Cancer Incidence in the Community Surrounding the Rocketdyne Facility in Southern California

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Summary

Background: An epidemiologic study of cancer incidence in the residential population surrounding the Santa Susana Field Laboratory (SSFL) was initiated in response to community concerns about the use of radioactive and toxic substances at this Rocketdyne facility and its possible effects on the health of those residents. The focus on cancer was motivated by previous findings from the UCLA Study of Rocketdyne Workers (1993-1999) in which occupational exposures to ionizing radiation among nuclear workers and exposures to chemicals used at the rocket-engine test stands were linked to excess rates of dying from several types of cancer between 1950 and 1994.

Methods: The investigators of this study explored the rates at which newly diagnosed cases of cancer occurred in Ventura and Los Angeles Counties between 1988 and 2002 in relation to distance from SSFL. The two-county region was divided into three exposure areas (less than 2 miles, 2-5 miles, and greater than 5 miles from SSFL), and the study period was divided into two follow-up periods (1988-1995 and 1996-2002). Data on more than 600,000 cancers and census block-group data for the residential population in the two-county region were obtained from the California Cancer Registry. Using these data, incidence rates of cancer were estimated for each exposure area, by category of age, gender, and race/ethnicity (non-Hispanic white, Hispanic, and other non-Hispanic).

Because exposure to radiation and chemicals used at SSFL may affect the risk of several types of cancers, analyses focused on the association between distance from SSFL and 12 adult cancer outcomes—three general groupings and 9 specific types of cancer. The general groupings were total cancers (excluding non-melanoma skin cancer), "radiosensitive" cancers believed to be affected by ionizing radiation (lung, female breast, thyroid, bone, and leukemias), and "chemosensitive" cancers believed to be affected by the types of chemicals used at SSFL (lung, bladder, liver, kidneys, and bone marrow). The specific cancer outcomes were melanoma, cancers of the colon and rectum, cancers of blood and lymph tissue (including leukemias, lymphomas, and multiple myeloma), lung cancer, female breast cancer, bladder cancer, prostate cancer, thyroid cancer, and cancers of the upper aerodigestive tract (oral and nasal cavities, pharynx, larynx, and esophagus). Total cancers for children under 15 years were analyzed separately.

For each cancer outcome, the incidence rates for residents living less than 2 miles and 2-5 miles from SSFL were compared with the incidence rate for residents living more than 5 miles from SSFL. These comparisons were expressed as ratios of incidence rates, i.e., "incidence rate ratios." If environmental hazards originating at SSFL migrated offsite and if community residents were exposed to those hazards, the expected incidence rate of cancer would likely be most elevated in the area closest to SSFL, i.e., the expected incidence rate ratio would be greater than 1 for persons living within 2 miles of SSFL. Estimated incidence rate ratios were corrected statistically ("standardized") for differences between exposure areas in the distribution of age, gender, and race/ethnicity; i.e., the main results presented in this report, comparing the exposure areas, were not biased (distorted) by the effects of these three demographic variables on cancer risk.

Results: Associations between distance from SSFL and cancer incidence differed by type of cancer outcome. Standardized incidence rate ratios were close to 1, indicating little or no association, for total cancers and radiosensitive cancers among adults; but the incidence rate of chemosensitive cancers was slightly elevated during both follow-up periods in the population living within 2 miles of SSFL. Results for the 9 specific cancers revealed some elevated incidence rates between 1988 and 1995 among persons living within 2 miles of SSFL. Specifically, the standardized incidence rate ratio was greater than 1.6 for cancers of blood and lymph tissue, bladder, thyroid, and upper aerodigestive tract. Between 1996 and 2002, the rate ratio among persons living within 2 miles of SSFL was greater than 1.6 for thyroid cancer. There were too few childhood cancers to yield informative results.

Discussion: The strongest and most consistent association observed in this study was for thyroid cancer, which was associated with distance from SSFL in both follow-up periods. This finding may have public-health significance because perchlorate, a component of rocket fuel used in large quantities at SSFL, is known to disrupt thyroid function, it has been shown to induce thyroid tumors in laboratory animals, and there is evidence from two other investigations that perchlorate migrated offside to contaminate the groundwater in areas surrounding SSFL. In addition, findings from one of those other studies suggest that the 1959 partial meltdown of a nuclear reactor at SSFL could have released appreciable amounts of radioactive cesium and iodine, which might have increased the incidence of thyroid cancer in the population surrounding SSFL. Furthermore, our results for cancers of the bladder, blood and lymph tissue, and upper aerodigestive tract are consistent with associations observed in the UCLA Worker Study between mortality from these cancers and occupational exposures to radiation and chemicals.

It is important to recognize that associations observed between distance from SSFL and the incidence of specific cancers are based on small numbers of cases in the region closest to SSFL. Thus, these associations are estimated imprecisely and may represent chance findings. In addition, observed associations may have been biased by certain methodologic limitations—use of distance from SSFL as a crude proxy measure for environmental exposures, mobility of the residential population before and during the follow-up period, and lack of information on other cancer risk factors, such as cigarette smoking and socioeconomic status, that might distort the observed associations.

Conclusion: Despite the methodologic limitations of this study, the findings suggest there may be elevated incidence rates of certain cancers near SSFL that have been linked in previous studies with hazardous substances used at Rocketdyne, some of which have been observed or projected to exist offsite. There is no direct evidence from this investigation, however, that these observed associations reflect the effects of environmental exposures originating at SSFL. Given these provocative findings and unanswered questions, it is tempting to recommend further analyses or future studies to address the health concerns of the community. Unfortunately, it is not clear at this time whether such additional analyses or studies will be sufficient to determine whether operations and activities at Rocketdyne affected, or will affect, the risk of cancer in the surrounding neighborhoods.

Purpose

The purpose of this report is to present findings on the incidence of cancer in the residential population surrounding the Santa Susana Field Laboratory of Rocketdyne in Southern California. Residents of this community have been concerned for several years that the use of radioactive and toxic substances at Rocketdyne may have adversely affected their health or might do so in the future.

Background

The Santa Susana Field Laboratory (SSFL) lies on 2,850 acres located at the top of the Simi Hills of eastern Ventura County, bordering Los Angeles County about 30 miles northwest of downtown Los Angeles. Initially intended after World War II as a remote worksite for testing new technologies, SSFL is now surrounded in the valleys and canyons by several residential communities. In 2000, there were approximately 150,000 residents living within 5 miles of the site (SSFL Advisory Panel, 2006). The facility is divided into four areas: three have involved the development and testing of rocket engines and related technologies and were established in 1948 by North American Aviation, later to become Rocketdyne; and one area was the site of Atomics International, which was involved in the operation of 10 nuclear reactors and other nuclear projects between the mid 1950s and the early 1980s when the last reactor was shut down. Since then, nuclear operations have been limited to clean up and storage of radioactive material and isolated experimentation. In 1984, Atomics International merged with Rocketdyne, which is now a division of the Boeing Company.

California Department of Health Services Study

In 1989, the media reported that the U.S. Department of Energy (DOE) had found widespread radioactive and chemical contamination at the SSFL site. Those reports generated concern among community residents about possible offsite contamination. In response to these concerns, the California Department of Health Services conducted a study to examine the occurrence of cancers in the area surrounding SSFL. In January 1991, they issued a preliminary report in which the authors found a higher-than-expected number of bladder-cancer cases diagnosed between 1983 and 1987 among residents of Los Angeles County living near SSFL. The Department of Health Services received public comments on the report and recommendations for refining the study.

In their follow-up investigation, researchers at the California Department of Health Services (1992) examined the incidence of cancer among residents of both Los Angeles and Ventura Counties. For Los Angeles County, data available from 1978 to 1988 were used to compare cancer incidence rates among non-Hispanic whites living close to SSFL to incidence rates among non-Hispanic whites living in the rest of the county. Standardized incidence ratios were calculated to estimate the rate of cancer, comparing populations that reside in census tracts at least partly within a 5-mile radius of the facility to the rest of Los Angeles County. Ventura County joined the statewide cancer surveillance system (California Cancer Registry) in 1988. Because the census tracts of interest in the county were within an area of rapid population expansion and because intercensal population estimates were unavailable for the county between 1980 and 1990, proportional incidence ratios were calculated to estimate the proportion of cases of a specific cancer site, comparing residents living near SSFL (census tracts within a 5-mile radius) with the rest of Ventura and Los Angeles Counties in 1988-1989. The analysis was restricted to non-Hispanic whites, as this was the vast majority of the population at the time. The authors of this investigation interpreted their findings as mostly "equivocal;" however, they did suggest that residents living in Los Angeles County near SSFL may have had an increased rate of bladder cancer relative to residents living elsewhere in the county.

The California Department of Health Services study was limited in its ability to evaluate cancer occurrence in the community primarily due to incomplete data on cancer incidence for the areas of interest before 1988. Since complete incidence data for both counties were available for a period of only two years, the investigators chose a relatively large geographic area (within 5 miles of the facility) to represent the region of potential exposure. Nonetheless, this approach resulted in imprecise rate estimates due to small numbers of site-specific cases in the region and an inability to examine geospatial differences in cancer occurrence. Moreover, estimates of the true effects of Rocketdyne exposures, if they exist, were diluted by using such a large geographic region since most of the population living within 5 miles of the facility presumably would not have been exposed. Furthermore, there was no information about the changing composition of the population during a period of rapid population growth and demographic change. Thus, the investigators were unable to evaluate temporal trends in cancer occurrence. Lastly, several of the cancers of interest (e.g., lung cancer) have relatively long induction/latent periods, for which the interval between first exposure to radiation or chemical carcinogens and cancer detection may be as much as several decades. Thus, the environmental effects of Rocketdyne exposures on cancer incidence, if they exist, could not be properly evaluated without additional follow-up.

UCLA Study of Rocketdyne Workers

Recognizing the methodologic difficulties of studying radiation and chemical exposures in residential populations (e.g., due to exposure measurement problems and population mobility), community residents decided the next step should be to seek support for a study of Rocketdyne workers. With the support of local legislators and funding from the U.S. Department of Defense (DOD), an occupational study was initiated in 1993 by the principal investigator of the current report and colleagues at the UCLA School of Public Health (Morgenstern et al., 1997; 1999; 2001). They estimated the effects of occupational exposures to ionizing radiation and chemicals on cancer mortality among approximately 55,000 workers employed at Rocketdyne. In this retrospective cohort study, the investigators measured exposures to both external and internal radiation among a subset of workers participating in a radiation monitoring program between 1950 and 1993 (Ritz et al., 1999a; 2000). Exposures to chemicals—including hydrazine compounds used in rocket fuels and asbestos—were measured by a job-exposure matrix that was created from employment records and an industrial-hygiene assessment in a subset of workers first employed at SSFL before 1980 (Ritz et al., 1999c). Cause of death for deceased workers was obtained from death certificates retrieved from company pension files, state vital statistic offices, and the U.S. National Death Index. Follow-up for cancer mortality for all subjects continued through December 31, 1994.

Results from the worker study indicated a trend of increasing rate of cancer mortality associated with increasing cumulative radiation dose among the externally monitored workers (Ritz et al., 1991a; 1991b). Rate-ratio estimates were highest for mortality due to lymphopoietic cancers (including leukemias, lymphosarcomas, and lymphomas) and lung cancer. In the internally monitored cohort, a trend was also observed between cumulative radiation exposure and cancer mortality (all sites), mortality due to lymphopoietic and upper-aerodigestive-tract cancers, but not lung cancer (Ritz et al., 2000). In addition, exposure to hydrazine (or other chemicals) used at the rocket-engine test stands was associated with an increased rate of dying from cancer, particularly lymphopoietic, bladder, and kidney cancers (Ritz et al., 1999c).

The Rocketdyne worker study was extended with additional funding to include 5 more years of follow-up, the collection of cancer incidence data, and refinement of the job-exposure matrix to measure trichloroethylene (TCE), mineral oils, polycyclic aromatic hydrocarbons (PAHs), and benzene. Zhao et al. (2005) found that TCE exposure was positively associated with the incidence of kidney and bladder cancers and that exposure to mineral oils was associated with the incidence and mortality of several cancers, including lung and melanoma. Ritz et al. (2006) found a positive association between hydrazine exposure and the incidence of lung and colorectal cancers. Analyses of radiation exposures have not yet been completed.

Despite evidence from the Rocketdyne worker studies that occupational exposures to radiation and chemicals may have increased the risk of dying from certain cancers, these results cannot readily be generalized to the population living near Rocketdyne. Although there have been several reports by the U.S. Environmental Protection Agency and others documenting chemical contamination in the groundwater and soil in the residential neighborhoods near SSFL, we do not know the extent to which local residents were exposed, and there is little evidence linking that contamination with the health status of residents. These reports, however, together with the positive findings from the worker study, have prompted new efforts to examine the possible health effects in the community.

Boeing Study of Rocketdyne Workers

Following public release of the final reports of the original Rocketdyne worker study (Morgenstern et al., 1997; 1999), the Boeing Company funded their own retrospective cohort study of cancer mortality among Rocketdyne workers. The results of this investigation were recently published in two articles—one focusing on radiation workers (Boice et al., 2006b), and the other focusing on aerospace workers who tested rocket engines (Boice et al., 2006c).

On the basis of their findings, Boice et al. (2006b) concluded that "radiation exposure has not caused a detectable increase in cancer deaths" in their cohort of radiation workers. Their study differed in several ways from the first study conducted at UCLA: 1) they included about 1,000 additional workers who were occasionally monitored for radiation, but who were not part of the Rocketdyne Health Physics Monitoring Program; 2) subjects were followed for an additional 5 years through the end of 1999; 3) they estimated radiation doses from biokinetic models for 16 organs or tissues and combined external and internal dose measurements in their analyses of specific cancers; 4) using other databases, they included radiation doses received before and after employment at Rocketdyne; 5) to estimate radiation effects, they compared radiation-monitored workers with unmonitored workers assumed to be unexposed; and 6) they relied heavily on significance testing (whether the null p value is less than or greater than 0.05) to interpret their findings. Aside from #4, which reduced the magnitude of radiation-cancer associations (see Table 5 in Boice et al., 2006b), and #6, which tends to discount associations observed with small numbers of cancer deaths, it is not clear how these differences affected the findings, nor is it clear whether differences in the magnitude of bias might explain discrepancies with the first study.

In their analyses of workers who tested rocket engines, Boice et al. (2006c) focused on duration of employment at SSFL and potential exposures to hydrazine and TCE. Although they found a few positive associations between these exposures and mortality from cancers of the kidney, lung, and stomach, the authors concluded that "work at the SSFL rocket engine test facility or as a test stand mechanic was not associated with a significant increase in cancer mortality overall or for any specific cancer." As in the radiation paper, it is not clear to what extent the inconsistent findings for the Boice et al. study and the original worker study were due to differences in subject selection, duration of follow-up, or exposure and covariate measurement.

SSFL Advisory Panel Study

The SSFL Advisory Panel (2006), funded by the California State Legislature and the Citizens' Monitoring and Technical Assistance Fund, conducted independent analyses of potential offsite impacts of contamination and accidents at SSFL, in particular the 1959 partial meltdown of a nuclear reactor (the Sodium Reactor Experiment) at the site, which was not reported to the public until 1979. The Panel's consultants estimated that, contrary to previous governmental reports, the partial meltdown could have released appreciable amounts of radioactive cesium and iodine—much more than was released at Three Mile Island in 1979—and they estimated that those radioactive releases produced about 260 excess cancers (95% confidence bounds of 0 to 1,800), of which 5% were thyroid cancers.

The Panel also assessed the potential for offsite contamination of perchlorate, which is a component of rocket fuel that was used in large quantities at SSFL and is known to disrupt thyroid function in humans. The Panel's consultant determined that perchlorate migrated rapidly off the SSFL site via surface water runoff until it reached the flood plain of the valley floor; then it percolated into the groundwater where it has been detected in several wells in recent years.

Current Investigation

In response to strong community concerns about the continued presence of radioactive and toxic substances in the area surrounding the SSFL, we conducted an epidemiologic study to examine cancer incidence in Ventura and Los Angeles Counties in relation to distance from SSFL. The new study offers several advantages over the previous community study: more complete data on cancer incidence; a much longer period of follow-up; better census data on the population, including race/ethnicity at the census block-group level; and special statistical methods appropriate for analyzing rare outcome events.

In addition to this epidemiologic study of cancer near SSFL, Yoram Cohen and colleagues (2006) at UCLA conducted an independent environmental assessment of the potential for offsite exposures associated with contaminants originating at SSFL. In their report, the authors concluded that there is the potential for offsite chronic exposures within 1-2 miles of SSFL from TCE, hydrazine, and other toxic substances through use of private groundwater wells, ingestion of home-grown crops, and inhalation. They identified several "hot spots" east, south and west of SSFL, where contaminant levels exceed health-based standards and could adversely affect the health of residents. Cohen et al. also determined that there is the potential for residential exposure to perchlorate through chronic ingestion of contaminated groundwater and area-grown crops in areas east of SSFL.

Methods

We conducted an exploratory, dynamic cohort study of cancer incidence in Ventura and Los Angeles Counties between 1988 and 2002. The main "exposure" variable for our analyses was distance from the center of each block group to SSFL. Some of the data, statistical methods, and findings in this report differ from those included in our preliminary report that was presented in Simi Valley in February 2006.

Cancer Data and Outcome Variables

Data on all reported cases of primary invasive cancer (excluding non-melanoma skin cancer) were collected from the California Cancer Registry for Ventura and Los Angeles Counties from 1988 (the first year of complete ascertainment of cancer data for both counties) until 2002 (the most recent calendar year in which data were obtained for the entire year). During this period, over 600,000 cancer cases were reported to the Registry. A given resident of the County may have had more than one primary cancer diagnosed during the follow-up period. For each case identified, the following data were also obtained from the Registry:

1) sociodemographic information—age at diagnosis, gender, race/ethnicity, occupation, and marital status; and
2) cancer diagnosis and histopathology—date of diagnosis, ICD-9 (-10) coding, SEER standard site-specific codes, histopathologic confirmation, laterality, presence of metastasis, lymph node involvement (and number of regional lymph nodes involved, if positive), tumor stage (based on criteria consistent with AJCC manual for staging of cancer, 3rd edition), grade, tumor size, vital status, and date of last follow-up or date of death.

The cancers of primary interest for this investigation are those that, on the basis of scientific evidence, are thought to be affected by ionizing radiation and chemicals used at Rocketdyne since the 1950s, particularly hydrazine compounds and trichloroethylene (Cohen et al., 2006). The primary sources of "radiosensitive" cancers were the BEIR VII report (National Research Council, 2006) and Boice (2006a). We included in this category cancers of the lung, female breast, thyroid, bone, and leukemias (excluding chronic lymphocytic leukemia). The primary source for “chemosensitive” cancers was Siemiatycki et al. (2006), and we included in this category cancers of the lung, bladder, liver, kidneys, and bone marrow.

We report here on the incidence rates of total cancers (excluding non-melanoma skin cancer and *in situ* cancers), radiosensitive cancers, chemosensitive cancers, and the following 9 site-specific cancers: melanoma, colorectal (colon and rectum), lymphopoietic (cancers of lymphatic and hematopoietic tissue, excluding chronic lymphocytic leukemia), lung, female breast, bladder, prostate, thyroid, and upper aerodigestive tract (oral and nasal cavities, pharynx, larynx, and esophagus). These specific cancer sites were chosen because of their possible connection with radiation or chemical exposures at Rocketdyne or because of their relatively frequent occurrence in the source population. Because cancers in children (<15 years of age) were very rare, we conducted separate analyses of all childhood cancers combined.

Location and Population Data

Residential information—census tract and block group, city and county of residence at date of diagnosis—was provided for each case by the California Cancer Registry. For cases diagnosed between 1988 and 1995, the 1990 census tract and block group were provided; for cases diagnosed between 1996 and 2002, the 2000 census tract and block group were provided. Residing in close proximity to SSFL was used as a proxy measure of potential exposure to hazardous materials used at the facility that may have contaminated soil, water or air in the surrounding community. For purposes of our analyses, we divided the two-county region into three exposure groups: census block groups whose centers were within 2 miles of SSFL (the region of greatest potential exposure); census block groups whose centers were between 2 and 5 miles of SSFL; and census block groups whose centers were more than 5 miles from SSFL (the reference group).

Numbers of residents in each block group in both counties, by age, gender and race/ethnicity were provided by the California Cancer Registry, which obtained those census data from the California Department of Finance. These numbers were used as the denominators for the cancer incidence rates in our analyses.

Statistical Analysis

Crude and stratum-specific incidence rates (expressed per 100,000/year) and their exact 95% confidence intervals (CIs) for each cancer outcome were estimated for residents in each exposure region (<2 miles, 2-5 miles, and >5 miles from SSFL). Estimates were stratified by age (<15, 15-39, 40-59, and 60+ years), gender, and race/ethnicity (non-Hispanic white, Hispanic, and other non-Hispanic). The results are also presented separately for two follow-up periods, 1988-95 and 1996-2002. This was done so that we could examine temporal trends and deal with changes in block-group definitions between the 1990 and 2000 censuses. As noted above, the California Cancer Registry geocoded cancer cases diagnosed before 1996 according to census-tract and block-group information from the 1990 census, while cases diagnosed in 1996 and later were geocoded according to census-track and block-group information from the 2000 census. Thus, a given address for a diagnosed case may be assigned to a different block group in 1990 than in 2000, and the exposure regions changed slightly between the two follow-up periods.

Crude (unadjusted) incidence rate ratios ("relative risks") and rate ratios standardized (adjusted) for age, gender, and race/ethnicity were estimated for each cancer outcome, comparing residents living within 2 miles and 2-5 miles from SSFL with residents living more than 5 miles from SSFL (the reference group). Standardized rate ratios were obtained separately for adults (age strata: 15-39, 40-59, and 60+ years) and children (age strata: <5, 5-9, and 10-14 years). Because many of the analyses involved small numbers of cancers, especially within strata, "exact" methods were used to analyze crude and stratified data, including estimation of mid-*p* 95% confidence limits (Berry & Armitage, 1995). All analyses for this report were performed using SAS® 9.1 (SAS Institute, 2004) and StatXact® 7 (Cytel, 2005).

Changes from Preliminary Analyses

Following the presentation of our preliminary findings in Simi Valley in February 2006, we noticed some inconsistencies that led us to make three changes in our methods. First, we abandoned the use of Geolytics® software to generate population denominators for our rate estimates because we found differences between our rate estimates and those reported by the California Cancer Registry. To rectify these inconsistencies, we obtained the block-group data used by the Registry. Second, we discovered that we had inadvertently included *in situ* cancers for some sites in our preliminary analyses. Thus, those cases were subsequently removed. Third, and most important, we found that some of our earlier findings, which were based on conventional large-sample (asymptotic) methods, were not valid because of small numbers of cancers detected for residents living within 5 miles of SSFL. Thus, all analyses in this report are now based on exact methods described above. As a result of these modifications in our methods, some of our findings changed, and we are no longer able to make inferences about differences in standardized rate ratios between racial/ethnic groups.

Results

Crude and stratum-specific cancer rates (per 100,000/year) and rate ratios (RR with 95% CIs) for the two follow-up periods are presented in Tables 1-8. Standardized rate ratios (SRRs with 95% CIs) are presented in Tables 9-13.

The results for all invasive cancers, excluding non-melanoma skin cancers, are shown in Table 1 (1988-95) and Table 2 (1996-2002). Compared with residents in the reference region (>5 miles from SSFL), residents living closer to SSFL do not appear to have elevated incidence rates in 1988-95, but the crude rates in the total population are somewhat elevated for both closer regions in 1996-2002 (RR for <2 miles = 1.15; 95% CI = 1.05, 1.26; and RR for 2-5 miles = 1.16; 95% CI = 1.13, 1.20). Note, however, that the crude rate is not greater within 2 miles of SSFL than between 2 and 5 miles, and cancer rates are not elevated among non-Hispanics who live closer to SSFL (Table 2).

Results are presented for radiosensitive cancers in Tables 3-4 and for chemosensitive cancers in Tables 5-6. Both sets of results are similar to those for all cancers. Crude RRs in the total population are somewhat greater than 1 for persons living within 5 miles of SSFL in 1996-2002, but the rates are not elevated for non-Hispanics who live closer to SSFL. In fact, the pattern of results in Tables 1-6 suggest that the crude RRs are confounded by age, gender, and race/ethnicity; note, for example, that the crude RR is greater than each of the race/ethnicity-specific RRs for residents living 2-5 miles from SSFL in Tables 2, 4 and 6.

Crude and stratum-specific incidence rates and rate ratios are shown for the 9 cancer sites in Table 7 (1988-95) and Table 8 (1996-2002). As with the previous results, the crude rates in the total population appear somewhat elevated for regions closer to SSFL in 1996-2002. Rate ratios are greatest within 2 miles of SSFL for melanoma (RR = 1.92; 95% CI = 1.29, 2.76), bladder cancer (RR = 1.46; 95% CI = 0.81, 2.43), and thyroid cancer (RR = 1.80; 95% CI = 1.07, 2.87). Furthermore, there is an inverse association between distance from SSFL and incidence for cancers of the lung, bladder, prostate, thyroid, and upper aerodigestive tract (Table 8). We see, as expected, that the 95% confidence intervals are wider for the site-specific cancers than for the composite cancer outcomes in Tables 1-6.

Estimated rate ratios for total, radiosensitive, and chemosensitive cancers—standardized for age, gender, and race/ethnicity—are presented in Table 9 (1988-1995) and Table 10 (1996-2002). When controlling for the potentially confounding effects of the three demographic covariates, there appear to be no elevations of these cancer rates within 5 miles of SSFL, except perhaps for chemosensitive cancers within 2 miles of SSFL (SRR in 1988-95 = 1.21; 95% CI = 0.88, 1.66; and SRR in 1996-2002 = 1.11; 95% CI = 0.84, 1.47).

Standardized rate ratios for the 9 specific cancers are presented in Table 11 (1988-95) and Table 12 (1996-2002). The pattern of standardized results is appreciably different from the pattern of crude results in Tables 7-8. In 1988-96, estimated rates within 2 miles of SSFL are elevated for cancers of the colon and rectum (SRR = 1.32; 95% CI = 0.86, 2.02), lymphopoetic system (SRR = 1.62; 95% CI = 0.94, 2.83), lung (SRR = 1.29; 95% CI = 0.89, 1.89), bladder (SRR = 1.62; 95% CI = 0.67, 4.12), thyroid (SRR = 2.50; 95% CI = 0.49, 18.6), and upper aerodigestive tract (SRR = 1.83; 95% CI = 0.91, 3.83). It should be noted, however, that the 95% confidence intervals for all these estimates are wider than the crude confidence intervals and all include the null value (1), implying a loss of precision when stratifying on the three covariates.

In 1996-2002, the standardized RRs for residents living <2 miles from SSFL are consistently smaller than are the crude RRs in Table 8. For example, the crude versus standardized estimates of the rate ratio are 1.92 vs. 1.17 for melanoma, 1.27 vs. 1.08 for lung cancer, 1.19 vs. 0.92 for breast cancer, and 1.46 vs. 1.20 for bladder cancer. The only cancer site with a consistent inverse association between distance to SSFL and incidence in both periods is thyroid. In 1996-2002, the SRR for thyroid cancer was 1.86 (95% CI = 0.75, 4.96) for residents living within 2 miles of SSFL and 1.47 (95% CI = 1.11, 1.93) for residents living 2-5 miles from SSFL.

Standardized RRs for all childhood cancers in both follow-up periods are shown in Table 13. Because of the small stratum-specific numbers of these cancers and children living within 2 miles of SSFL (including zeros in several strata), the SRRs cannot be estimated and the 95% confidence intervals are wide. For children under 15 years of age living within 2 miles of SSFL, there was only one new cancer reported between 1988 and 1995 and 5 cancers reported between 1996 and 2002. For children living 2-5 miles from SSFL, the SRR was 1.20 (95% CI = 0.70, 2.06) in 1988-95 and 1.40 (95% CI = 0.88, 2.26) in 1996-2002.

Discussion

The results from this study suggest little or no association between residential distance from SSFL and the incidence of total cancers or the group of (radiosensitive) malignancies thought to be affected by ionizing radiation. There was, however, a weak inverse association during both follow-up periods between distance from SSFL and the group of (chemosensitive) malignancies thought to be affected by exposure to chemicals used at Rocketdyne and found or projected by others to exist offsite (Cohen et al., 2006; SSFL Advisory Panel, 2006).

Although we found in our site-specific analyses that several types of cancer were associated with distance from SSFL, the specific findings differed between the two follow-up periods. Between 1988 and 1995, adults living within 2 miles of SSFL had elevated incidence rates of several cancers, which were not due to the confounding effects of age, gender, or race/ethnicity. Standardized rate ratios were highest (>1.6) for cancers of the thyroid, upper aerodigestive tract, bladder, and lymphopoietic system. The bladder-cancer finding is consistent with the "equivocal" finding from the study by the California Department of Health Services (1992), and this cancer was associated with TCE exposure among Rocketdyne workers (Zhao et al., 2005). Furthermore, findings for upper-aerodigestive-tract and lymphopoietic cancers are consistent with associations observed in the UCLA Rocketdyne worker study between mortality from these cancers and exposures to radiation and chemicals used at the rocket-engine test stands (Morgenstern & Ritz, 2001).

Between 1996 and 2002, incidence rates for residents living within 2 miles of SSFL were not elevated or only minimally elevated (SRR < 1.2) for all cancers except thyroid, lung, and upper aerodigestive tract. The strongest and most consistent association observed in this study was for thyroid cancer, which was inversely associated with distance from SSFL during both periods. This finding may have public-health significance because perchlorate is known to disrupt thyroid function by inhibiting the uptake of iodine (Soldin et al., 2001), it has been shown to induce thyroid tumors in laboratory animals (California EPA, 2004), and there is evidence that perchlorate migrated offsite to contaminate the groundwater in areas surrounding SSFL (Cohen et al., 2006; SSFL Advisory Panel, 2006). In addition, findings from the SSFL Advisory Panel Study (2006) suggest that the 1959 partial meltdown at SSFL could have released appreciable amounts of radioactive iodine, which might have increased the incidence of thyroid cancer in the population (Ron & Schneider, 2006).

It is important to recognize that the associations observed between distance from SSFL and the incidence of specific cancers are based on small numbers of cases within strata of the regions closest to SSFL. Thus, precision of effect estimation is often poor (resulting in wide confidence intervals), and statistical power for detecting effects is low—which implies that some of our estimates may be chance findings and should be interpreted cautiously. Furthermore, we have no direct evidence that the associations we observed—even if they reflect real differences among the three regions—necessarily reflect the effects of environmental exposures originating at SSFL.

The main methodologic limitation of this study is the absence of data—either environmental or individual-level—for measuring exposures to ionizing radiation or toxic chemicals. Distance from SSFL is a very crude proxy that does not take into consideration the fate and transport of hazardous substances migrating offsite, local geological and meteorological conditions, and the behavior of residents that would affect their levels of exposure. It might be possible to generate better indicators of environmental exposures by applying the models of Cohen et al. (2006) for predicting geographic-specific exposure concentrations; but this approach would probably not allow us to separate the effects of different exposures (due to collinear relations), and it still has major limitations for the study of cancers that have long induction and latent periods (from first exposure of individuals to disease detection). The main problem is substantial population mobility before and during the follow-up period, especially in the Hispanic population. It is likely that some new cancers detected in the vicinity of SSFL between 1988 and 2002 occurred among residents who did not live in that area very long and therefore could not have been exposed to offsite contaminants; conversely, some new cancers detected in the reference region (>5 miles from SSFL) might have previously lived in the region closest to SSFL; and it is likely that some persons potentially exposed before 2002 may have moved away from the two-county area so that subsequent cancer occurrences would not be identified in this study.

Another methodologic limitation is the lack of information on potential confounders, i.e., other cancer risk factors that are associated with exposure status in the population (Rothman & Greenland, 1998). We were able to control only for the potentially confounding effects of age, gender, and race/ethnicity. It is possible that differences in cancer rates between the three regions were partly due to the effects of other cancer risk factors, such as cigarette smoking for lung, bladder, and upper-aerodigestive-tract cancers (Thun & Henley, 2006), air pollution for lung, bladder, and childhood cancers (Samet & Cohen, 2006), diet for colon, breast, and prostate cancers (Willett, 2006), and socioeconomic status and various occupational exposures for several cancers (Kawachi & Kroenke, 2006; Siemiatycki et al., 2006). Unfortunately, the only effective method of controlling for the effects of these variables involves measuring them accurately in all members of the two-county study population or in random samples of all geographic groups.

Conclusions

Despite the methodologic limitations discussed above, our findings suggest there may be elevated incidence rates of certain cancers near SSFL that have been linked in previous studies with hazardous substances used at Rocketdyne, some of which have been observed or projected to exist offsite. Since there are several alternative explanations for our findings, including chance and bias, it is tempting to recommend extending our study to include additional information on environmental exposures and potential confounders and the use of more sophisticated Bayesian methods of statistical analysis (Elliott et al., 2000; Banerjee et al., 2004). It is not clear, however, if this ecologic approach will yield more informative and less biased results. Even if average levels of environmental exposures and covariates are measured accurately for small areas such as census block groups, the distributions of those variables will be heterogeneous within groups and their joint distributions within groups will be missing. Therefore, estimates of exposure effects on cancer incidence may be severely distorted by ecologic bias; moreover, controlling for confounders could increase bias (Morgenstern, 1998). In addition, if only small proportions of the groups were exposed to any SSFL-related hazard, estimation of that exposure effect would be made even more difficult.

An alternative approach for learning more about environmental risk factors for cancers in the communities near SSFL is to conduct an observational study at the individual level, e.g., a cohort or case-control study. Unfortunately, this approach would be costly, and it would still be subject to problems of exposure measurement, population mobility, and relatively small numbers of exposed residents.

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Table 1. Crude and stratum-specific incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and by gender, age, or race/ethnicity: **All cancers**, **1988-1995;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All	Gender		Age (years)				Race/Ethnicity		
		Male	Female	<15	15-39	40-59	60+	Non-Hispanic White	Hispanic	Other Non-Hispanic
<2 mi.	**329.4** (297.4, 363.6)	**314.0** (270.4, 362.6)	**344.7** (299.2, 395.3)	**3.8** (0.1, 21.3)	**46.2** (29.3, 69.3)	**305.5** (246.0, 375.1)	**2172.9** (1921.8, 2443.6)	**364.5** (327.4, 404.1)	**153.2** (93.6, 236.6)	**175.9** (93.6, 300.7)
# cases	390	185	205	1	23	91	275	357	20	13
RR	**0.93** (0.84, 1.03)	**0.87** (0.75, 1.00)	**1.00** (0.87, 1.14)	**0.25** (0.01, 1.24)	**0.75** (0.49, 1.11)	**0.76** (0.62, 0.93)	**1.18** (1.05, 1.33)	**0.65** (0.59, 0.72)	**1.06** (0.67, 1.61)	**0.58** (0.32, 0.96)
2-5 mi.	**356.9** (346.0, 368.0)	**346.8** (331.7, 362.4)	**367.0** (351.4, 383.0)	**13.1** (8.9, 18.5)	**63.4** (56.5, 70.8)	**410.6** (387.3, 434.8)	**1953.4** (1878.4, 2030.2)	**420.2** (406.5, 434.2)	**161.4** (142.6, 181.7)	**189.4** (166.1, 214.9)
# cases	4083	1986	2097	31	311	1169	2570	3574	270	239
RR	**1.01** (0.98, 1.04)	**0.96** (0.92, 1.00)	**1.06** (1.02, 1.11)	**0.86** (0.59, 1.21)	**1.04** (0.92, 1.16)	**1.02** (0.97, 1.08)	**1.06** (1.02, 1.11)	**0.75** (0.72, 0.77)	**1.12** (0.99, 1.26)	**0.62** (0.54, 0.70)
>5 mi. (referent)	**352.8** (351.4, 354.1)	**360.7** (358.8, 362.6)	**344.8** (342.9, 346.6)	**15.2** (14.6, 15.8)	**61.2** (60.4, 62.1)	**401.4** (398.2, 404.6)	**1836.1** (1827.6, 1844.5)	**560.8** (558.2, 563.4)	**144.2** (142.8 145.6)	**305.3** (302.5, 308.0)
# cases	264552	135048	129477	2563	20358	60170	181427	177322	40433	46797

Table 2. Crude and stratum-specific incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and by gender, age, or race/ethnicity: **All cancers**, **1996-2002;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All	Gender		Age (years)				Race/Ethnicity		
		Male	Female	<15	15-39	40-59	60+	Non-Hispanic White	Hispanic	Other Non-Hispanic
<2 mi.	**396.9** (362.7, 433.1)	**405.7** (356.8, 458.5)	**388.3** (341.4, 439.9)	**18.2** (5.9, 42.5)	**82.6** (57.8, 114.3)	**419.8** (357.3, 490.1)	**1777.2** (1580.1, 1989.1)	**451.9** (410.8, 495.6)	**233.0** (163.2, 322.6)	**146.3** (85.3, 234.3)
# cases	500	253	247	5	36	160	299	447	36	17
RR	**1.15** (1.05, 1.26)	**1.18** (1.04, 1.33)	**1.12** (0.99, 1.27)	**1.28** (0.47, 2.84)	**1.48** (1.05, 2.03)	**1.09** (0.93, 1.27)	**1.02** (0.91, 1.14)	**0.72** (0.66, 0.79)	**1.49** (1.06, 2.04)	**0.47** (0.29, 0.74)
2-5 mi.	**400.3** (388.9, 412.0)	**393.5** (377.4, 410.1)	**407.0** (390.7, 423.6)	**17.2** (12.5, 23.1)	**68.3** (60.4, 76.8)	**417.1** (395.3, 439.6)	**1796.0** (1731.3, 1862.2)	**536.3** (519.5, 553.4)	**160.7** (145.0, 177.5)	**189.5** (170.4, 209.8)
# cases	4623	2246	2377	44	276	1384	2919	3872	385	366
RR	**1.16** (1.13, 1.20)	**1.15** (1.10, 1.19)	**1.18** (1.13, 1.23)	**1.21** (0.89, 1.61)	**1.23** (1.09, 1.38)	**1.08** (1.03, 1.14)	**1.03** (0.99, 1.07)	**0.86** (0.83, 0.89)	**1.03** (0.93, 1.13)	**0.61** (0.55, 0.68)
>5 mi. (referent)	**344.4** (343.1, 345.7)	**343.5** (341.7, 345.3)	**345.2** (343.4, 347.0)	**14.2** (13.7, 14.8)	**55.7** (54.9, 56.5)	**385.0** (382.2, 387.8)	**1747.2** (1739.2, 1755.2)	**625.2** (622.2, 628.2)	**156.6** (155.3 157.9)	**308.6** (306.1, 311.1)
# cases	278607	137426	141164	2742	17691	74539	183625	164275	55901	58431

Table 3. Crude and stratum-specific incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and by gender, age, or race/ethnicity: **Radiosensitive cancers**,* **1988-1995;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All	Gender		Age (years)				Race/Ethnicity		
		Male	Female	<15	15-39	40-59	60+	Non-Hispanic White	Hispanic	Other Non-Hispanic
<2 mi.	**118.3** (99.5, 139.6)	**74.7** (54.3, 100.3)	**161.4** (130.8, 197.1)	**0.0** (0.0, 14.1)	**12.0** (4.4, 26.2)	**127.6** (90.3, 175.1)	**758.5** (614.4, 926.3)	**126.6** (105.3, 151.0)	**53.6** (21.6, 110.5)	**121.8** (55.7, 231.1)
# cases	140	44	96	0	6	38	96	124	7	9
RR	**1.03** (0.87, 1.22)	**1.11** (0.82, 1.48)	**1.00** (0.81, 1.21)	**0.00** (0.00, 1.78)	**0.69** (0.28, 1.44)	**0.78** (0.56, 1.06)	**1.37** (1.12, 1.67)	**0.68** (0.57, 0.81)	**1.25** (0.55, 2.48)	**1.22** (0.60, 2.24)
2-5 mi.	**126.7** (120.3, 133.4)	**67.4** (60.8, 74.4)	**186.2** (175.2, 197.7)	**4.2** (2.0, 7.8)	**19.0** (15.3, 23.2)	**173.5** (158.5, 189.4)	**648.3** (605.4, 693.2)	**151.4** (143.3, 159.9)	**46.6** (36.9, 58.2)	**66.6** (53.1, 82.4)
# cases	1450	386	1064	10	93	494	853	1288	78	84
RR	**1.11** (1.05, 1.17)	**1.00** (0.91, 1.11)	**1.15** (1.08, 1.22)	**0.65** (0.33, 1.17)	**1.09** (0.88, 1.33)	**1.06** (0.97, 1.16)	**1.17** (1.10, 1.26)	**0.82** (0.77, 0.86)	**1.09** (0.87, 1.35)	**0.67** (0.54, 0.82)
>5 mi. (referent)	**114.5** (113.7, 115.3)	**67.2** (66.4, 68.1)	**161.6** (160.3, 162.9)	**6.5** (6.1, 6.9)	**17.4** (17.0, 17.9)	**163.1** (161.1, 165.2)	**551.8** (547.1, 556.4)	**185.3** (183.8, 186.8)	**42.8** (42.0, 43.6)	**99.6** (98.1, 101.2)
# cases	85874	25171	60700	1090	5802	24452	54521	58596	12002	15276

* Includes cancers of the lung, bone, female breast, thyroid, and leukemias (excluding chronic lymphocytic leukemia).

Table 4. Crude and stratum-specific incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and by gender, age, or race/ethnicity: **Radiosensitive cancers**,* **1996-2002;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All	Gender		Age (years)				Race/Ethnicity		
		Male	Female	<15	15-39	40-59	60+	Non-Hispanic White	Hispanic	Other Non-Hispanic
<2 mi.	**136.5** (116.9, 158.5)	**75.4** (55.4, 100.2)	**196.5** (163.6, 234.1)	**3.6** (0.1, 20.3)	**32.1** (17.6, 53.9)	**167.9** (129.3, 214.4)	**552.8** (446.2, 677.2)	**156.7** (133.0, 183.4)	**64.7** (31.0, 119.0)	**60.3** (24.2, 124.2)
# cases	172	47	125	1	14	64	93	155	10	7
RR	**1.21** (1.04, 1.40)	**1.27** (0.94, 1.68)	**1.19** (0.99, 1.41)	**0.60** (0.03, 2.96)	**1.70** (0.97, 2.78)	**1.14** (0.88, 1.44)	**1.05** (0.85, 1.28)	**0.74** (0.63, 0.87)	**1.40** (0.71, 2.50)	**0.59** (0.26, 1.17)
2-5 mi.	**137.3** (130.6, 144.3)	**64.3** (57.9, 71.2)	**208.7** (197.1, 220.7)	**6.6** (3.9, 10.6)	**24.0** (19.5, 29.3)	**161.5** (148.1, 175.7)	**575.9** (539.4, 613.9)	**185.4** (175.6, 195.6)	**48.0** (39.6, 57.6)	**68.3** (57.2, 81.0)
# cases	1586	367	1219	17	97	536	936	1339	115	132
RR	**1.22** (1.16, 1.28)	**1.08** (0.98, 1.20)	**1.26** (1.19, 1.33)	**1.09** (0.65, 1.72)	**1.27** (1.03, 1.54)	**1.09** (1.00, 1.19)	**1.09** (1.02, 1.16)	**0.88** (0.83, 0.93)	**1.04** (0.86, 1.24)	**0.67** (0.56, 0.79)
>5 mi. (referent)	**112.9** (112.2, 113.7)	**59.3** (58.6, 60.1)	**165.4** (164.1, 166.6)	**6.1** (5.7, 6.4)	**18.9** (18.4, 19.4)	**147.9** (146.2, 149.6)	**528.5** (524.2, 533.0)	**211.4** (209.7, 213.2)	**46.2** (45.5, 46.9)	**102.1** (100.7, 103.6)
# cases	91366	23728	67631	1173	6005	28638	55548	55552	16482	19332

* Includes cancers of the lung, bone, female breast, thyroid, and leukemias (excluding chronic lymphocytic leukemia).

Table 5. Crude and stratum-specific incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and by gender, age, or race/ethnicity: **Chemosensitive cancers**,* **1988-1995;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All	Gender		Age (years)				Race/Ethnicity		
		Male	Female	<15	15-39	40-59	60+	Non-Hispanic White	Hispanic	Other Non-Hispanic
<2 mi.	**74.3** (59.6, 91.6)	**83.2** (61.5, 109.9)	**65.6** (46.6, 89.7)	**0.0** (0.0, 14.1)	**4.0** (0.5, 14.5)	**63.8** (38.4, 99.6)	**529.4** (410.3, 672.3)	**84.7** (67.5, 105.1)	**23.0** (4.7, 67.2)	**27.1** (3.3, 97.7)
# cases	88	49	39	0	2	19	67	83	3	2
RR	**1.09** (0.88, 1.33)	**1.00** (0.75, 1.32)	**1.22** (0.88, 1.65)	**0.00** (0.00, 6.57)	**1.20** (0.20, 3.97)	**0.91** (0.56, 1.40)	**1.33** (1.04, 1.68)	**0.75** (0.60, 0.93)	**1.05** (0.27, 2.85)	**0.43** (0.07, 1.43)
2-5 mi.	**74.0** (69.0, 79.1)	**81.9** (74.6, 89.6)	**66.0** (59.4, 72.9)	**0.8** (0.1, 3.0)	**2.4** (1.3, 4.3)	**82.2** (72.0, 93.4)	**454.5** (418.6, 492.3)	**89.7** (83.4, 96.3)	**22.7** (16.1, 31.2)	**35.7** (26.0, 47.7)
# cases	846	469	377	2	12	234	598	763	38	45
RR	**1.08** (1.01, 1.16)	**0.99** (0.90, 1.08)	**1.22** (1.10, 1.35)	**0.48** (0.08, 1.60)	**0.73** (0.39, 1.25)	**1.17** (1.03, 1.33)	**1.14** (1.05, 1.24)	**0.80** (0.74, 0.86)	**1.04** (0.74, 1.41)	**0.57** (0.42, 0.76)
>5 mi. (referent)	**68.4** (67.9, 69.0)	**82.8** (81.9, 83.7)	**54.0** (53.2, 54.7)	**1.8** (1.6, 2.0)	**3.3** (3.2, 3.5)	**70.0** (68.7, 71.4)	**398.3** (394.4, 402.3)	**112.3** (111.1, 113.5)	**21.9** (21.4, 22.5)	**62.7** (61.4, 63.9)
# cases	51266	31000	20265	296	1113	10496	39358	35511	6147	9608

* Includes cancers of the liver, lung, bone marrow, bladder, and kidney.

Table 6. Crude and stratum-specific incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and by gender, age, or race/ethnicity: **Chemosensitive cancers**,* **1996-2002;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All	Gender		Age (years)				Race/Ethnicity		
		Male	Female	<15	15-39	40-59	60+	Non-Hispanic White	Hispanic	Other Non-Hispanic
<2 mi.	**81.0** (66.0, 98.3)	**99.4** (76.2, 127.4)	**62.9** (44.9, 85.6)	**0.0** (0.0, 13.4)	**4.6** (0.6, 16.6)	**70.8** (46.7, 103.1)	**433.9** (340.1, 545.6)	**93.0** (75.0, 114.1)	**51.8** (22.4, 102.0)	**17.2** (2.1, 62.2)
# cases	102	62	40	0	2	27	73	92	8	2
RR	**1.27** (1.04, 1.54)	**1.32** (1.02, 1.68)	**1.21** (0.87, 1.63)	**0.00** (0.00, 6.71)	**1.45** (0.24, 4.80)	**1.31** (0.88, 1.87)	**1.15** (0.91, 1.44)	**0.77** (0.62, 0.94)	**2.30** (1.07, 4.38)	**0.28** (0.05, 0.92)
2-5 mi.	**71.7** (66.9, 76.7)	**83.2** (75.9, 91.0)	**60.4** (54.3, 67.0)	**0.8** (0.1, 2.8)	**2.2** (1.0, 4.2)	**54.2** (46.6, 62.8)	**391.9** (361.9, 423.4)	**100.7** (93.5, 108.2)	**17.1** (12.3, 23.2)	**31.1** (23.7, 40.0)
# cases	828	475	353	2	9	180	637	727	41	60
RR	**1.13** (1.05, 1.21)	**1.10** (1.01, 1.21)	**1.16** (1.04, 1.29)	**0.48** (0.08, 1.59)	**0.70** (0.34, 1.29)	**1.00** (0.86, 1.16)	**1.04** (0.96, 1.12)	**0.83** (0.77, 0.90)	**0.76** (0.55, 1.02)	**0.50** (0.39, 0.64)
>5 mi. (referent)	**63.6** (63.1, 64.2)	**75.3** (74.5, 76.2)	**52.1** (51.4, 52.8)	**1.6** (1.5, 1.8)	**3.2** (3.0, 3.4)	**54.3** (53.2, 55.3)	**377.1** (373.4, 380.8)	**120.8** (119.5, 122.1)	**22.5** (22.0, 23.0)	**61.8** (60.7, 62.9)
# cases	51459	30139	21314	315	1006	10507	39629	31735	8025	11699

* Includes cancers of the liver, lung, bone marrow, bladder, and kidney.

Table 7. Crude incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and type of cancer: **Site-specific cancers**, **1988-1995**; Los Angeles and Ventura Counties, CA.

Distance From SSFL	Melanoma	Colorectal	Lympho-poietic*	Lung	Breast	Bladder	Prostate	Thyroid	Upper Aerodigestive Tract†
<2 mi.	**6.8** (2.9, 13.3)	**42.2** (31.3, 55.7)	**29.6** (20.6, 41.1)	**52.4** (40.2,67.1)	**100.9** (77.0, 129.9)	**11.0** (5.8, 18.8)	**79.8** (58.6,106.1)	**5.1** (1.9, 11.0)	**12.7** (7.1, 20.9)
# cases	8	50	35	62	60	13	47	6	15
RR	**0.74** (0.34, 1.40)	**1.04** (0.78, 1.36)	**1.25** (0.88, 1.72)	**1.11** (0.86, 1.42)	**0.95** (0.73, 1.21)	**1.19** (0.66, 1.98)	**0.77** (0.57, 1.01)	**0.94** (0.38, 1.96)	**0.81** (0.47, 1.31)
2-5 mi.	**15.1** (13.0, 17.6)	**39.2** (35.7, 43.0)	**23.1** (20.4, 26.0)	**54.3** (50.1,58.7)	**118.8** (110.0, 128.1)	**9.4** (7.7, 11.4)	**96.0** (88.1,104.4)	**6.5** (5.1, 8.1)	**15.9** (13.7, 18.4)
# cases	173	449	264	621	679	108	550	74	182
RR	**1.65** (1.41, 1.91)	**0.97** (0.88, 1.06)	**0.97** (0.86, 1.10)	**1.15** (1.06, 1.25)	**1.11** (1.03, 1.20)	**1.02** (0.84,1.23)	**0.92** (0.85,1.00)	**1.20** (0.95, 1.50)	**1.02** (0.88, 1.17)
>5 mi. (referent)	**9.2** (9.0, 9.4)	**40.6** (40.2, 41.1)	**23.7** (23.3, 24.0)	**47.1** (46.6,47.6)	**106.6** (105.6, 107.7)	**9.2** (9.0, 9.5)	**104.2** (103.1, 105.2)	**5.4** (5.2, 5.6)	**15.7** (15.4, 15.9)
# cases	6894	30485	17755	35294	40049	6934	39000	4042	11740

* Cancers of the lymphatic and hematopoietic tissue (excluding chronic lymphocytic leukemia).
† Includes cancers of the oral and nasal cavities, pharynx, larynx, and esophagus.

Table 8. Crude incidence rate (per 100,000/yr; 95% CI) and rate ratio (RR; 95% CI), by distance from SSFL and type of cancer: **Site-specific cancers**, **1996-2002**; Los Angeles and Ventura Counties, CA.

Distance From SSFL	Melanoma	Colorectal	Lympho-poietic*	Lung	Breast	Bladder	Prostate	Thyroid	Upper Aerodigestive Tract†
<2 mi.	**21.4** (14.1, 31.2)	**35.7** (26.1, 47.8)	**27.0** (18.7, 37.7)	**52.4** (40.5, 66.7)	**132.1** (105.3, 163.5)	**10.3** (5.5, 17.6)	**126.7** (100.3,157.9)	**12.7** (7.3, 20.6)	**18.3** (11.6, 27.4)
# cases	27	45	34	66	84	13	79	16	23
RR	**1.92** (1.29, 2.76)	**0.92** (0.68, 1.22)	**1.12** (0.79, 1.55)	**1.27** (0.99, 1.60)	**1.19** (0.96, 1.47)	**1.46** (0.81, 2.43)	**1.23** (0.98, 1.53)	**1.80** (1.07, 2.87)	**1.29** (0.84, 1.91)
2-5 mi.	**21.6** (19.0, 24.5)	**42.3** (38.7, 46.3)	**29.1** (26.0, 32.4)	**48.4** (44.5,52.6)	**139.4** (129.9, 149.2)	**9.1** (7.4, 11.0)	**112.5** (103.9, 121.5)	**10.1** (8.4, 12.1)	**16.5** (14.3, 19.1)
# cases	250	489	336	559	814	105	642	117	191
RR	**1.94** (1.71, 2.19)	**1.09** (0.99, 1.19)	**1.21** (1.08, 1.34)	**1.17** (1.07, 1.27)	**1.26** (1.18, 1.35)	**1.28** (1.05, 1.55)	**1.09** (1.01, 1.18)	**1.44** (1.19, 1.72)	**1.17** (1.01, 1.34)
>5 mi. (referent)	**11.2** (10.9, 11.4)	**39.0** (38.5, 39.4)	**24.1** (23.8, 24.5)	**41.4** (41.0, 41.8)	**110.6** (109.6, 111.6)	**7.1** (6.9, 7.3)	**102.9** (102.0, 103.9)	**7.0** (6.9, 7.2)	**14.2** (13.9, 14.4)
# cases	9033	31512	19522	33494	45224	5737	41187	5702	11452

* Cancers of lymphatic and hematopoietic tissue (excluding chronic lymphocytic leukemia).
† Includes cancers of the oral and nasal cavities, pharynx, larynx, and esophagus.

Table 9. Standardized rate ratio* (SRR; 95% CI), by distance from SSFL and type of cancer: **All cancers, radiosensitive cancers, and chemosensitive cancers, 1988-1995;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All Cancers	Radiosensitive Cancers[†]	Chemosensitive Cancers[¶]
<2 miles	**0.95** (0.82, 1.09)	**1.05** (0.82, 1.33)	**1.21** (0.88, 1.66)
2-5 miles	**0.97** (0.93, 1.01)	**1.03** (0.96, 1.11)	**1.06** (0.96, 1.17)
>5 miles (referent)	**1**	**1**	**1**

* Standardized for age (15-39, 40-59, 60+ years), gender, and race/ethnicity (non-Hispanic white, Hispanic, and other non-Hispanic).

† Includes cancers of the lung, bone, female breast, thyroid, and leukemias (excluding chronic lymphocytic leukemia).

¶ Includes cancers of the liver, lung, bone marrow, bladder, and kidney.

Table 10. Standardized rate ratio* (SRR; 95% CI), by distance from SSFL and type of cancer: **All cancers, radiosensitive cancers, and chemosensitive cancers, 1996-2002;** Los Angeles and Ventura Counties, CA.

Distance from SSFL	All Cancers	Radiosensitive Cancers†	Chemosensitive Cancers¶
<2 mi.	**0.93** (0.82, 1.05)	**0.98** (0.79, 1.21)	**1.11** (0.84, 1.47)
2-5 mi.	**0.94** (0.91, 0.98)	**0.96** (0.90, 1.03)	**0.92** (0.84, 1.01)
>5 mi. (referent)	**1**	**1**	**1**

* Standardized for age (15-39, 40-59, 60+ years), gender, and race/ethnicity (non-Hispanic white, Hispanic, and other non-Hispanic).

† Includes cancers of the lung, bone, female breast, thyroid, and leukemias (excluding chronic lymphocytic leukemia).

¶ Includes cancers of the liver, lung, bone marrow, bladder, and kidney.

Table 11. Standardized rate ratio* (SRR; 95% CI), by distance from SSFL and cancer site: **Site-specific cancers, 1988-1995**; Los Angeles and Ventura Counties, CA.

Cancer Site	**<2 miles**	**2-5 miles**	**>5 miles (referent)**
Melanoma	**0.57** (0.23, 1.36)	**1.17** (0.94, 1.46)	**1**
Colorectal	**1.32** (0.86, 2.02)	**1.00** (0.87, 1.13)	**1**
Lymphopoietic†	**1.62** (0.94, 2.83)	**0.93** (0.78, 1.10)	**1**
Lung	**1.29** (0.89, 1.89)	**1.12** (1.00, 1.26)	**1**
Breast	**0.92** (0.65, 1.31)	**1.00** (0.90, 1.11)	**1**
Bladder	**1.62** (0.67, 4.12)	**0.97** (0.74, 1.27)	**1**
Prostate	**0.90** (0.60, 1.35)	**0.94** (0.84, 1.06)	**1**
Thyroid	**2.50** (0.49, 18.61)	**1.26** (0.89, 1.78)	**1**
Upper Aerodigestive Tract¶	**1.83** (0.91, 3.83)	**1.14** (0.93, 1.41)	**1**

* Standardized for age (15-39, 40-59, 60+ years), gender, and race/ethnicity (non-Hispanic white, Hispanic, and other non-Hispanic).

† Cancers of lymphatic and hematopoietic tissue (excluding chronic lymphocytic leukemia).

¶ Includes cancers of the oral and nasal cavities, pharynx, larynx, and esophagus.

Table 12. Standardized rate ratio* (SRR; 95% CI), by distance from SSFL and cancer site: **Site-specific cancers, 1996-2002**; Los Angeles and Ventura Counties, CA.

Cancer Site	**<2 miles**	**2-5 miles**	**>5 miles (referent)**
Melanoma	**1.17** (0.67, 2.07)	**1.22** (1.01, 1.46)	**1**
Colorectal	**0.83** (0.55, 1.24)	**0.92** (0.81, 1.04)	**1**
Lymphopoetic[†]	**1.07** (0.64, 1.78)	**1.01** (0.86, 1.18)	**1**
Lung	**1.08** (0.76, 1.54)	**0.93** (0.83, 1.04)	**1**
Breast	**0.92** (0.69, 1.24)	**0.98** (0.89, 1.08)	**1**
Bladder	**1.20** (0.51, 2.86)	**1.02** (0.78, 1.34)	**1**
Prostate	**1.10** (0.80, 1.51)	**0.92** (0.82, 1.02)	**1**
Thyroid	**1.86** (0.75, 4.96)	**1.47** (1.11, 1.93)	**1**
Upper Aerodigestive Tract[¶]	**1.22** (0.65, 2.31)	**0.96** (0.79, 1.17)	**1**

* Standardized for age (15-39, 40-59, 60+ years), gender, and race/ethnicity (non-Hispanic white, Hispanic, and other non-Hispanic).

† Cancers of lymphatic and hematopoietic tissue (excluding chronic lymphocytic leukemia)

¶ Includes cancers of the oral and nasal cavities, pharynx, larynx, and esophagus.

Table 13. Standardized rate ratio* (SRR; 95% CI), by distance from SSFL and period:
All childhood cancers, 1988-2002; Los Angeles and Ventura Counties, CA

Distance from SSFL	1988-1995	1996-2002
<2 miles	---† (0.05, ∞)	**---**† (1.22, ∞)
2-5 miles	**1.20** (0.70, 2.06)	**1.40** (0.88, 2.26)
>5 miles (referent)	**1**	**1**

* Standardized for age (<5, 5-9, 10-14 years), gender, and race/ethnicity (non-Hispanic white, Hispanic, and other non-Hispanic).

† The point estimate of the rate ratio is indeterminate because of the small numbers of stratum-specific cancers and children living within 2 miles of SSFL (including zeros in several strata).