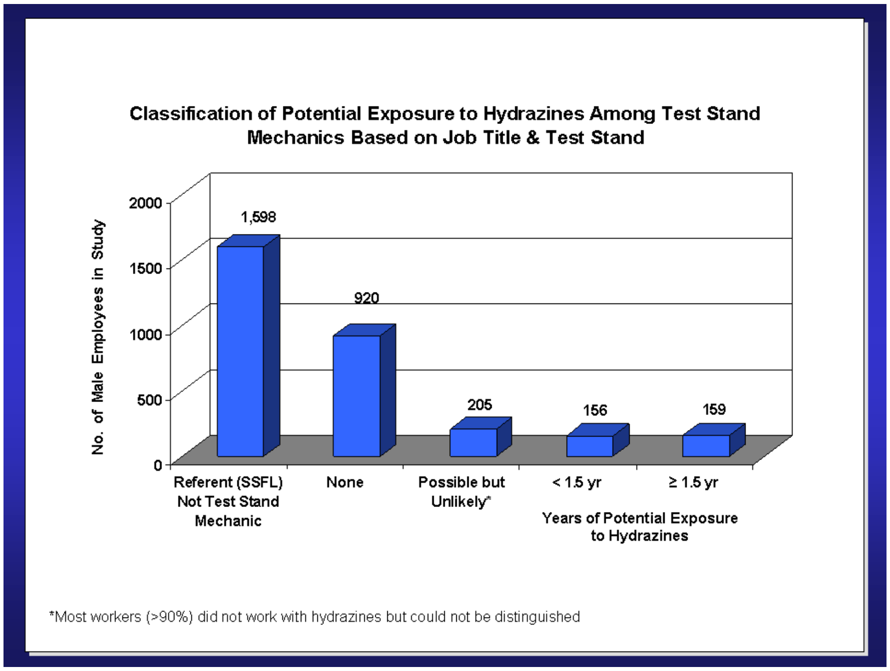

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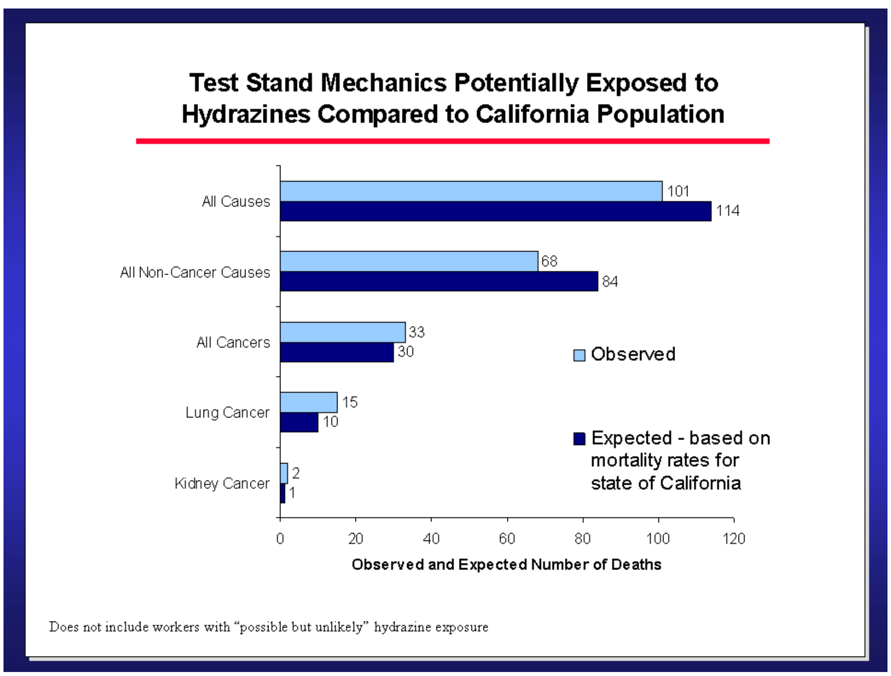

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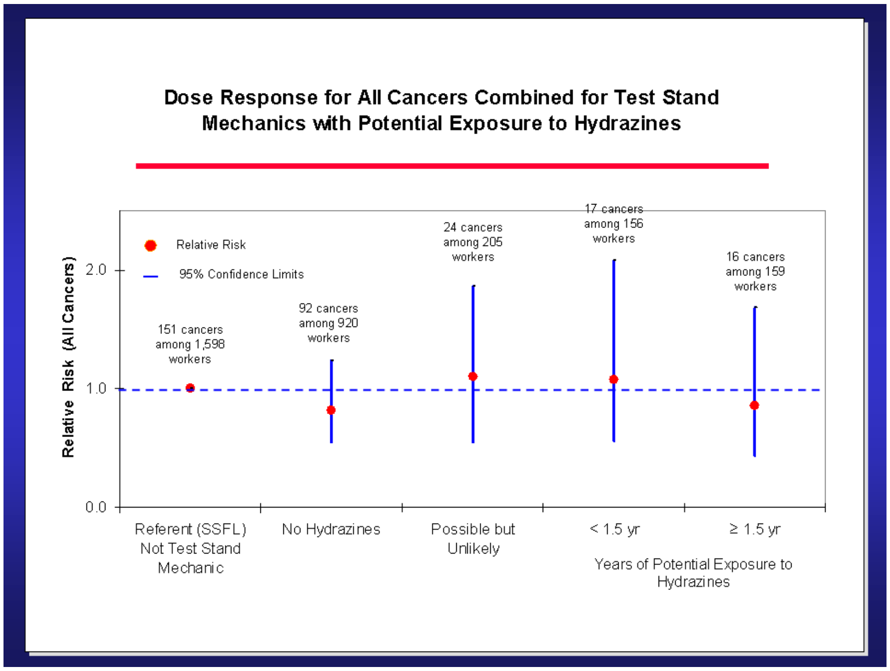

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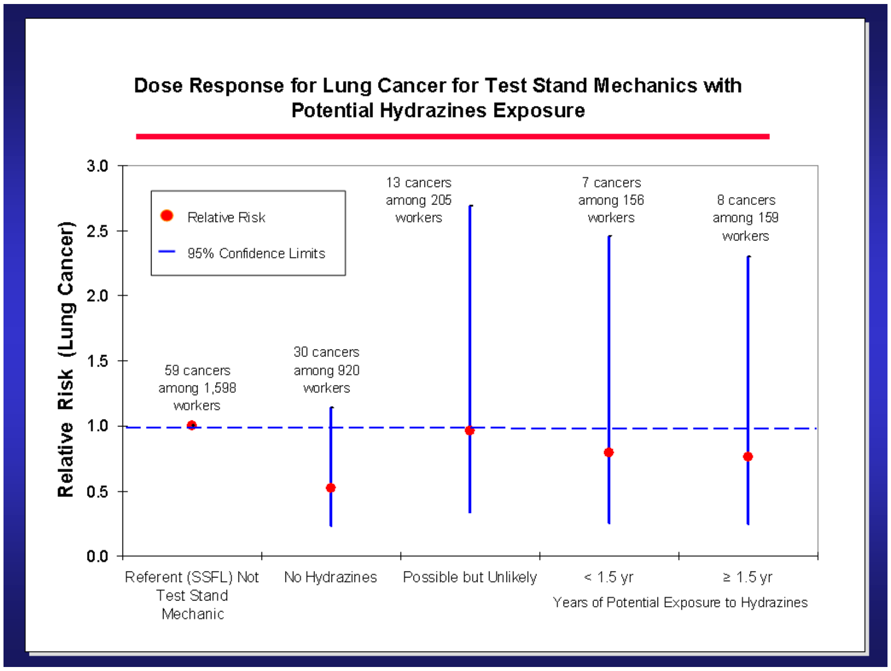

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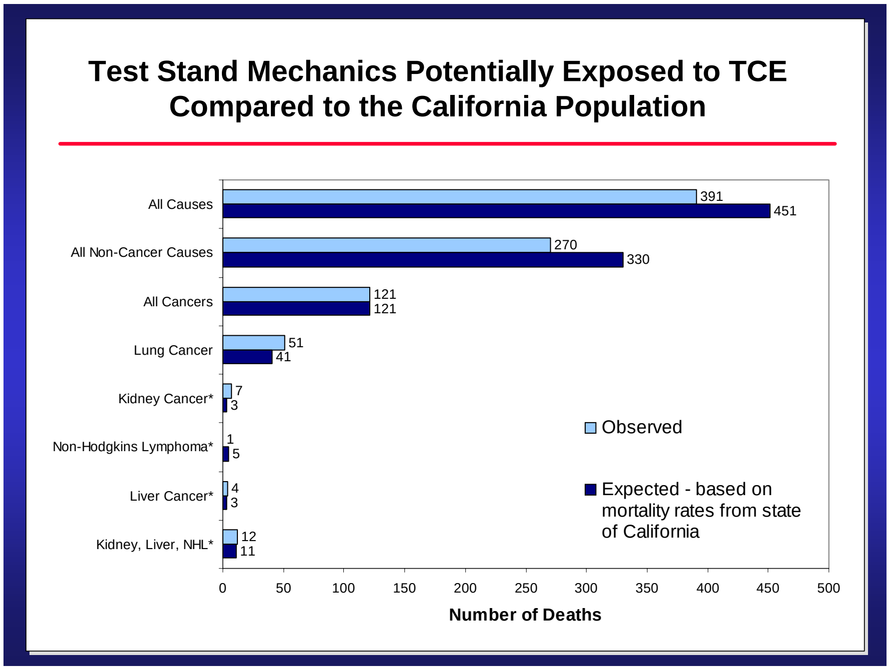

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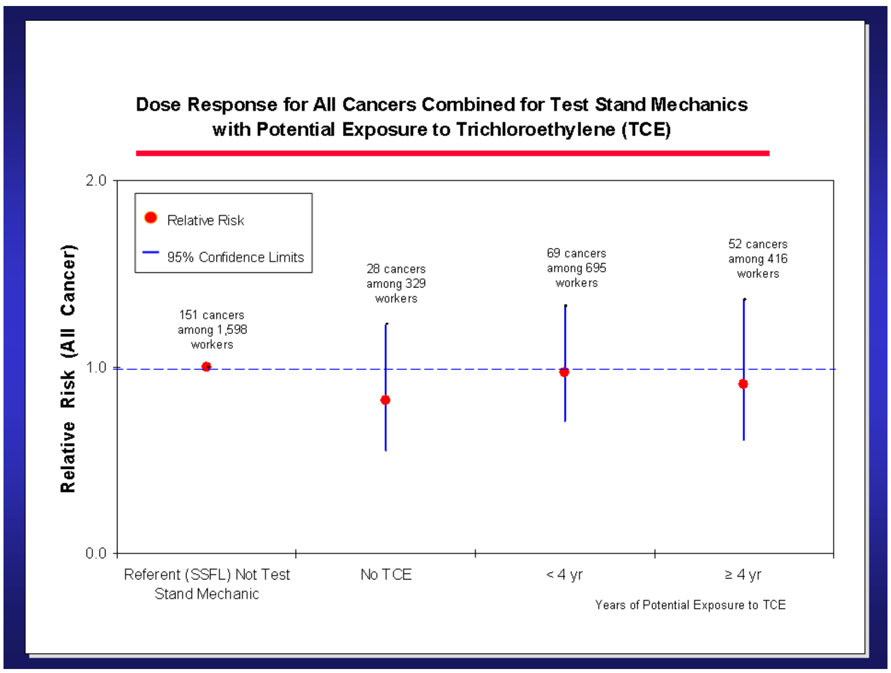

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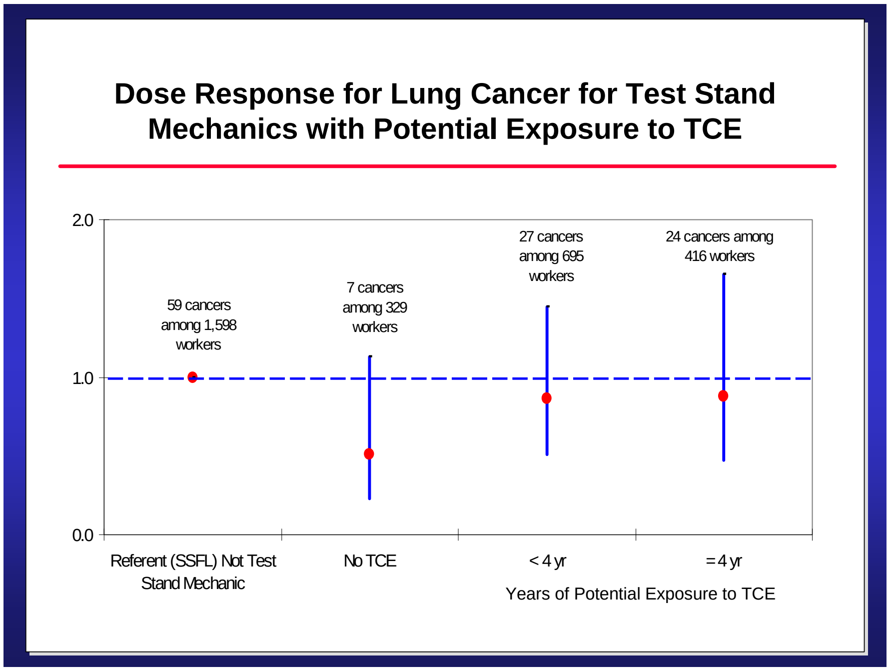


Figure 21

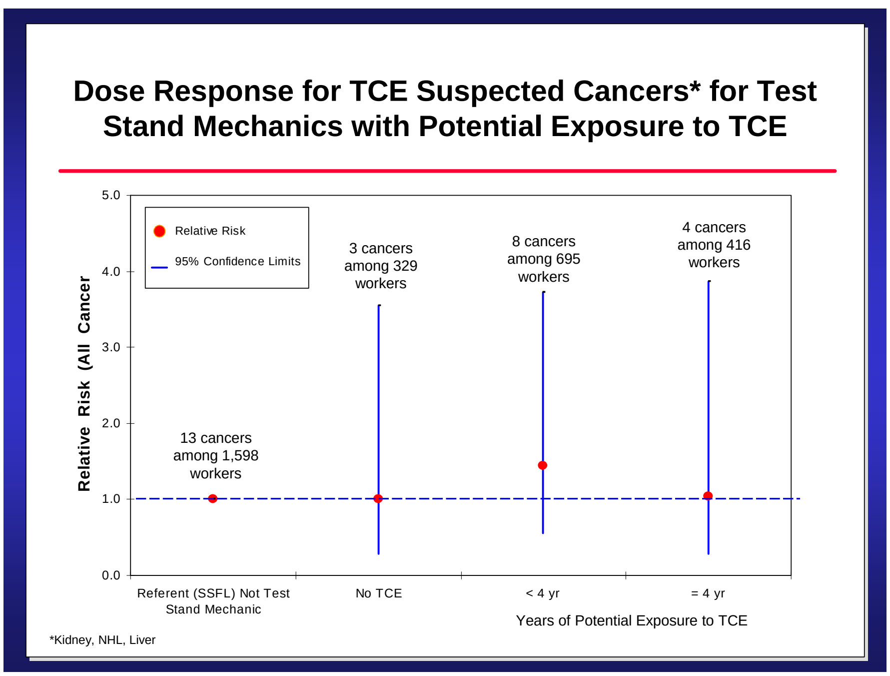


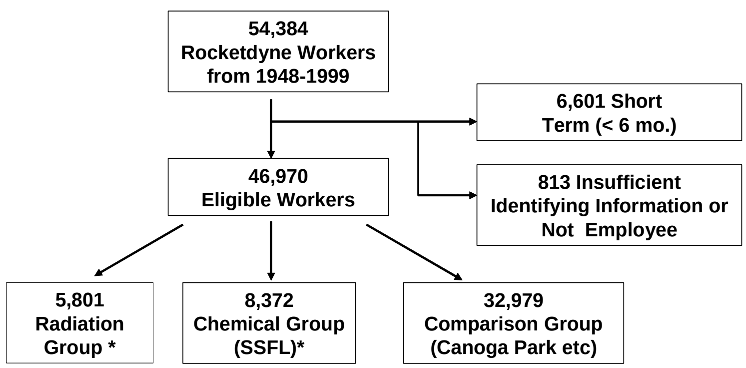
Figure 22

14. PowerPoint Presentation 6-8 April 2005

Rocketdyne Follow-On Health Study
6-8 April 2005
Overview

Figure 1pp

Who was in the study?



99.2% of eligible workers as of 12/31/99 were traced

*182 workers included in both groups

Figure 2pp

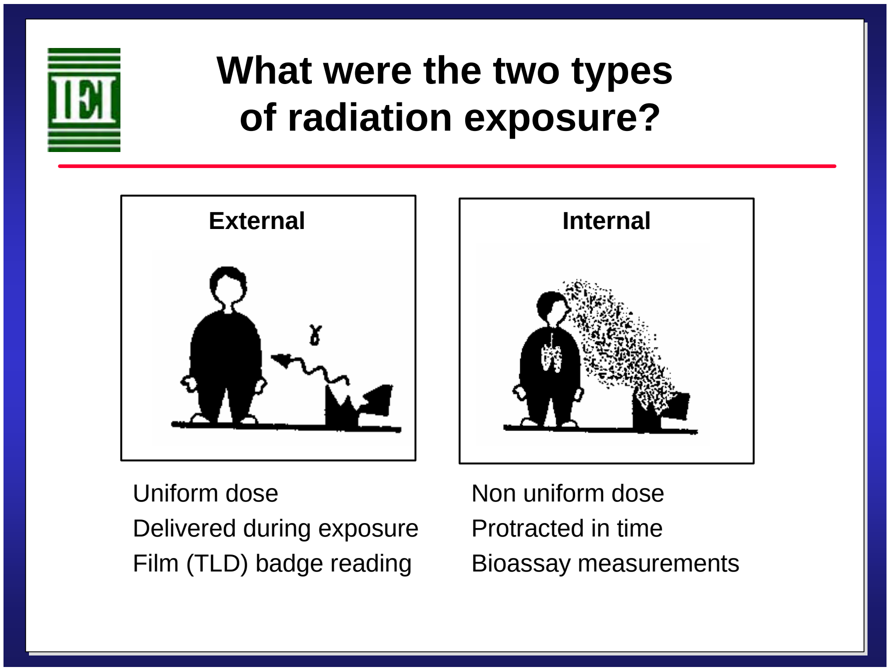


Figure 3pp

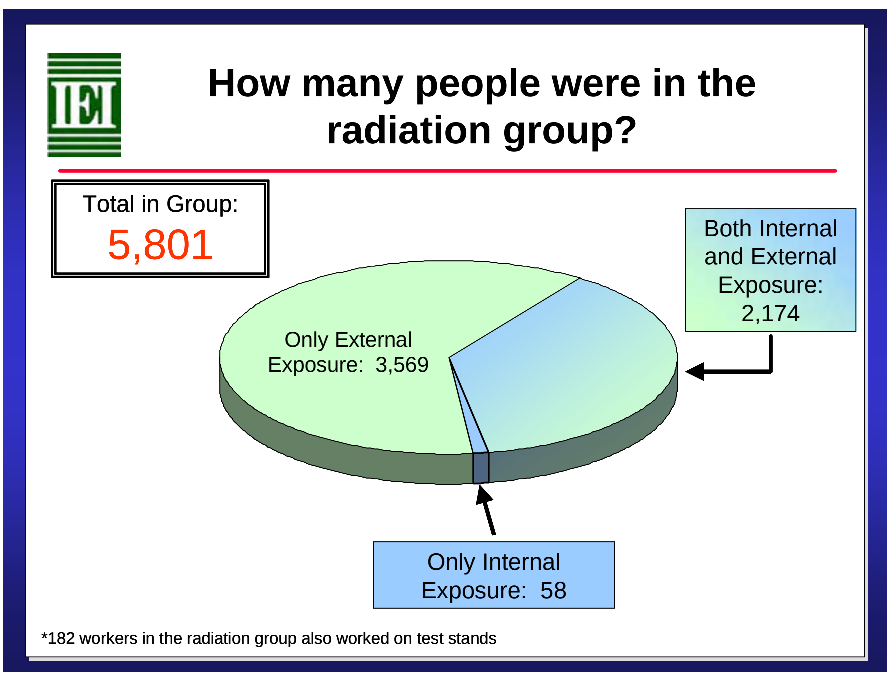


Figure 4pp

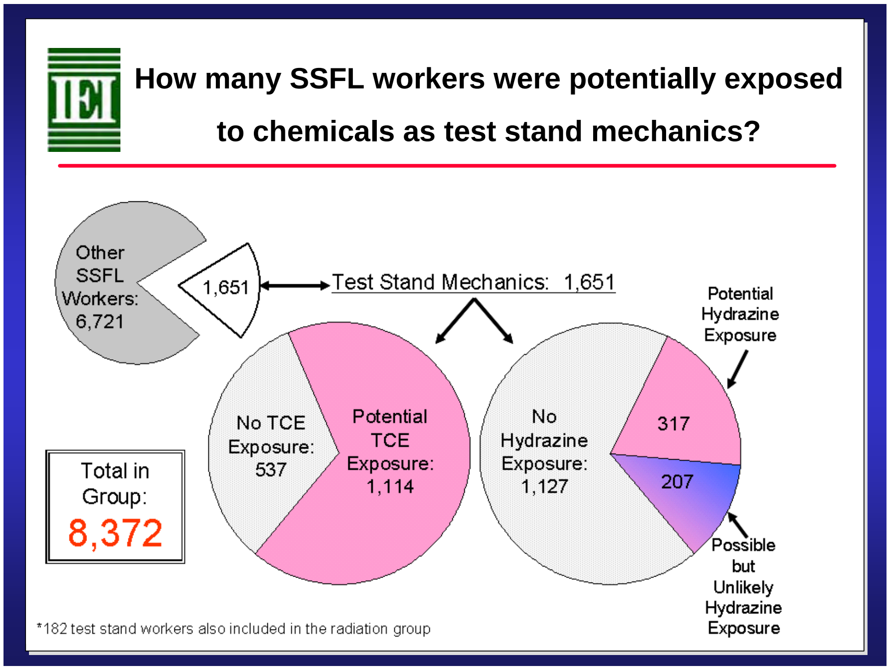
Potential Chemical Exposure Characterized by Years Worked

- Work at SSFL
- Work as Test Stand Mechanic
  - Exposure to “Test Stand Environment”, including chemical mixture of fuels, oxidizers, exhaust gasses, solvents and other chemicals
  - Hydrazines
  - TCE as a “Utility Solvent”
  - TCE as a “Flush Solvent”

Figure 5pp

Nine Discussion Sessions

Figure 6pp



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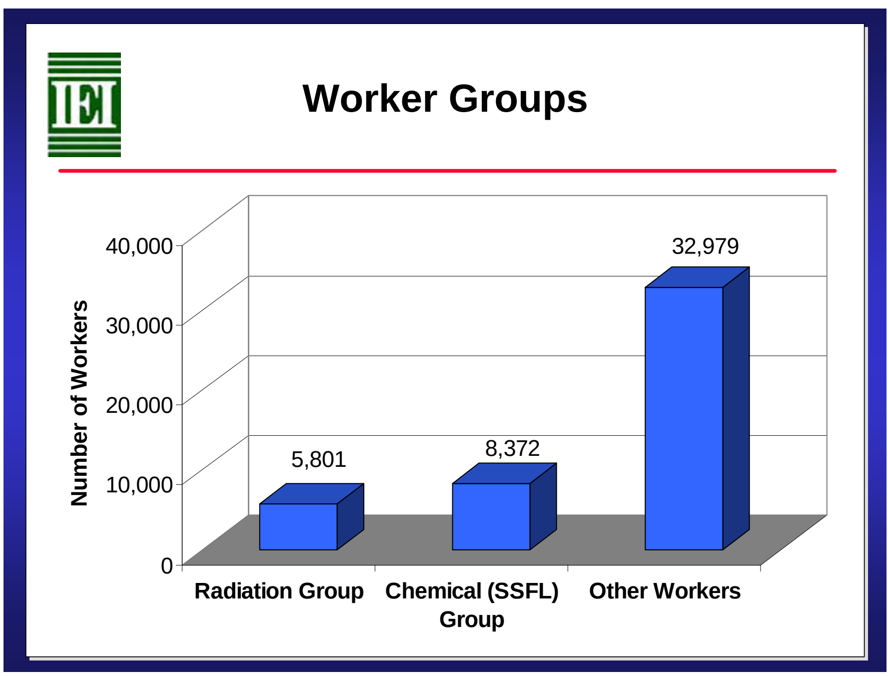

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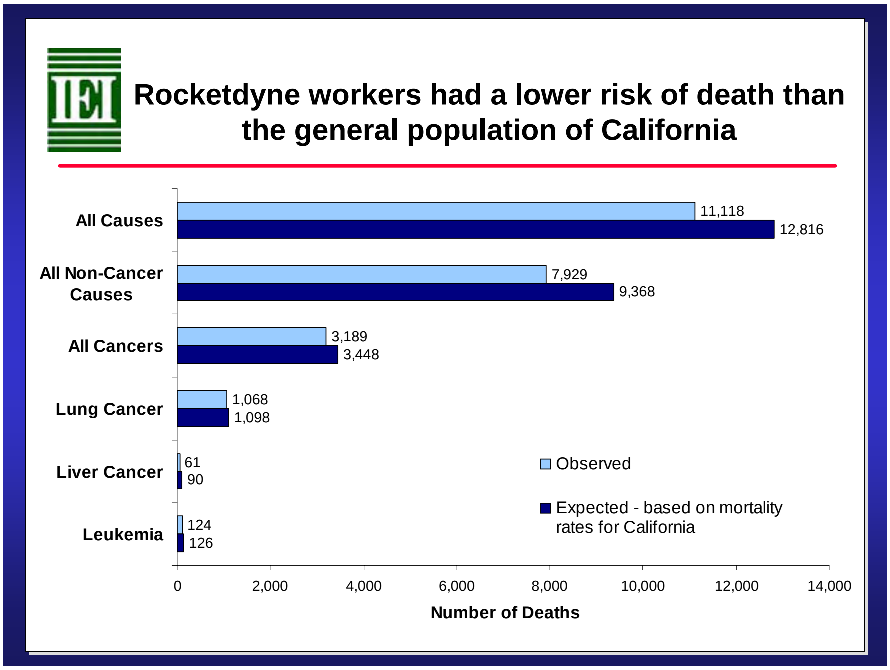

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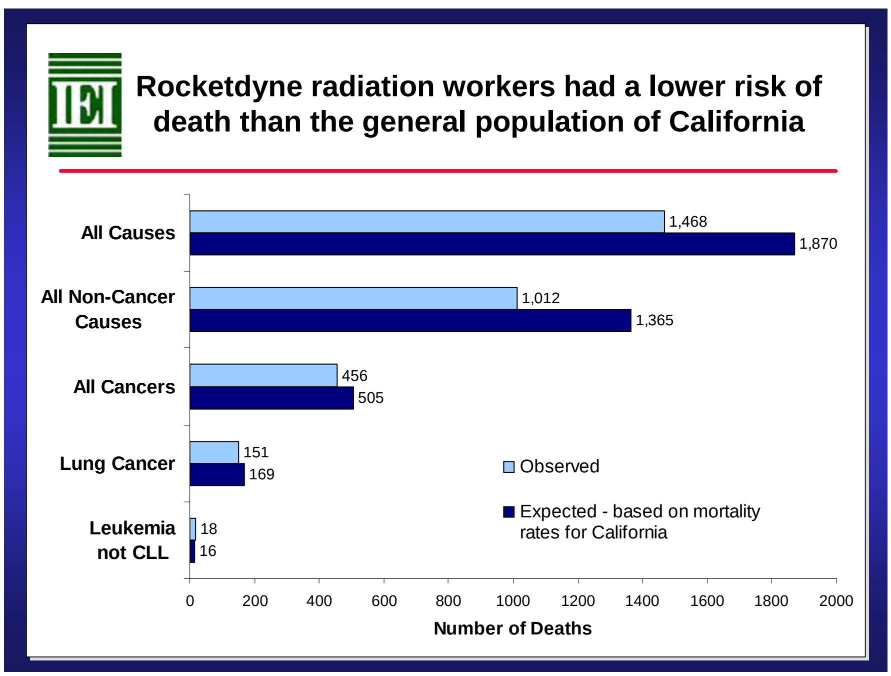

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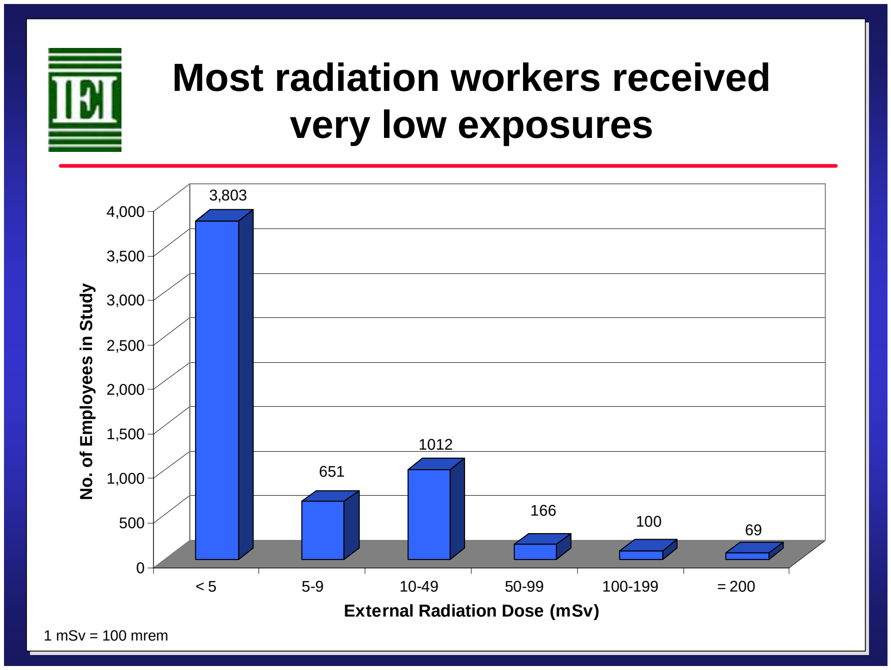

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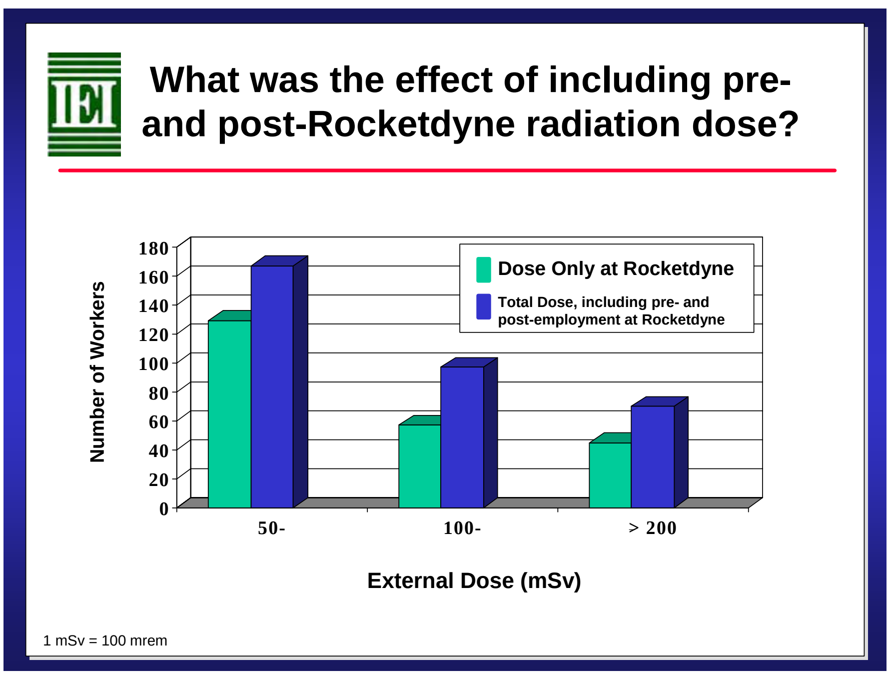

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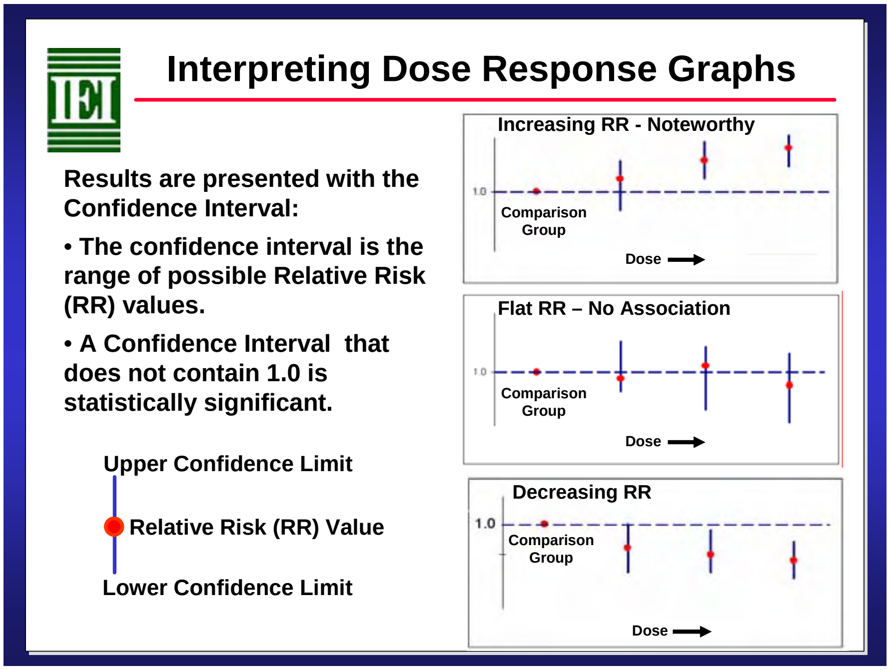

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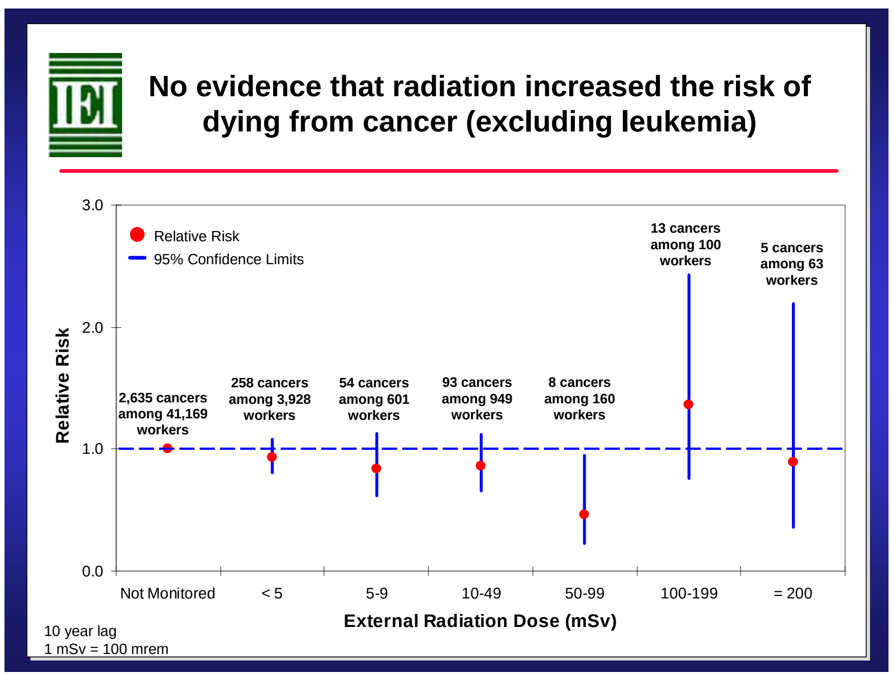

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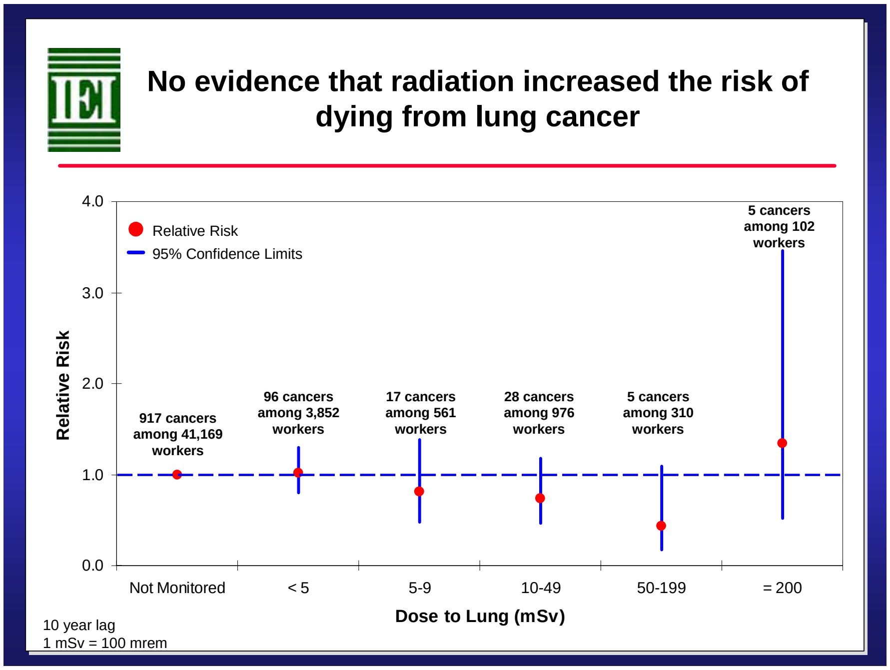

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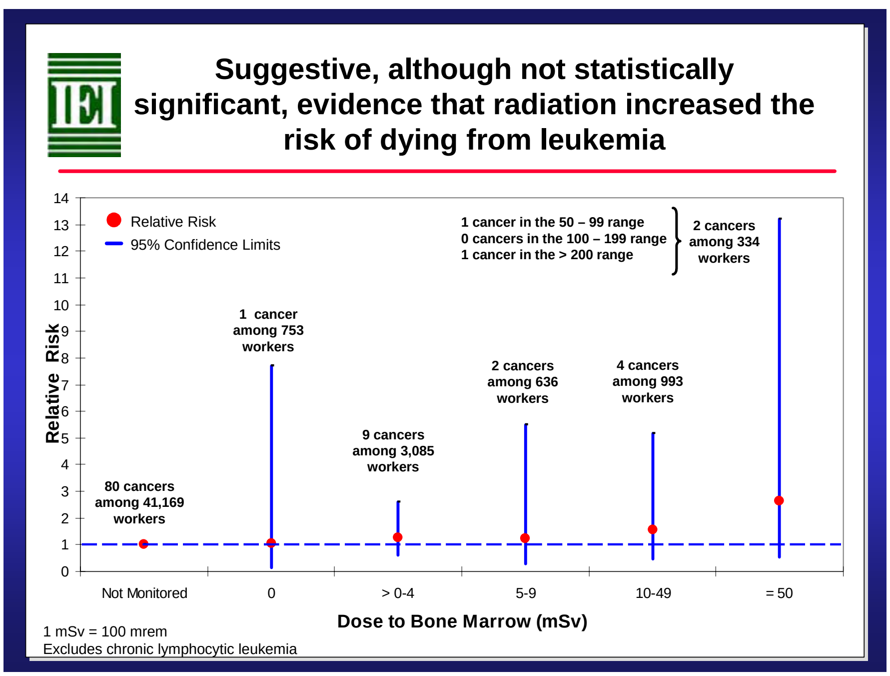


Figure 16pp

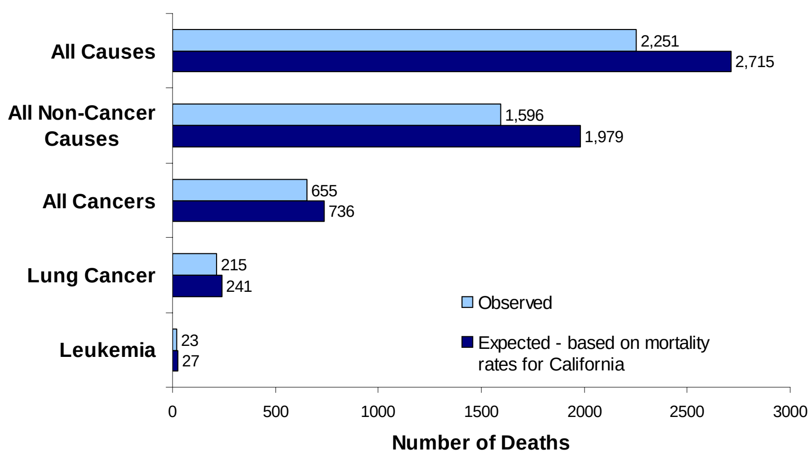
Radiation Summary Findings

Radiation exposure has not caused a detectable increase in cancer deaths among Rocketdyne workers

- Mean dose was low
- There were no significant trends between radiation dose and any cancer, including lung cancer
- Suggestive trend for leukemia was based on small numbers (18 observed v 15.5 expected) and trend was not statistically significant

Figure 17pp

SSFL workers (Chemical Group) had a lower risk of death than the general population of California



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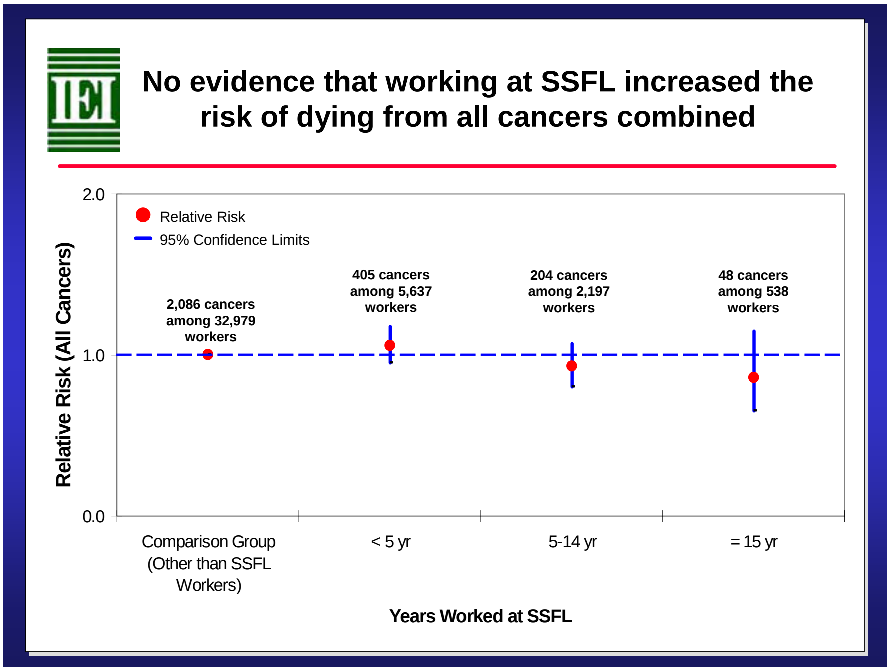

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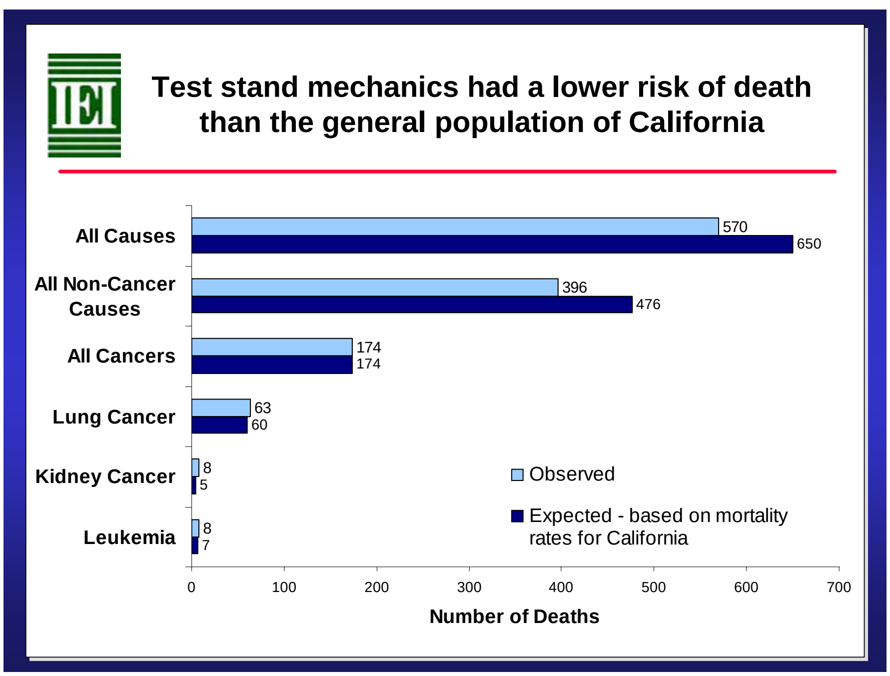

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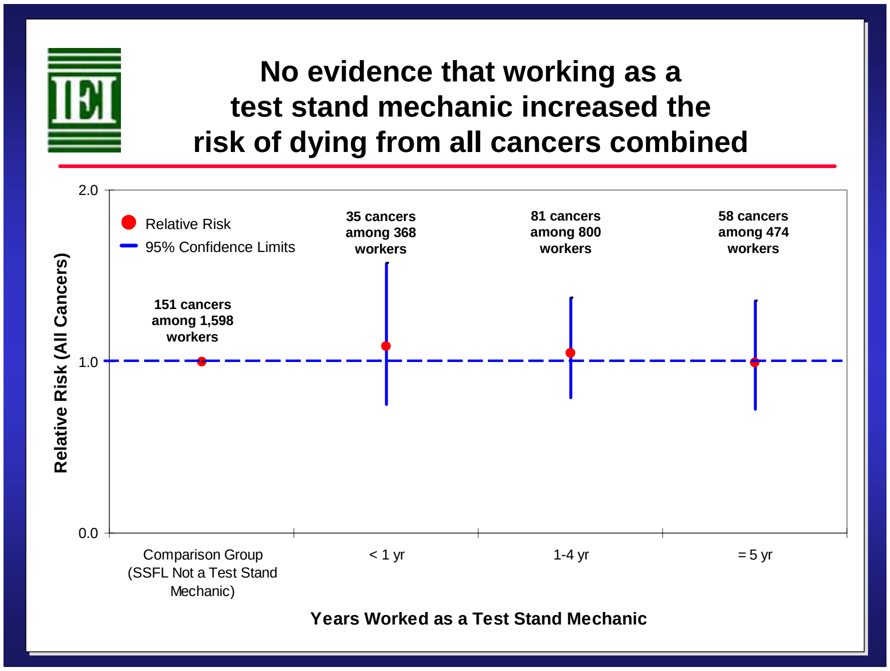

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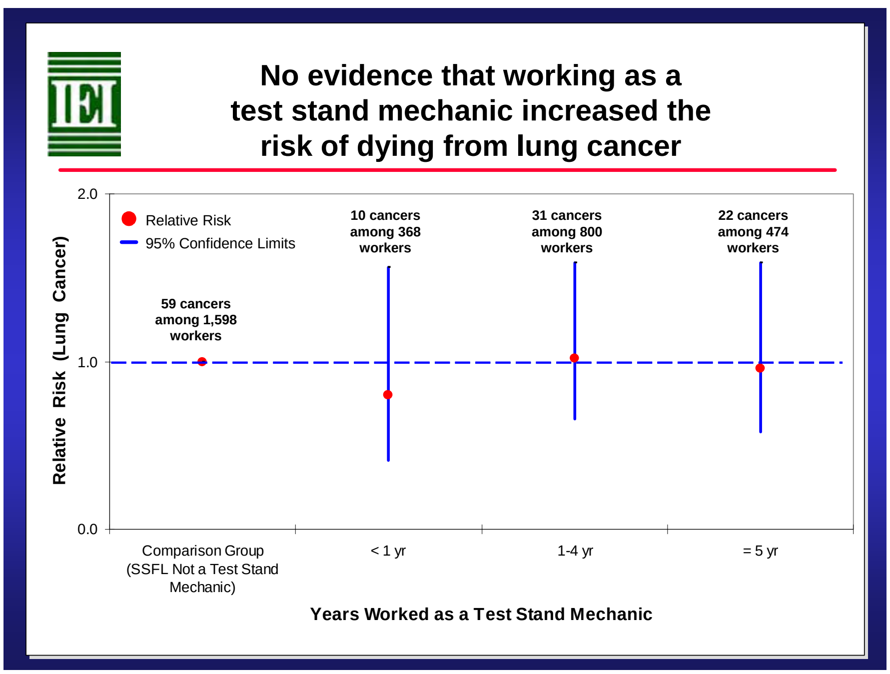

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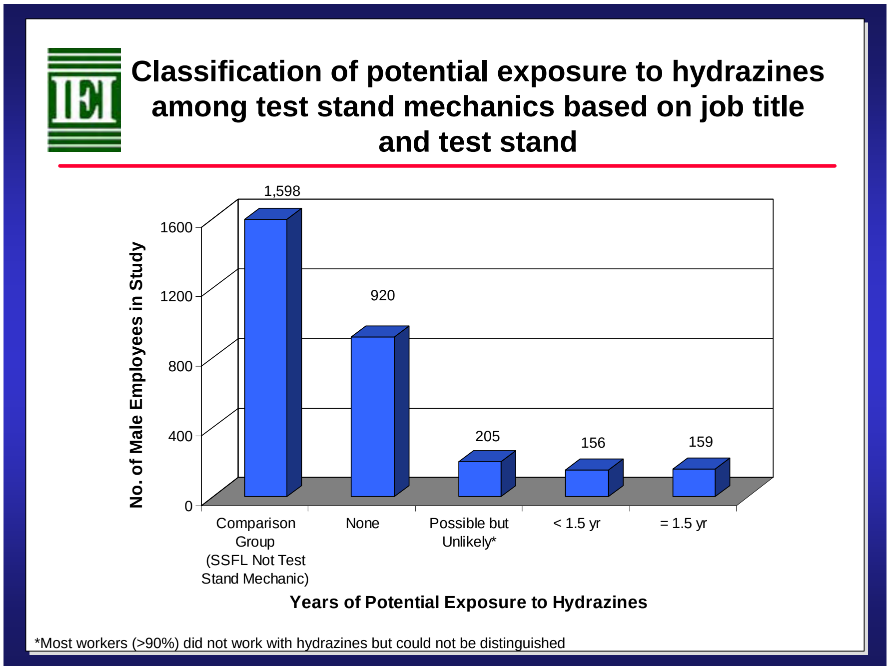

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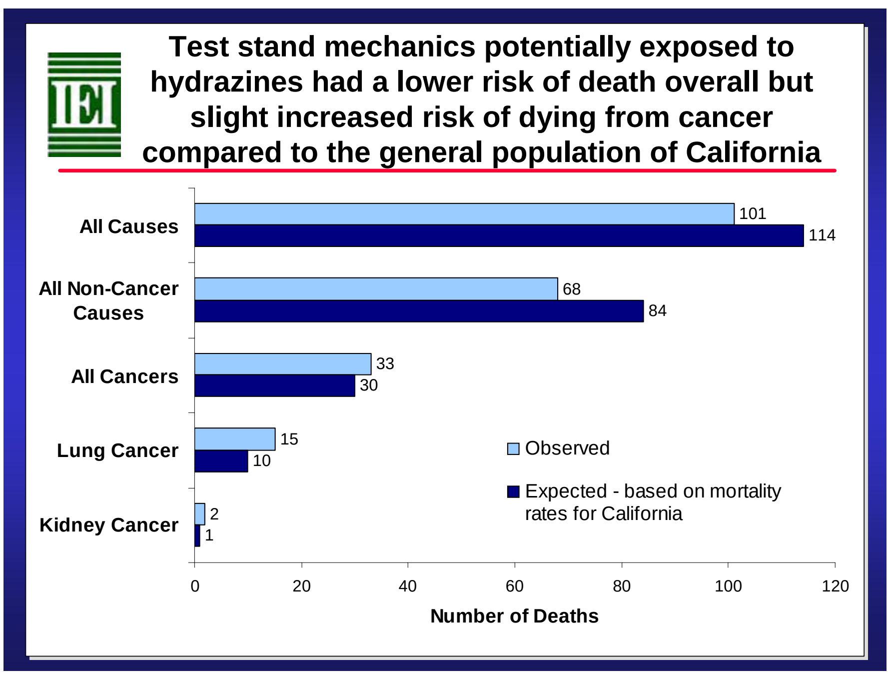

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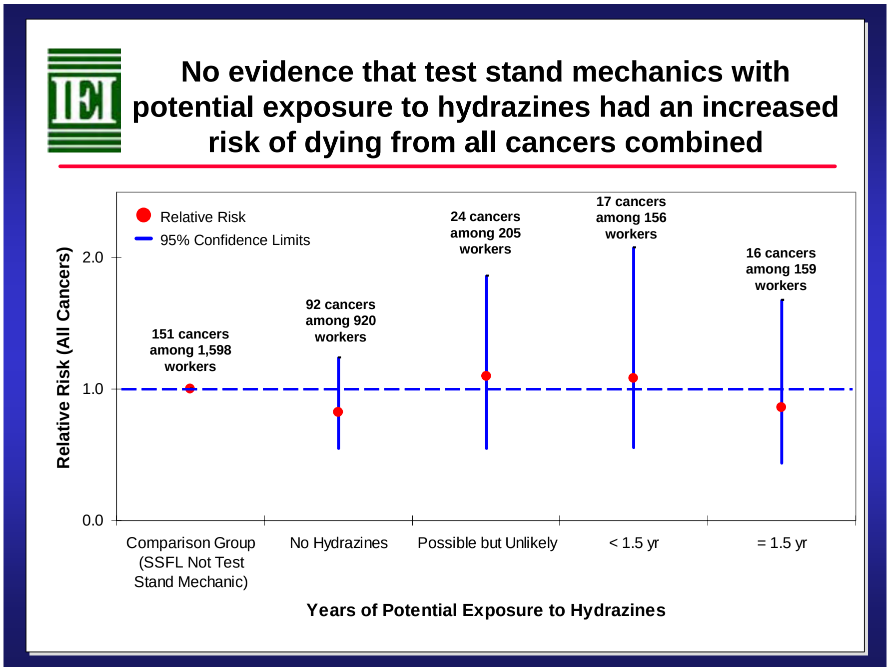

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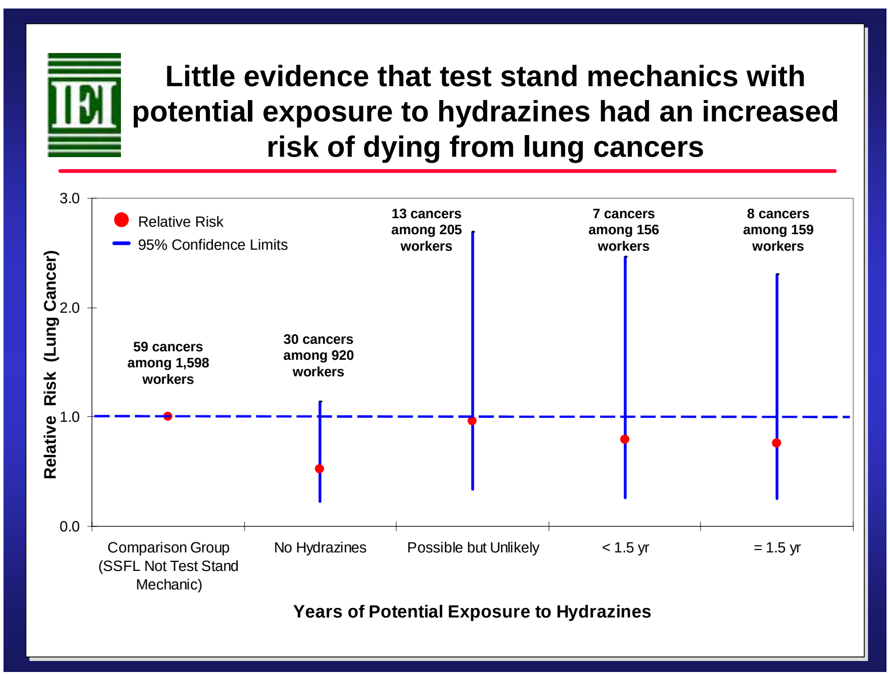

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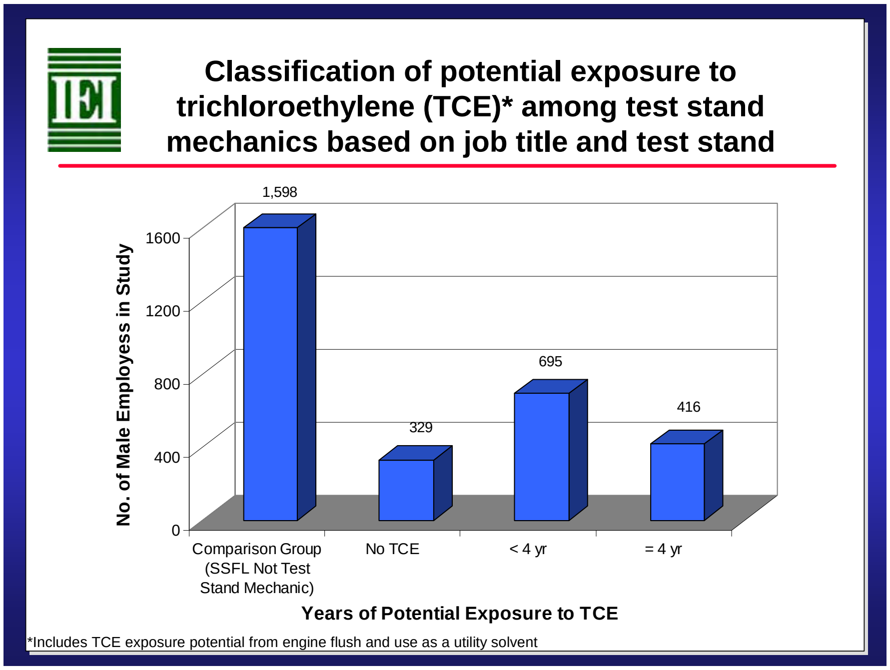

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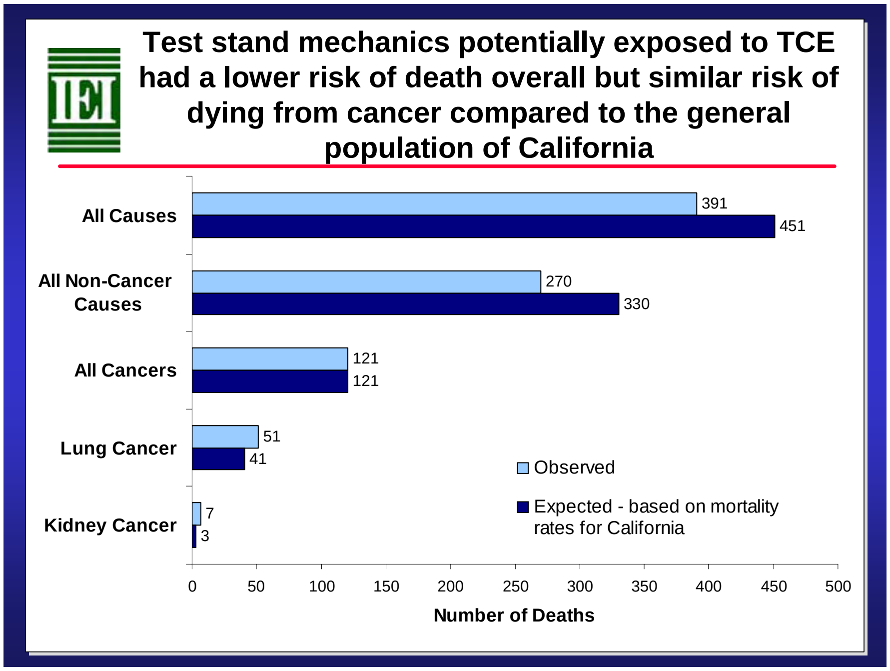

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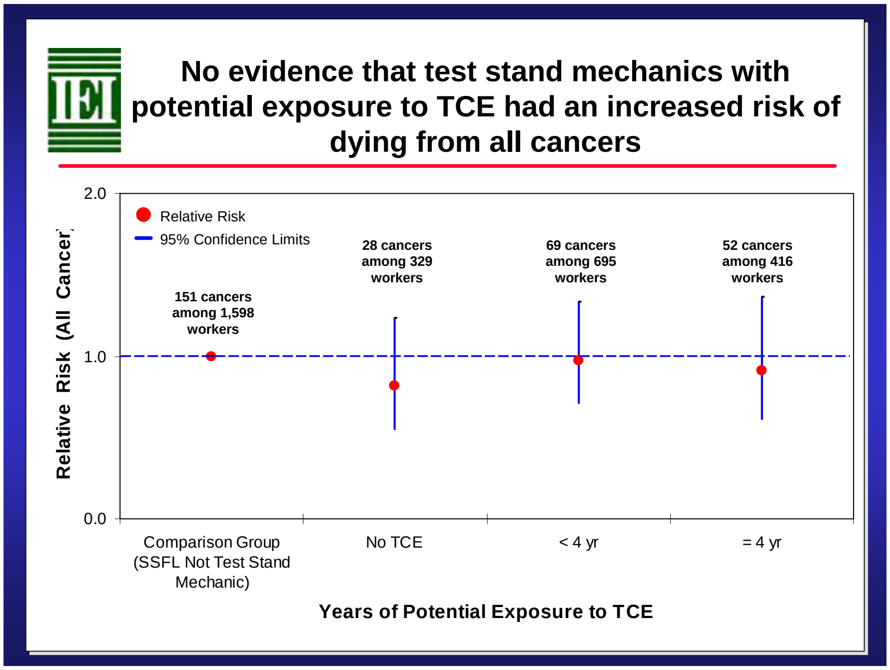

Figure 29pp

Chemical Summary Findings

Work at SSFL, as a test stand mechanic or with specific chemicals, has not caused a detectable increase in cancer deaths among Rocketdyne workers

– There were no significant trends or any significant excesses of cancer among workers at SSFL, or among test stand mechanics

– Hydrazines were not linked to significant increased risk of cancer, although lung cancer elevated compared to general population

– TCE was not linked to any significant increased risks of cancer

Figure 30pp

Limitations

- Low exposures limit ability to detect increased risks, if they existed
- Chemical exposure only “potential” since few measurements made in early years
- Lifestyle factors such as diet and tobacco use not known
- Mortality rather than illness

Figure 31pp

Strengths

- Multiple data sources used to identify study groups
  - 99.2% of eligible workers traced
- Comprehensive Radiation Assessment
  - Doses obtained pre and post Rocketdyne
  - Comprehensive estimates of internal radiation doses
- Chemical Exposure Assessment
  - Worker assignments to specific test stands
  - Accurate assessment of hydrazines and TCE exposure
- Additional analyses conducted
  - Including comparisons to other workers at local Rocketdyne facilities such as Canoga Park

Figure 32pp

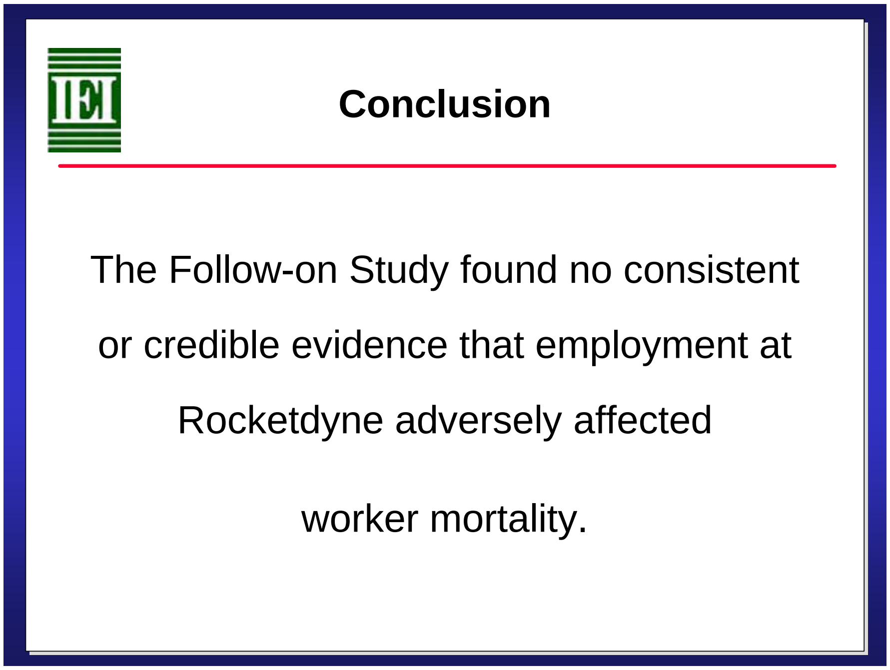
Conclusion
The Follow-on Study found no consistent or credible evidence that employment at Rocketdyne adversely affected worker mortality.

Figure 33pp