The Potential for Offsite Exposures Associated with Santa Susana Field Laboratory, Ventura County, California

Final Draft Report

Report Prepared by
Center for Environmental Risk Reduction
University of California at Los Angeles, California

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This study was funded by the Agency for Toxic Substances and Disease Registry (ATSDR) through a contract arrangement by Eastern Research Group, Inc. (ERG) with the University of California, Los Angeles (UCLA). The study focused on assessing the potential exposures of communities surrounding Santa Susana Field Laboratory (SSFL) to contaminants associated with SSFL. The following individuals have contributed to the study:

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1.0 INTRODUCTION

1.1 Overview

This report reviews the available monitoring data and various studies that have focused on the potential environmental impact of Santa Susana Field Laboratory (SSFL) on its surrounding communities. The report's major objectives are (a) to provide an independent review of the adequacy and accuracy of available monitoring data on chemical and radionuclide contamination at the SSFL site and surrounding communities; (b) to assess the present level of contamination, due to chemicals and radionuclides, at the SSFL facility and the surrounding communities; (c) to estimate emissions of chemicals associated with various SSFL-related activities; (d) to identify, to the extent possible, locations that SSFL is likely to have impacted; (e) to assess the potential migration of contaminants from SSFL, and (f) to identify potential significant exposure pathways associated with the release of contaminants from the SSFL area.

This report was prepared by a study team whose members came from the University of California at Los Angeles (Center for Environmental Risk Reduction, Chemical Engineering Department, Civil and Environmental Engineering Department, School of Public Health), the Universitat Rovira i Virgili in Spain, and Sonoma Technology in California. In addition to reviewing available reports and conducting independent analyses, UCLA study participants have visited the SSFL site and surrounding communities on numerous occasions. UCLA study group members have also attended a number of public meetings[1.1] in which members of the community have presented their concerns. Such public meetings and personal interviews with community members have helped the authors shape the structure of this report in order to address issues that are of concern to the community.

Sources of information considered in the study included reports addressing site characterization and inspection, contaminant monitoring, exposure and risk assessment, environmental assessments, and site evaluation, as well as accident reports, emission logs, toxic release inventories, hydrogeology investigations, unpublished memos and letters from regulatory branches, Hazard Ranking System (HRS) evaluations, radiological surveys, well usage reports, meteorological records, studies of population distributions and community health,[1.2] and personal communications. Critical review of the above information along with independent data analyses and modeling were conducted to (a) screen and rank the chemicals of concern according to their toxicity, environmental persistence, emissions, and/or monitored concentrations; (b) estimate emissions of contaminants from SSFL; (c) evaluate air dispersion of contaminants from SSFL; and (d) evaluate the extent of subsurface contamination and potential offsite contaminant migration.

The study's sources were SSFL logs and reports provided by the Boeing Company, as well as various monitoring and/or assessments conducted by the Agency for Toxic Substances and Disease Registry (ATSDR), the U.S. Department of Energy (DOE), the California Department of

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[1.1] Meetings attended were organized by SSFL Workgroup members, the U.S. Environmental Protection Agency (EPA), the Committee to Bridge the Gap, the Southern California Federation of Scientists, the Rocketdyne Cleanup Coalition, the California Department of Toxic Substances Control, the Los Angeles Regional Water Quality Control Board, and the U.S. Department of Energy.

[1.2] Wright et al., 1990; DHS, 1992; Reynolds et al., 1992; Morgenstern et al., 1997, 1999, and 2001.

Toxic Substances Control (DTSC), the U.S. Nuclear Regulatory Commission (NRC), Washington Mutual Bank, the U.S. Environmental Protection Agency (EPA), Atomics International (AI), the California Department of Health Services (DHS), the Committee to Bridge the Gap, the U.S. Geological Survey (USGS), Ventura County Air Pollution District (VCAPD), the Office of Environmental Health and Human Affairs (OEHHA), the Los Angeles Regional Water Quality Control Board (RWQCB), the Southern California Water Company (SCWC).

This report assesses potential exposure scenarios and identifies exposure locations that may be of greatest concern. Where possible, it discusses the implications of the various findings to human health risk. Because of the lack of reliable monitoring and emission data, it was not possible to conduct quantitative dose reconstruction and health risk assessment. Therefore, this report does not present a quantitative risk assessment. Notwithstanding, its review and analyses should be directly useful for subsequent risk assessment and epidemiological studies and to those who need to assess the future potential land use of SSFL and ensure public protection. Finally the report summarizes the potential public health hazard posed by SSFL, and makes recommendations, as deemed appropriate, that are relevant to public protection.

1.2 Site Operations and History

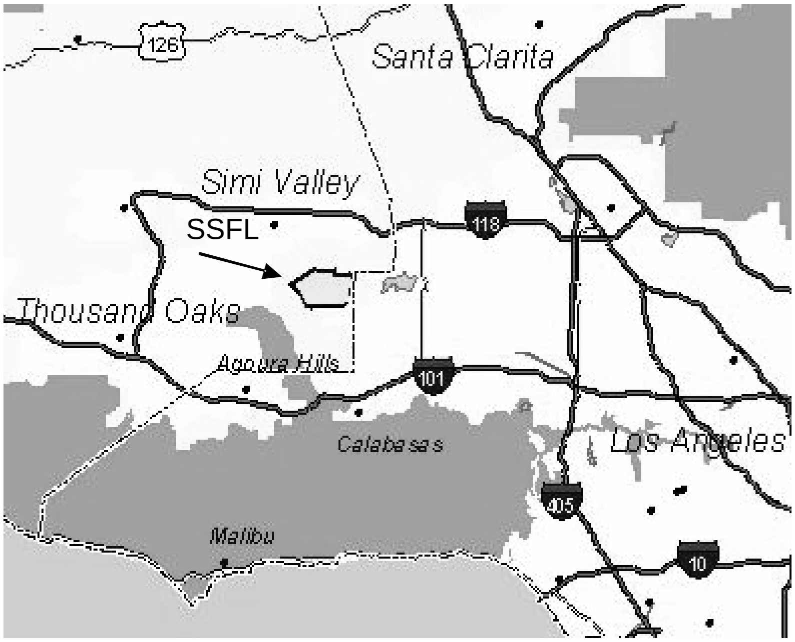
1.2.1 Location and Operational History

SSFL is a complex of industrial facilities located in the Simi Hills of southeastern Ventura County, California. The facility is approximately 30 miles northwest of downtown Los Angeles (see Figure 1-1), between Simi and San Fernando Valleys. SSFL occupies roughly 2,600 acres, at altitudes ranging from approximately 1,500 feet to 2,200 feet.

In 1948, North American Aviation acquired the land area now known as SSFL. The SSFL site has been used primarily for testing liquid fuel-propelled rocket engines, many related to the early Apollo space missions. In addition, the SSFL site was the location of research, development, and testing of MX missile engines, water jet pumps, “Star Wars” lasers, liquid metal heat exchanger components, coal gasification and liquification processes, and related technologies. In 1955, Atomics International (a division of North American Aviation) and DOE began developing and testing nuclear reactors on the site. Operations at SSFL have involved the use of organic solvents, hydrazine fuels, kerosene-based fuels, oxidizers, liquid metals, asbestos, polychlorinated biphenyls (PCBs), hydraulic oils, and various radionuclides (see Appendix C for a complete listing).

Atomic International (AI) merged with Rocketdyne in 1984 and Rocketdyne’s name was kept. In 1996, all nuclear operations ended; since that time the nuclear reactors and reactor sites have been undergoing decontamination and decommissioning (D&D) under the oversight of DOE. Boeing and Rocketdyne merged in 1996. SSFL is now jointly owned by Boeing and the National Aeronautics and Space Administration (NASA), and is operated by the Rocketdyne Propulsion and Power Division of Boeing.

Figure 1-1 Location of Santa Susana Field Laboratory



Source: ATSDR (2000)

1.2.2 Facility Description

The SSFL site is divided into four administrative areas (I, II, III, and IV) and undeveloped buffer properties to the northwest and south, as shown in Figure 1-2 (Robinson, 1998; Ogden, 1998b). A detailed map listing the various present and past use areas of SSFL is provided in Figure 1-3.

- Area I consists of 671 acres owned by Boeing and 42 acres owned by NASA in the northeast portion of the site. Area I houses administrative and laboratory facilities including the North American Kindleberger Atwood Lab (NAKA), the former Area I Thermal Treatment Facility (TTF), also known as the open pit burning facility; and three rocket engine test areas: the Bowl, the Canyon, and the Advanced Propulsion Test Facility (APTF) areas. The Bowl and Canyon test areas were phased out of operation in the late 1960s and 1970s.

- Area II consists of 410 acres at the north-central portion of the site. It is owned by NASA and operated by Rocketdyne. Area II contains two formerly used rocket test firing facilities (Coca, Delta) and two currently operating rocket test firing facilities (Alfa, Bravo), as well as the NASA-associated Systems Test Laboratories (STL). Delta test areas were phased out of operation in the late 1960s and 1970s. The Coca test area was shut down in May 1988. The Alfa and Bravo test areas are currently in operation.

- Area III consists of 114 acres at the northwest portion of the site and is owned and operated by Rocketdyne. The Systems Test Laboratories–IV (STL-IV) and the Engineering Chemistry Lab (ECL) are located in Area III.

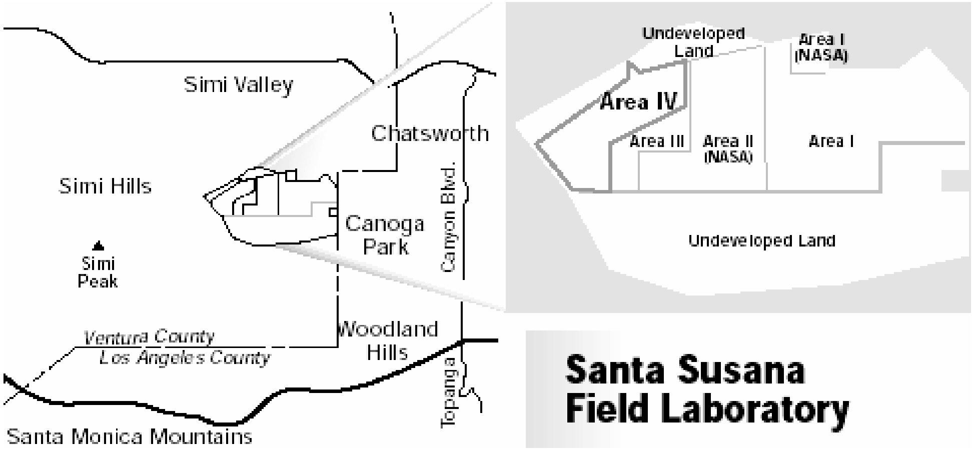
- Area IV consists of 290 acres owned by Boeing and operated by Boeing's Rocketdyne Division and 90 acres leased by the DOE. DOE and its contractors operated nuclear reactors, associated fuel facilities, and laboratories within this area from 1955 until 1988. Area IV is the location of the former Sodium Reactor Experiment complex (SRE) and the Rockwell International Hot Lab. Since 1988, the site has maintained a program to monitor and clean up radiological contamination.

- The Buffer Areas consist of two undeveloped plots (175 and 1,140 acres) northwest and south of SSFL, respectively (Figure 1-2). Two National Pollutant Discharge Elimination System (NPDES) discharge outfalls and drainage channels are located within the southern boundary area (outfalls 001-002; see Figure 3-9 for NPDES outfall locations). The northern boundary was purchased by Boeing from the adjoining Brandeis-Bardin Institute in 1997 (GRC, 1999).

Chemical waste generated at the SSFL facility was treated and stored on site, including in surface impoundments (ponds). SSFL has had 28 of these ponds over the course of its history; they are designed to collect cooling and rinse water, storm water runoff, and accidental spills (GRC, 1987). Eleven of the ponds were designated in 1977 as hazardous waste facilities under the Resource Conservation and Recovery Act (RCRA) of 1976 (GRC, 1987). Since 1977 only two of these eleven ponds were reportedly the only impoundments that were part of the water reclamation system hat stored and treated hazardous wastes on a routine basis: the Engineering Chemistry Lab (ECL) pond in Area III and the Laser Engineering Test Facility (LETF) pond in Area I (GRC, 1987). These two ponds were excavated in 1984 and the material was sent to a Class I disposal facility (Hargis, 1985). Active use of the other nine impoundments ceased in 1985, and those ponds have been undergoing RCRA closure (GRC, 1987). Five impoundments are still in use (R-1, Perimeter, Silvernale, R2-A, and R2-B ponds; Figure 1-3; Boeing, 2003).

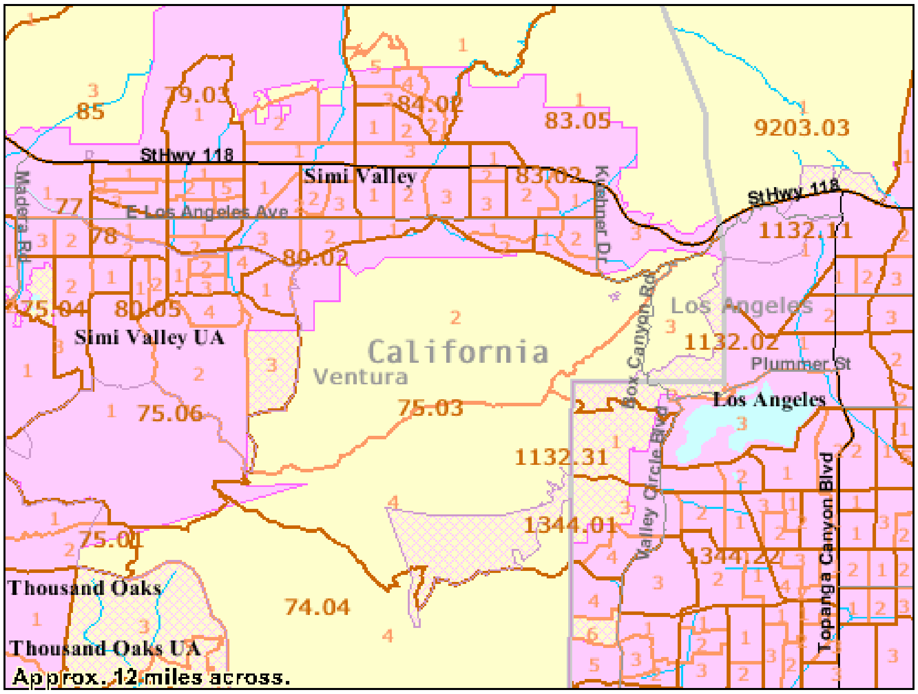
In addition to surface impoundments, there are 17 known areas where waste materials were stored or treated (Hargis, 1985). According to Groundwater Resources Consultants (GRC, 1987), many of these areas may have lacked proper containment facilities to prevent release of contaminants to the environment in the event of improper storage or spills throughout their operation. Appendix D summarizes information on these waste management facilities, including their reported use and types of waste handled.

Figure 1-2. Santa Susana Field Laboratory



Source: ATSDR, 2000

Figure 1-5. Locations of Census Tracts Corresponding to Data Used for Table 1-1



Source: U.S. Census Bureau

1.3 The Surrounding Community

Dynamic changes in population density around SSFL and continual migration of residents into and out of various areas make the association of potential exposures with specific population segments an impractical task. Nonetheless, in order to evaluate the pertinent exposure pathways, one must consider the population distribution around SSFL and land use in the SSFL area.

The communities surrounding SSFL have changed since the area's early industrialization in 1946. The area was sparsely populated before 1970. USGS maps (USGS, 1952, 1967) indicate that fewer than six buildings were present in the areas directly bordering SSFL before 1967, with approximate near-border population of 20 individuals. Development in the area and population increased significantly since the establishment of SSFL. In 2000, the population within 1 mile of SSFL was about 6,000 (U.S. Census Bureau, 2000). As Table 1-1 shows, the total population increase during the 1980–2000 period (in the selected communities shown in Figure 1-4, all of which lie within 4 miles of SSFL) was approximately 62%. (Figure 1-5 shows the census tracts from which the table's data were drawn.)

Table 1-1. Demographics of Selected Tracts Surrounding SSFL Within a 4-Mile Radius

Variable	**1980**	**1990**	**2000**
Total Population	3,597	5,118	9,488
Children 9 years of age or younger	317 (9%)	481 (9%)	1,306 (14%)
Persons 65 years of age or older	162 (4%)	290 (6%)	404 (4%)
Females 15 to 44 years of age	956 (27%)	1,325 (26%)	1,910 (20%)
Total housing units	1,211	1,834	6,771
Total housing units built in the last 10 years	—	368 (20%)	4,937 (73%)

Note: Demographic statistics within a 4-mile radius of SSFL for 1990 and 2000; data from census tracts 75.03, Ventura, and tracts 1132.31/1132.02/1344.01, Los Angeles, California (U.S. Census Bureau). The percentages in brackets designate the percent of the specific population group of the total population for the indicated year.

Figure 1-4. Communities and Land Use Surrounding SSFL

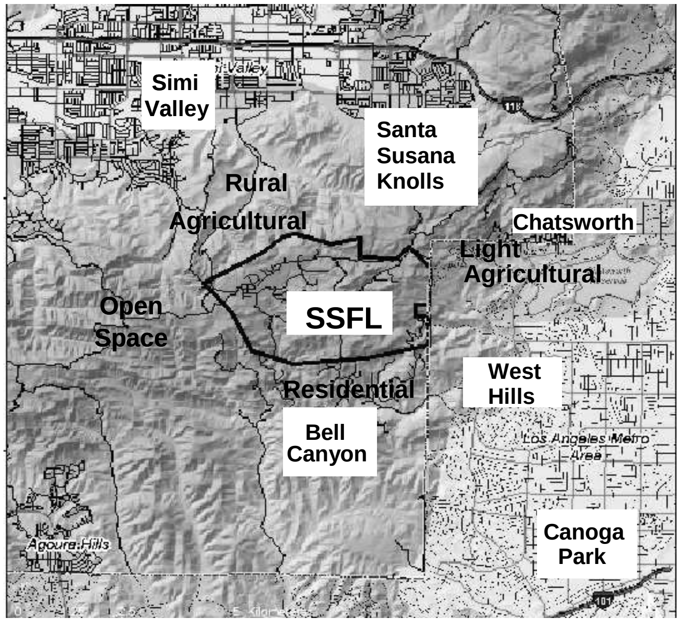
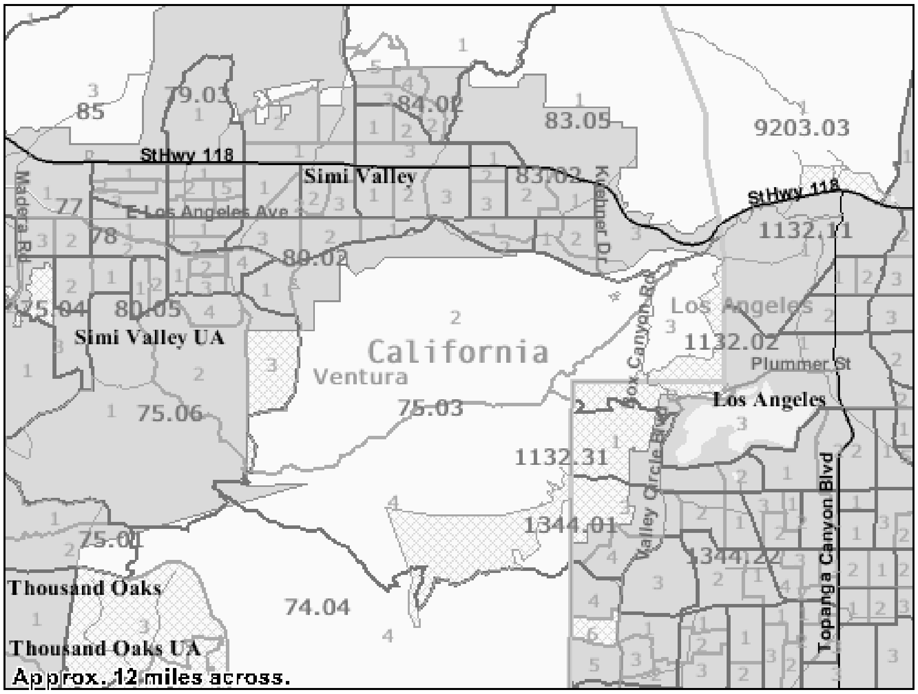


Figure 1-5. Locations of Census Tracts Corresponding to Data Used for Table 1-1



Source: U.S. Census Bureau

Currently, there are residents who live directly adjacent to the eastern and southern site boundaries. Two mobile home parks are located east of the site on Woolsey Canyon Road. The major communities surrounding SSFL are indicated in Figure 1-4. The residential areas closest to the facility are Bell Canyon to the south, Lakeside Park and Dayton Canyon to the east, and Box Canyon and Woolsey Canyon to the northeast. The nearest communities are Chatsworth (~3 miles east, population ~67,000), Canoga Park (~5 miles southeast, population ~100,000), Simi Valley (~3 miles north, population ~100,000), and Thousand Oaks (~7 miles southwest, population ~100,000).[1.3] The neighboring lands to the north and west of SSFL are zoned rural/agricultural or agricultural. Lands to the south of the facility are zoned rural. To the east, land has been designated as light agricultural.

1.4 Community Concerns

In meetings ATSDR held by the Agency for Toxic Substances and Disease Registry (ATDSR) in Chatsworth, Simi Valley, and West Hills on October 5 and 6 and November 3, 1999, the public expressed concerns about SSFL's potential impact on community health. These concerns were heightened in view of the 1992 California Department of Health Services (DHS reports suggesting high incidences of bladder and lung cancer in communities surrounding SSFL.[1.4] Particular public health concerns identified at the ATSDR meetings were asthma, immune system disorders, neurological disorders, birth defects, and several types of cancer (breast, bladder, lung, prostate, thyroid, skin, leukemia, and liver) (ATSDR, 1999). Other community concerns identified at other public meetings[1.5] and resident interviews (Appendix G) included the potential for contamination of well supplies in Simi and San Fernando Valleys, the potential for contamination of private and community gardens and/or livestock, and inadequacy of environmental sampling and monitoring programs.

The UCLA study group considered community concerns that were brought to its attention both via public meetings and directly by members of the public. The study also considered public concerns documented in available reports. Health effects implications associated with SSFL chemicals of potential concern (COPCs) are listed in Appendix F and are discussed in Section 6.2. In order to address public concerns regarding exposure to contaminants via the groundwater pathway, the study group attempted to retrieve updated well logs and well information (Appendix K; Table 4-1); unfortunately, all the necessary information was not forthcoming.[1.6] A previous assertion regarding inactivity of all wells within a 1-mile radius (ATSDR, 1999) could not be verified by the present study. Therefore, relevant conservative assumptions were made, as

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[1.3] Population estimates are based on 2000 census data (U.S. Census Bureau).

[1.4] A preliminary report by DHS (DHS, 1992) suggested a high incidence of bladder cancer for the 1983–1987 period among residents near SSFL in Los Angeles County. A subsequent study (Reynolds et al., 1992) confirmed the higher rate of bladder cancer among men living near SSFL (again, in Los Angeles County) in 1983–1988. That study also reported a higher incidence of lung cancer in Ventura County residents near SSFL. As acknowledged in the Reynolds et al. study, the relatively small number of cancer cases within 5 miles of SSFL and the area's low population limited the detection sensitivity of the study.

[1.5] These meetings were held by the SSFL Workgroup (12/10/03; 3/24/04), DTSC (7/15/03; 3/17/04), the Bell Canyon Homeowners Association (1/25/04), UCLA (8/19/2003), the Los Angeles RWQCB (2/10/03; 3/14/03; 4/24/03; 6/25/03; 8/20/03; 4/14/04) and DOE (6/3/2004).

[1.6] Correspondence with agencies and private well companies is documented in Appendix J.

deemed appropriate, regarding well usage in the areas north and east of SSFL.[1.7] Given public concerns about the impact of SSFL on community livestock and edible crops, an effort was made to ascertain the existence and locations of community gardens and/or farms. That information was incomplete, so the study group considered various scenarios to assess SSFL's possible impact on community gardening and farming activities. The community has also expressed concerns about potential exposures to SSFL-associated chemicals due to outdoor activities near SSFL (e.g., gardening, camping and hiking leading to exposure to surface water originating from SSFL). Unfortunately, detailed population activity patterns are not available for the communities surrounding SSFL. Consequently, where deemed appropriate, the study group used information from local residents (Appendix G).

Finally, the report also addresses community concerns regarding the adequacy of monitoring data and confusion regarding the role and responsibilities of various government agencies with respect to SSFL. These concerns are addressed throughout the report and in recommendations about monitoring programs and implications of available monitoring data (Sections 1.4, 3, 5.1, and 6). A list of various agencies and their regulatory responsibilities and onsite activities is provided (Appendix P) based on the compilation by Montgomery-Watson Groundwater Consultants (MWG, 2000).

1.5 Evaluation of SSFL Site Assessment Reports, Quality of Monitoring Data, and Reported Emissions

1.5.1 Overview

The study group reviewed SSFL-related reports detailing site investigations and monitoring programs (Appendix O) in order to (a) assess the quality and reliability of available monitoring data, (b) identify contaminants of concern (COCs), (c) assess the level of contamination in and around the SSFL facility, and (d) evaluate the potential for offsite contaminant migration.

The type and number of documents reviewed by the UCLA study team are listed in Table 1-2. In all, the team reviewed 291 documents from 35 different sources.

1.5.2 Assessment of the Quality of Monitoring Studies and Data Reliability

The quality and reliability of reports and documents reviewed in this study were evaluated according to several critical factors. For monitoring reports, critical review factors included measurement sensitivity, randomness of sampling, sufficiency of data points, appropriateness of methodology, uncertainty, reproducibility, evidence that a monitoring sample was representative of the site or background, potential for sample contamination, acceptability of analytical methods, and adherence to standard quality assurance/quality control methods. Reports were also assessed for their overall methodology and the degree to which they supported or conflicted with the other reports. Data gaps and chemicals not routinely monitored were listed and assessed as

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[1.7] Groundwater wells were not identified for the Bell Canyon community by the Ventura and Los Angeles Water Resources Departments.

COPCs (Appendix C). Assessments of data quality are presented throughout this report when relevant monitoring data are reviewed. The study team also considered details regarding specific violations cited in EPA, DTSC, and DHS inspection reports in assessing potential the potential for offsite contaminant migration and under-reporting of the extent of contamination and/or releases of contaminants (Appendix E).

Chapter 8 discusses, in detail, the available offsite monitoring reports' adequacy and the implications of their monitoring data. It is nonetheless useful to summarize here the study team's concerns about the two major SSFL-related offsite monitoring studies conducted at the Brandeis-Bardin Institute (BBI) and Santa Monica Mountains Conservancy (SMMC) areas (McLaren-Hart, 1993, 1995) and at Bell Canyon (Ogden, 1998a). Air monitoring was not conducted or reported in either of these two studies. Moreover, background samples were taken from locations that were not representative of the Bell Canyon study area (Ogden, 1998a).[1.8] Sampling was deficient with respect to the sampled media for the Bell Canyon[1.9] study (Ogden, 1998a) and the number of areas sampled for the BBI/SMMC study (McLaren-Hart, 1993).[1.10] For example, proper monitoring protocols—such as grid spacing of samples—were not followed (EPA, 2002). It is also noted that despite detections of plutonium-238, cesium-137, and strontium-90 significantly above background (McLaren Hart, 1995), re-sampling was only conducted 2 years after the initial detection, and only tritium was assessed in this second round of monitoring. Given the deficiencies in the above studies, the study team is concerned that the extent of contamination in these offsite areas was incompletely mapped.

Limited or inadequate monitoring data (see Chapter 8) have made it impossible to arrive at a definitive quantitative evaluation of the rates of contaminant migration over the lifetime of the SSFL and to rule out certain contaminant migration pathways. Data limitations that have been identified include, but are not limited to: (a) inadequate assessment of vertical and horizontal hydraulic gradients; (b) insufficient delineation of the extent of groundwater contamination in areas east of the facility; (c) lack of current well use surveys in areas east, northeast, and south of the facility; (d) lack of long-term (>4 years) historical onsite meteorological data; (e) lack of air monitoring data (historical and current) for chemicals and radionuclides; and (f) potential for non-detection of significant concentrations in past monitoring programs due to the detection limits of monitoring devices (1948–1980s).

[1.8] In the Ogden study, Bell Canyon background sampling included sampling from areas between SSFL and Bell Canyon. It is noted that background samples in the Ogden study were not from the same bedrock formation as in the residential yards from which samples were taken.

[1.9] Water samples were not taken from Bell Creek despite the fact that 90 percent of the NPDES discharges were released to streams that flow into Bell Creek (Ogden, 1998a). .

[1.10] Only four sites were sampled in the 1993 McLaren-Hart study (McClaren-Hart, 1993). .

Table 1-2. Category and Number of Reports Reviewed and Information Sources

Report/Document Category	Number of Reports/ Documents	Source of Information	Number of Reports/ Documents
Offsite monitoring reports	16	Atomics International	2
Onsite monitoring reports	53	Agency for Toxic Substances and Disease Registry	7
Environmental surveys ('59–'02)	26	Committee to Bridge the Gap	1
Inspection reports	10	Fireman reports	1
Accident reports	3	U.S. Environmental Protection Agency	3
Emission estimation reports	3	California Department of Health Services	3
Closure reports	8	U.S. Department of Energy	4
Risk assessments	1	Rocketdyne/Boeing	16
Epidemiologic studies	4	Ventura County Air Pollution Control District	1
Site characterization studies	20	UCLA	4
Unpublished correspondence	21	U.S. Geological Survey	2
Production/release reports	50	Department of Toxic Substances Control	1
Meteorological reports	3	National Research Council	1
Water quality reports	3	Oak Ridge Institute	2
Scientific reviews	52	Regional Water Quality Control Board	2
Monitoring protocol guidelines	15	Southern California Water Quality Department	1
Health Ranking System reports	1	Rockwell	8
Well inventories	2	Consulting firms (Techlaw, Ogden, McLaren-Hart, Montgomery-Watson, Klinefelder, ITC, ICF Kaiser, Hargis and Assoc., Haley and Aldrich, GRC, ERG, ERD, ERC, EG&G, CH2MHill, Sonoma Technology, and ABB Environmental)	59
		Other (toxicity studies, scientific papers, etc.)	134

1.5.3 Identification of Contaminants of Concern and Assessment of the Level of Contamination

Available monitoring data and chemical use data, as well as SSFL activity reports, were reviewed (Appendix O) to identify the specific COCs that have been used at SSFL (Appendix C) and their respective offsite media concentrations (Appendix H). Reported monitored concentrations above existing health-based standards (Appendix N) were compiled (Appendix H), and a ranking analysis was performed (Appendix M) for COPCs (Appendix C) using the Scoring Chemicals and Ranking Assessment Model (SCRAM). Subsequently, site-specific information was used to identify the top 20 COCs, as detailed in Chapter 2.

1.5.4 Evaluation of Potential for Offsite Contaminant Migration and Community Exposure

In order to ascertain the potential for contaminant migration and community exposure to SSFL-associated COCs (identified in Chapter 2), it is essential to first confirm that:

- The COCs have indeed been stored and/or used at SSFL.

- There is evidence or sufficient reason to assert the potential release of COCs from SSFL to one or more environmental media.

- Conditions exist for migration of chemicals from SSFL to locations where human exposure is possible.

- Chemical concentrations at receptor locations of concern are or may have been above regulated health standards.

The potential for migration of contaminants and radionuclides to offsite areas was assessed based on (a) review and analysis of available monitoring data, site assessments and activity reports, and offsite monitoring studies (Appendix H); (b) estimates of air emissions of chemicals from various activities at SSFL (Appendix I); (c) air dispersion modeling to identify receptor locations at which exposure concentrations may be of concern (Appendix S); (d) review of site-related hydrogeology and meteorology (Section 3.2.2 and Appendix I); (e) experimental evaluation of subsurface diffusive transport and retention of TCE in site core samples (Appendix U); (f) review of SSFL-related groundwater modeling studies (Section 3.2.2); (g) modeling estimates of volatilization of organics from the SSFL soil based on reported soil vapor analysis (Section 3.3.2). Sections 3 and 4 summarize information on the potential exposure pathways examined and discuss these pathways (see also Section 2.1, Table 2-1). The above analysis served as the basis for subsequent assessment of locations in the vicinity of the SSFL and exposure scenarios that could lead to exposures at above tolerable levels (Appendices H, R, and T). This analysis also considered various scenarios of exposure periods and frequency relative to the time of detection (Table 3-1 and Appendix H).

Offsite monitoring studies[1.11] have documented the presence of offsite contamination (Appendix H), suggesting that contaminants have migrated away from the site. The air migration pathway was evaluated based on available air and soil monitoring data and numerical analysis using air dispersion modeling (Appendix I). The groundwater migration pathway was evaluated based on information in available hydrogeologic characterization reports, groundwater modeling and monitoring studies, and experimental evaluation of contaminant sorption and diffusion in site soil core samples (Sections 3.3.2 to 3.4). The surface water pathway was evaluated based on NPDES (National Pollutant Discharge Elimination System) permits, NPDES monitoring reports (Appendix H), and surface water pathway analyses (Sections 3.3.1 to 3.3.3). Given evidence of offsite groundwater TCE plume migration[1.12] (Appendix H), it is reasonable to expect that some chemicals could have migrated from SSFL to offsite receptor locations via the groundwater pathway. There is also evidence that contaminants may have migrated off site via the permitted surface water outfalls northwest and south of the facility (Appendix H). An expanded discussion of the individual pathways is provided in Chapters 3 through 5.

[1.11] Boeing, 1990–2003, 2002; CA EPA, 2000; CDHS, 1999; EPA, 2000; GRC, 1990a, 1990b, 2000; Klinefelder, 2000; Lawrence Livermore National Lab, 1997; Masry and Vititoe, 1998; McLaren Hart, 1993; Ogden, 1995, 1998a; PSOMAS, 2003; Rocketdyne, NPDES Annual Reports (various years), 1995.

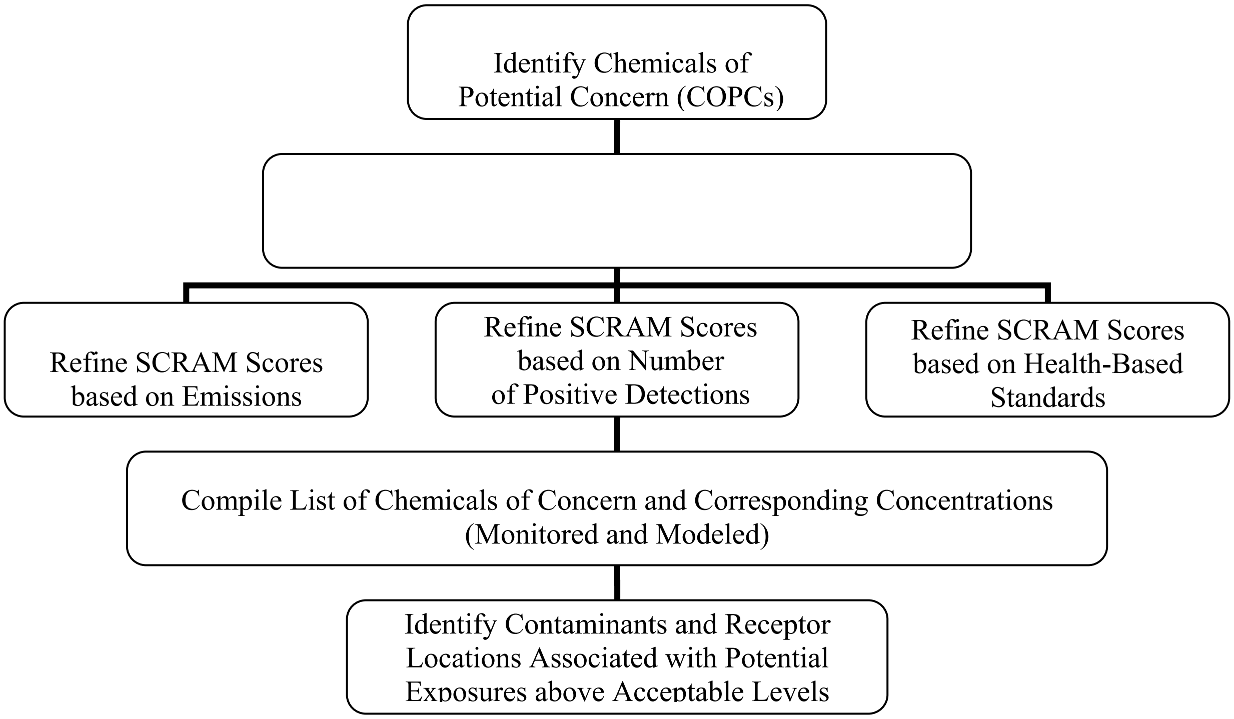
[1.12] TCE and its degradation products have been detected in groundwater plumes emanating from the northeastern portion of the site (Appendix H).

2.0 IDENTIFICATION OF CHEMICALS OF CONCERN

Many chemicals have been detected, used, or stored on site at SSFL. Some of these are of particular concern given their toxicological properties and/or potential for persistence in the environment. In the first phase of the process of identifying the COCs, the study team considered all contaminants to avoid missing potentially significant contaminants that were infrequently monitored or for which health-based standards do not yet exist. Thus a list of contaminants used on site (i.e. COPCs) was compiled from the reports and documents listed in Section 1.4 (Appendix C).

The SSFL-associated chemicals (Appendix C) were ranked according to their toxicology and environmental persistence (Appendix M). Ranking results were then weighted with information (Appendix M; Figure 2-1) that allowed a site-specific ranking and identification of the site-specific COCs of primary concern. The COCs were then subcategorized according to the phases in which they have been detected or likely to be present (Table 2-4). Available monitoring data were subsequently reviewed to identify the time periods and locations of the monitoring sites (Appendix H) at which concentrations were detected above the relevant environmental standards (Appendix N). The study team used this information in assessing the potential for exposure to the COCs (Section 4). This process for identifying COCs is outlined in Figure 2-1; the details are presented in Sections 2.1 and 2.2.

Figure 2-1. Flowchart Illustrating the Process of Identifying the Chemicals of Concern



2.1 Chemicals of Potential Concern

COPCs associated with SSFL activities were identified based on a review of reports on those activities, as well as environmental monitoring and remediation activities between 1946 and 2003 (Appendix O). Chemicals were included in the list of COPCs (Appendix C) if they met one of the following criteria (EPA, 1989):

- Detection sensitivity was above an existing health-based standard. Detection sensitivities were assessed for all monitoring reports (for each chemical assessed) and were compared to health-based standards to determine the relevance of monitoring results.
- Detection in at least one sample.
- Detection above levels found in associated blanks or reliable background samples. Monitored background samples were assessed for reliability,[2.1] and any suspected deficiencies in monitoring accuracy were noted.
- Association with SSFL according to historical site information. Chemical usage reports and emission reports were used to identify contaminants that were not regularly sampled.
- Status as a known byproduct of chemicals detected at SSFL. Oxidation products of major air contaminants and transformation products of water and soil contaminants were identified and evaluated for potential listing as COPCs.
- Reported concentrations above an existing health-based standard. Chemicals were listed as COPCs if they were detected at concentrations above published regulatory standards for air, soil, or water.

Regulatory standards compared against COPC levels in water included EPA's Maximum Contaminant Levels, or MCLs (established for drinking water[2.2]) and, where MCLs were unavailable, DHS Action Levels (ALs). For soil, the study team used EPA Region 9's Residential Soil Screening Levels (RSSLs) and, where no RSSLs were available, DHS ALs. For air, the team used the National Ambient Air Quality Standards (NAAQS) for SO_2, NO_2, CO, O_3, Pb, and particulate matter and the National Emission Standards for Hazardous Air Pollutants (NESHAPs) for various other toxicants. For radionuclide contamination, comparison standards included EPA National Emission Standards (for iodine, gross beta, strontium-90, and tritium; the limits are 4 millirems per year per person) and NESHAPs (for other emissions; the limits are 10 mrem/year/person).

[2.1] Reliable background samples include multiple samples taken in areas that (a) are not potentially affected by contaminants from SSFL and (b) have the same geological formation or soil type (in the case of soil background) as SSFL.

[2.2] Onsite and offsite water sources were used in the past for drinking water. Therefore, only MCLs meet the Applicable or Relevant and Appropriate Requirements (ARARs) for comparison with contaminant levels in groundwater.

The primary COPCs listed in Table 2-1 have been used, stored, or produced at the SSFL. Offsite monitoring studies[2.3] have revealed the presence of offsite contamination (Appendix H), suggesting that contaminants have migrated away from the SSFL area. Offsite contaminants that were detected above health-based standards include, but are not limited to, radionuclides (tritium, potassium-40, radium-226/-228, thorium-228/-232, plutonium-238, cesium-137), metals (lead, beryllium, manganese, chromium), aliphatic hydrocarbons (TCE, vinyl chloride, 1,1-DCE, 1,1-DCA, 1,2-DCE), aromatic compounds (PCBs, PCDD / PCDFs), and oxygenated organic compounds (perchlorate) (Appendix H).

Table 2-1. Contaminants (or Chemical Categories) of Concern: Potential Sources, Exposed Populations, Exposure Periods, and Pathway Elements

Source	Transport Medium	Chemicals of Potential Concern	Potentially Exposed Populations	Time[a]
Air stripping	Air	Radionuclides,[b] metals	Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, Sage Ranch, Simi Valley, Santa Susana Knolls, West Hills, Bell Canyon, Canoga Park	1987–present
Thermal treatment (burning)	Air	Hydrazines,[c] TCE, perchlorate, dioxins, dibenzofurans, beryllium, mixtures of fuels/explosives	Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, Sage Ranch, Simi Valley, Santa Susana Knolls, West Hills, Bell Canyon, Canoga Park	1958–1990
Spills/accidents/ volatilization	Air	Radionuclides, TCE, metals, hydrazines, perchlorate	Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, Sage Ranch, Simi Valley, Santa Susana Knolls, West Hills, Bell Canyon, Canoga Park	1948–present
Chemical storage (unlined ponds and spills) and NPDES outfalls	Groundwater (wells)	Radionuclides, TCE, metals, hydrazines, perchlorate, VOCS,[d] PCBs, dioxins, PAHs, furans	Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, Sage Ranch, Simi Valley, Santa Susana Knolls, Chatsworth, Ahmanson Ranch, Bell Canyon, West Hills, Canoga Park, Woolsey Canyon, Dayton Canyon	1948–present
Chemical storage (spills/leaks) and NPDES outfalls	Groundwater to surface water	Radionuclides, TCE, metals, hydrazines, perchlorate, VOCs, PCBs, dioxins, PAHs, furans	Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, Sage Ranch, Simi Valley, Santa Susana Knolls, Chatsworth, Bell Canyon, West Hills, Canoga Park, Woolsey Canyon, Dayton Canyon	1948–present
Chemical storage (spills/leaks), NPDES outfalls, air/water deposition	Surface soil/ sediment	Radionuclides, metals, PAHs, dioxins, PCBs, furans	Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, Sage Ranch, Bell Canyon, West Hills	1948–present

Notes:
a. Time period of chemical use and potential exposure to surrounding communities. **b.** Radionuclides emit alpha, beta, and gamma radiation. **c.** Hydrazines include mono-methyl hydrazine (MMH) and unsymmetrical dimethylhydrazine (UDMH) and transformation products (e.g., nitrosoamines). **d.** VOCs include, but are not limited to, carbon tetrachloride, chloroform, chloromethane, benzene, 1,1-DCA, 1,2-DCA, 1,1-DCE, 1,2-DCE, methylene chloride, tetrachloroethene, 1,1,1-TCA, TCE, trichlorofluororethane, toluene, and vinyl chloride.

[2.3] Boeing, 1990–2003, 2002; CA EPA, 2000; CDHS, 1999; EPA, 2000; GRC, 1990a, 1990b, 2000; Klinefelder, 2000; Lawrence Livermore National Lab, 1997; Masry and Vititoe, 1998; McLaren Hart, 1993; Ogden, 1995, 1998a; PSOMAS, 2003; Rocketdyne, NPDES Annual Reports (various years), 1995.

2.2 Identifying and Ranking Chemicals of Concern

The goal of contaminant ranking is to identify, among the many chemicals associated with SSFL, a subset of COPCs that are of primary concern. COPCs were initially ranked using the Scoring Chemicals and Ranking Assessment Model (SCRAM; Appendix M and Table 2-2).

SCRAM was developed to rank/order chemicals based on a composite score that considers physicochemical and toxicological parameters (Appendix M; Tables 2-3 and 2-4). SCRAM ranks chemicals based on their:

- Persistence in biota, soil, sediment, water, and air.
- Potential for bioaccumulation.
- Acute toxicity in terrestrial (plants, mammals, herps, birds, invertebrates) and aquatic (plants, amphibians, warm and cold water fish, invertebrates) environments.
- Subchronic/chronic toxicity in terrestrial and aquatic environments.
- Subchronic/chronic toxicity in humans (general, reproductive, developmental, carcinogenic, mutagenic, behavioral, immune, and endocrine effects).

The final score is a composite of the chemical and uncertainty scores. The latter is a numerical characterization of missing or substandard toxicological and physicochemical information. It is emphasized that ranking based on the SCRAM composite score is not a site-specific ranking: it depends only on chemical properties, not contaminant concentrations, the volume of chemicals present at the site, or emission rates. Therefore, the study team used site-specific factors to weight the SCRAM scores so as to arrive at a more relevant ranking for SSFL-associated COCs (Appendix M; Table 2-4). A number of different rankings that were evaluated in this study were derived (Appendix M) by weighting the SCRAM composite scores by:

- Air emissions estimates (for air contaminants).
- Air emissions estimates with respect to EPA inhalation reference concentrations (RfCs)[2.4] (for air contaminants).
- The number of NPDES water detections (for water contaminants).
- The maximum concentration detected in water or soil with respect to the health-based standards (MCLs for water and oral EPA reference doses, or RfDs, for soil contaminants).
- The number of positive offsite and onsite soil detections (for soil contaminants).

[2.4] An RfC is the estimated contaminant concentration in air (e.g., milligrams of pollutant per cubic meter of air) to at which continuous inhalation exposure over a lifetime is likely to be without risk (i.e., risk $<10^{-6}$) of deleterious effects, even for sensitive groups. The RfC is derived from various types of human or animal data, with uncertainty factors generally applied to reflect limitations of the data used. (See EPA, 2002. Review of the Reference Dose and Reference Concentration, Risk Assessment Forum, U.S. Environmental Protection Agency, Washington, DC 20460, EPA/630/P-02/002F.)

Table 2-2. Physicochemical and Toxicological Parameters$^{(a)}$ Used in SCRAM to Rank COPCs

Overview of Toxicological and Physicochemical Parameters	**Parameter Scales Used to Estimate Magnitudes**
Acute terrestrial and aquatic effects	LD_{50} or ED_{10}
Sub-chronic/chronic terrestrial effects	LOAEL or ≥ 90 day NOAEL
Sub-chronic/chronic aquatic effects	MATC, NOEC, or LOEC
Sub-chronic/chronic human effects	LOAEL or ≥ 90 day NOAEL
Carcinogenicity	$(1/ED_{10}) \times$ (weight of evidence)
Reproductive toxicity	RfD
Mutagenic effects	Potency/severity
Behavioral effects	Severity
Immune system effects	Severity
Endocrine effects	Potential
Persistence in biota, air, water, soil, or sediment	Degradation half-life ($t_{1/2}$) in the specific medium
Bioconcentration/bioaccumulation	BAF, BCF, , water solubility, log(Kow)

Notes: LD_{50}, LOAEL, NOAEL, MATC, ED_{10}, and RfD are toxicological parameters determined from controlled animal studies. An LD_{50} (lethal dose-50) is the average contaminant dose at which 50 percent of a test population will die. A LOAEL (lowest observed adverse effect level) is the lowest dose at which an adverse effect is first observed; a NOAEL (no observed adverse effect level) is the highest dose at which no adverse effect is observed. A MATC is a maximum acceptable toxicant concentration for freshwater organisms. A NOEC is the highest concentration with no observable effect. An ED_{10} (effective dose) is the estimated dose at which 10 percent of a study population develops adverse effects relative to the control response. A RfD (reference dose) is EPA's estimate of the daily chemical intake (by oral route) below which no appreciable risk (i.e., > 10^{-6} risk) is expected over a lifetime of exposure (70 years). The degradation half-life in a given environmental medium is the time it takes for the chemical concentration to decrease to one-half its initial value (in the medium) through degradation reactions. Kow is the octanol-water partition coefficient for the contaminant. BAF, the bioaccumulation factor, is the steady-state ratio of chemical concentration in the organisms to the chemical concentration in the external environmental phase, taking into account chemical intake via food ingestion. BCF is the bioconcentration factor defined as the ratio of the concentration of the chemical in the organism to that in the surrounding environmental phase.

The SCRAM ranking (R_{SCRAM}) for air contaminants, R_{Air}, was refined as below:

$$R_{Air} = R_{SCRAM} E/(I_{AIR} RfC) \qquad (1)$$

in which E is the estimated or reported emission rate (mg chemical/day), I_{air} is the inhalation rate (m^3 air/day), and RfC (mg pollutant/m^3 air) is the reference inhalation concentration. With the above ranking, chemicals with significantly low emissions or high concentration thresholds of concern (i.e., RfCs) would be ranked low. Conversely, chemicals with high emissions and low RfCs would be assigned a higher rank. The resulting ranking for air contaminants is provided in Table 2-3.

Two different refined SCRAM rankings of groundwater or surface water contaminants were developed. In the first approach the score was refined as

$$R_W = R_{SCRAM} N_{MCL} \tag{2}$$

in which R_w is the weighted score for either surface water or groundwater and N_{MCL} is the number of detections at concentrations above the MCL (Appendix M and Table 2-3). In the second approach the SCRAM score was refined as follows:

$$R_w = R_{SCRAM} \left(\frac{C_w^{\max}}{MCL} \right) \tag{3}$$

where MCL is the maximum contaminant level (mg/L) health standard and $C_w^{\max}$ is the maximum detected concentration (mg/L) for the chemical under consideration. The rankings based on the above two approaches (Eqs. 1 and 2) are provided in Tables 2-3 and 2-4. The rankings were limited by a lack of monitoring data and MCL standards for some of the chemicals associated with SSFL.

The SCRAM ranking for soil contaminants was refined as follows:

$$R_{soil} = R_{SCRAM} I_{soil} \left(\frac{C_{soil}^{\max}}{RfD} \right) \tag{4}$$

in which I_{soil} is the rate of soil intake (kg soil/kg body mass), $C_{soil}^{\max}$ is the maximum detected concentration of the specific chemical in soil (mg chemical/kg soil), and *RfD* is the chemical's oral reference dose (mg/kg body mass). The ranking of soil contaminants based on the above refinement of the SCRAM scores is provided in Table 2-4.

Contaminants of greatest concern in the air include, but are not limited to, hydrazine, TCE, methyl chloroform (1,1,1-TCA), methylene chloride, carbon tetrachloride, various aromatic hydrocarbons, and various metals. COCs in the water pathway include TCE and its various degradation products, perchlorate, various metals, and soluble organics. Contaminants of greatest concern in the soil are beryllium, arsenic, carbon tetrachloride, and chromium.

Note that bias in the refined relative rankings (Tables 2-3 to 2-5) could be introduced by infrequent or inadequate monitoring data, under-reporting of releases and emissions, use of non-sensitive detection methods, inadequate accounting of oxidation byproducts, and uncertainty or lack of health-based exposure concentration standards or reference dose for the COPCs. Nonetheless, the study team's approach (using multiple weighting methods) provides greater confidence that the list of site-specific COCs does not exclude chemicals for which monitoring was inadequate, emission estimates were not available, or standards have not been set.

Table 2-3. Refined SCRAM Ranking for Air and Water Contaminant (Based on Equations 1 and 2)

Rank	SCRAM-Ranked COPCs	Air Emission-Weighted COCs(a)	Water Detection-Weighted COCs (b)
1	PCB	Hydrazine	TCE
2	Mercury	1,1,1-TCA (methylchloroform)	Perchlorate
3	2,3,7,8-TCDD	TCE	Lead
4	Hydrazine	1,2-DCA	Chromium
5	Fluorene	Methylene chloride (dichloromethane)	Carbon tetrachloride
6	Toluene	Carbon tetrachloride	Mercury
7	TCE	Xylene	PCB
8	Benzene	Benzene	DEHP
9	Beryllium	Toluene	1,1-DCE (vinylidene chloride)
10	Bis(2-ethylhexyl)phthalate (DEHP)	Manganese	Benzene
11	n-Nitrosodimethylamine	Nickel	1,1-DCA
12	Perchlorate	Lead	1,2-DCA
13	Carbon tetrachloride, selenium	Cadmium	Toluene
14	1,1-DCA, 1,1-DCE	Selenium	Nickel
15	Arsenic, chromium, 1,2-DCA, cyanide, manganese	Arsenic	Tetrachloroethene
16	Chloroform, trans-1,2-DCE, cis-1,2-DCE, copper, nickel, vanadium	Vinyl chloride	Beryllium
17	Tetrachloroethene, cadmium	Beryllium	cis-1,2-DCE
18	Xylene, cobalt, vinyl chloride, methylene chloride, strontium	Mercury	Manganese
19	Lead, 1,1,1-TCA	Chromium	Trans-1,2-DCE
20	Diethylphthalate	PCBs	Vinyl chloride

(a) Adjusted SCRAM scores based on Eq. 1.
(b) Adjusted SCRAM scores based on Eq. 2.

Table 2-4. Refined SCRAM Scores for Soil and Water Contaminants Based on Health-Based Standards and Equations 3 and 4

Weighted Rankings	Offsite		Onsite	
	Water Contaminants (MCL-Weighted Rankings)(a)	Soil Contaminants (Oral RfD-Weighted Rankings)(b)	Water Contaminants (MCL-Weighted Rankings) (a)	Soil Contaminants (Oral RfD-Weighted Rankings) (b)
1	TCE	Beryllium	TCE	Carbon tetrachloride
2	Vinyl chloride	Arsenic	Lead	Chromium (total)
3	DEHP		Chromium	Pentachlorophenol
4	Lead		Carbon tetrachloride	Arsenic
5	Carbon tetrachloride		1,2-DCA	Toluene
6	Manganese		Vanadium	1,2-Dichlorobenzene
7	Benzene		Perchlorate	1,2-Dichlorobenzene
8	1,2-DCE		Manganese	Ethylbenzene
9	Chromium (total)		1,1-DCA	
10	Perchlorate		Mercury	
11	Beryllium		1,2-DCE	
12	Nickel		Benzene	
13	1,1-DCA		Silver	

(a) Refined SCRAM scores based on maximum detected concentration with respect to MCLs (Eq. 3)
(b) Refined SCRAM scores based on maximum detected soil concentration and oral RfDs (Eq. 4).

Table 2-5. SSFL Phase-Specific Chemicals of Concern

Air	Water	Water and Air	Water, Air, and Soil
Hydrazine 1,1,1-TCA Methylene chloride Xylene Selenium Cadmium	Perchlorate 1,1-DCE cis-1,2-DCE trans-1,2-DCE 1,1-DCA DEHP Chloromethane	Vinyl chloride Benzene Cadmium Manganese Nickel NDMA	TCE 1,2-DCA Beryllium Carbon tetrachloride Tetrachloroethene Lead Chromium Arsenic

2.3 Radionuclides[2.5] of Concern

Monitoring data,[2.6] site activity reports,[2.7] and other documents were used to assess radionuclides of concern. Table 2-6 summarizes the categories and corresponding numbers of reports used in this study.

Table 2-6. Category of Reports/Documents and Sources of Information for Radionuclides

Report/Document Category	Number of Reports/ Documents	Source of Information	Number of Reports/ Documents
Epidemiologic studies	2	Atomics International	2
Monitoring surveys ('59–'02)	30	Committee to Bridge the Gap	1
Inspection reports	10	Fireman reports	1
Accident reports	3	U.S. Environmental Protection Agency	3
Emission estimation reports	3	California Department of Health Services	5
Closure reports	4	U.S. Department of Energy	11
Risk assessments	1	Rocketdyne/Boeing	16
		Various consulting firms	19
		UCLA	2
		Ventura County Air Pollution Control District	1

Radionuclides were used at SSFL between 1955 and 1996. (The NRC reactor license was terminated on September 27, 1996, and the facility was transferred to DOE for decontamination and decommissioning.) Operations at SSFL that may generated radioactive waste, discharged effluents, or emitted chemicals into the air included nuclear power generation activities, experiments using radionuclides, decladding of irradiated nuclear fuels, examination of reactor components, and decontamination and decommissioning activities. According to various archived documents, all radionuclide operations were conducted at the Energy Technology Engineering Center (ETEC) located in Area IV. This area included the

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[2.5] Many naturally occurring and a few manmade chemicals can emit ionizing radiation and are, therefore, referred to as radioactive. For the sake of simplicity, radioactive materials can be grouped into alpha, beta, and photon emitters, depending on the particles or energy that they emit.

[2.6] Monitoring data include yearly reports by Atomics International (AI), Rockwell, and Boeing from 1955 to the present. Monitoring data for radionuclides are primarily reported in terms of alpha and beta levels. The gross alpha and beta measures allow screening of nearly all known radioactive materials without chemical speciation.

[2.7] AI, 1960, 1962; Committee to Bridge the Gap, undated; Dempsey, 1990, 1997; DHS, 1988a, 1989a, 1989b, 1991, 1999; DHS, 1989 a and b; DOE, 1989, various years; EG&G, 1979; EE, 1989; EPA, 1989a; ETEC, 1987; GRC, 1990a, 1990b, 1990c; Hart, 1962; Hughes, 1989; ICF Kaiser, 1993, 1995; ITC, 1999; Klinefelder, 2000; Lawrence Livermore National Lab, 1997; McLaren/Hart, 1993, 1995; Morgenstern, 1997, 2001; Oak Ridge Associated Univ., 1986; Oak Ridge Institute, 1997; Oldenkamp, 1991; Ogden, 1995, 1998a; Police and Fireman's Benefit Society Report, 1961; Robinson, 1998; Rocketdyne, 1991, 1996; Rockwell, 1987; Rutherford, 1994, 1999; Tuttle, 1992; V.C.A.P.D, 1989.

Systems for Nuclear Auxiliary Power, or SNAP (building T059); the Hot Lab; the Sodium Reactor Experiment Complex, or SRE; the former Sodium Disposal Facility, or SDF (building T886); the Radioactive Materials Disposal Facility, or RMDF; the Old Conservation Yard; and associated disposal ponds (Western, Lower and Upper).

A comprehensive assessment of radionuclide use and contamination was not possible due to the lack of historical radionuclide activity reports, breakdown of radionuclide monitors during accidental leaks, lack of air monitoring, faulty sediment monitoring procedures,[2.8] and inadequate offsite assessment and ongoing onsite assessment[2.9] of radionuclide contamination and delineation. These limitations prevent a quantitative assessment of past exposures. Irrespective of the lack of sufficient monitoring, the available data do suggest that radionuclides have been detected off site and that there has been migration of radionuclides (Appendix H).

Various studies concerning the presence of radionuclides on site and off site are consistent with the general conclusion that radionuclides from Area IV have migrated to offsite areas. Radionuclides have washed down from Area IV onto what was part of the Brandeis-Bardin Institute (BBI) property,[2.10] located north of Area IV (McLaren/Hart, 1993; 1995). Strontium-90 and tritium were detected in BBI soils at concentrations above background levels; plutonium-238 and cesium-137 were detected in BBI soils above background levels and health-based standards,[2.11] and radium-226/-228 and strontium-90 were detected in northwest NPDES surface water releases above MCLs (McLaren Hart, 1993, 1995; Rockwell, 1987). Potassium-40, thorium-228/-232, and tritium were detected in Bell Canyon soils above health-based standards (Ogden, 1998). Cesium-137, potassium-40, and thorium-228/-232 were detected in Ahmanson Ranch soils above health-based standards (Klinefelder, 2000). Cesium-137 was detected above health-based standards in Canoga Park soils (Lawrence Livermore National Lab, 1997).

In June and July of 1978, radiological surveys were conducted of the Rockwell International Facilities in Canoga Park and at the SSF (EG&G, 1979). Gamma emitters were not detected above background levels in surface water channels originating from the property. Given that the half-life for certain gamma emitters is relatively short (e.g., cobalt 60 has a ~5.3 day half-life), such sort-lived radionuclides would have decayed long before the above monitoring. It is also noted that monitoring for Uranium 233, -234, -235, and -238 was limited to Bell Canyon. In these areas levels did not exceed health-based standards or conservative background levels (Odgen, 1998).

In summary, given the radionuclides emitted from onsite activities, monitoring studies, radionuclide toxicities, offsite distributions and lifetimes, the primary radionuclides of concern were strontium-90, plutonium-238, cesium-137, tritium, radium-226/-228, potassium-40, and thorium-228/-232.

[2.8] Offsite areas have had limited sampling and radiological characterization of surface water owing, in part, to the intermittent surface water flows from the SSFL.

[2.9] DOE (June 3, 2004) announced the detection of tritium in groundwater under Area IV. The extent of this contamination is still being delineated.

[2.10] This area was purchased by Rocketdyne and is now part of the SSFL buffer zone.

[2.11] RESRAD 6.1 (ANL2001)–Soil Guidelines for Resident Farmer (most conservative) or DHS-based standards for soil.

CHAPTER 3. AIR PATHWAY ANALYSIS

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3.0 AIR PATHWAY ANALYSIS

3.1 Overview: Availability of Information and Investigative Rationale

SSFL is located within the South Coast Air Quality Management District (SCAQMD). Air pollution controls and permits at SSFL are regulated by the Ventura County Air Pollution Control District (VCAPCD). Facilities with permits regulated by VCAPCD include conventional combustion units, a coal gasification unit, the sodium heaters, the low nitrous and sulfurous oxide combustor, and the sodium burn facility. There were some non-permitted facilities (which do not require permits), such as the solid propellant area, the propellant research area, the combustion heat transfer laboratory, the engineering chemistry lab, the continuous wave laser lab, and the coca-delta fuel farm. Various SSFL activities since the commencement of operations at the facility have resulted in releases of air toxics into the atmosphere. Such emissions include both accidental releases and chronic releases—that is, releases that happened in the course of SSFL facilities' routine operations.

Except for accounts of accidental TCE releases (CH2M Hill, 1993), Rocketdyne has compiled no historical accident accounts (e.g., of tank ruptures). It also appears there has been no monitoring of offsite chemical concentrations or estimates via dispersion modeling; if such information exists, it has not been made available to the UCLA study team (Lafflam, 1989; ICF Kaiser, 1993). No air monitoring data were found for hydrazines, which is surprising considering how often hydrazines are used. Both EPA and DOE expressed concern about inadequate air sampling on site and off site, and about the lack of onsite meteorological data for most of SSFL's years of operation (EPA, 1989a; DOE, 1989, 1990). Extensive review of SSFL-related documents revealed that there are incomplete records of emissions during years of intensive rocket testing (Section 3.2, Appendix S).

Air monitoring data for chemicals of concern were not available for the offsite areas surrounding SSFL. Therefore, potential exposures associated with SSFL were assessed through analysis. In this analysis, air toxic chemicals of potential concern (COPCs) were identified (Appendix C), archived documents were reviewed and various EPA approved analysis methods were employed to estimate the significant toxic air emissions from SSFL activities (Section 3.2, Appendices S and T), and air dispersion simulations were carried out to estimate the concentration field of contaminants emitted from SSFL as illustrated in this Chapter (see also Appendix I). As expected, higher outdoor air toxic concentrations were encountered to the northeast and southwest of SSFL emissions. Outdoor air toxic concentrations decreased with distance downwind from the SSFL. The concentration field data obtained using the above analysis was combined with standard exposure analysis (Chapter 6) to assess the potential for adverse exposure levels to SSFL released air toxics (see also, Appendix T).

3.2 SSFL Air Emissions

3.2.1 Rocket Engine Tests (1948 to Present)

Rocket engine testing, or RET—shown in Figure 3-1—began at SSFL in 1948 (ATSDR, 1999). Between 1953 and 1961 over 8,000 tests on rocket engines were completed, many related to the early space missions. During the 1970s and 1980s, the site was primarily used to test engines for the NASA space shuttle program, with declining numbers of tests since the 1990s. Fuels combusted at SSFL during these tests include beryllium, ethanol, hydrazine and derivatives, hydrogen, isopropyl alcohol, combinations of kerosene and liquid oxygen, as well as nitrogen tetroxide (NTO) and pentaborane (Appendix S.) Rocket test firing over the operating history of the facility routinely released products of combustion of rocket engine fuels into the atmosphere: carbon dioxide, carbon monoxide, hydrogen gas, hydrogen chloride, nitrogen gas, nitrous oxide, chlorine, metallic oxide particulates (e.g., aluminum oxide), soot, organic compounds (e.g., polyaromatic hydrocarbons, or PAHs), and volatile organic compounds (VOCs). In addition to combustion products, release of air contaminants may have resulted from activities such as accidental spills, venting after tests, cryogenic boil-off, metal plating, fuel storage and distribution, painting, and degreasing.

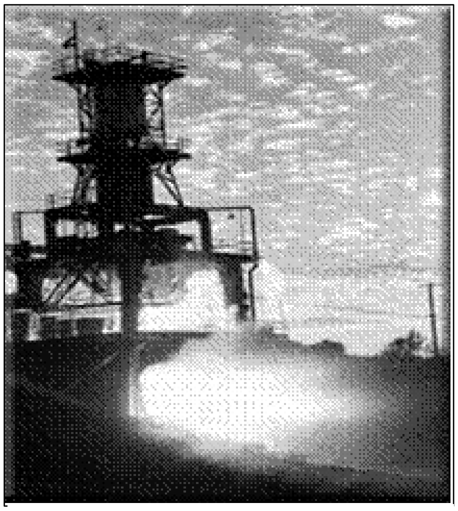


Figure 3-1. Photograph of a Rocket Engine Test.

In the early days of RET, rocket fuels contained high levels of beryllium. Particles of beryllium were released to the air and deposited onto soil around the facility. Rockwell states that onsite beryllium-containing solids were removed from SSFL after the use of beryllium-containing fuels was discontinued (Ecology and Environment, 1991). It is noted, however, that there are monitoring data (Ogden, 1998a) indicating that beryllium may still be in soil and thus could be of an exposure concern (Ogden, 1998a; Appendix H).

3.2.2 Evaporative Emissions of Trichloroethene and Other Toxic Organics

TCE has been used at the SSFL site to flush rocket engines during degreasing (Sullivan, 1999). TCE was applied to flush rocket engines of residual fuel before and after each test. Analysis of records (CH2M Hill, 1993) suggests that typically 50 to 100 gallons of TCE were applied per engine flush. TCE was emitted to the air when this liquid evaporated.

Evaporative emissions associated with the use of TCE as a cleaning solvent in an open environment would be expected to result in significant emissions. Note that a significant percentage of the TCE produced in the United States has been used for metal degreasing, and that evaporation from degreasing is responsible for a significant percentage of the TCE released to the air. The EPA (1997, 2001a) emissions inventory program reveals that, of the total TCE solvent used in the United States, about 25% is released as fugitive emissions. Fugitive emissions associated with equipment cleaning can reach as high as 50% to 95% of the TCE used in such applications.

In addition to degreasing activities, TCE and other toxic organic air emissions (e.g., methyl chloroform, or TCA) resulted from storage tank breathing losses, emissions associated with laboratory activities, and removal from groundwater by (ST) operation (see Section 3.2.5; Rockwell International, 1994; Melvold, 1994). SSFL reportedly has had a capture system for liquid TCE spills since around 1960, but this system was reportedly unreliable (Hargis and Associates, 1985).

3.2.3 Thermal Treatment Facility (1958 to Present)

SSFL employed open-pit burning, referred to as the thermal treatment facility (TTF), to dispose of waste in Area I. The TTF was operational from 1958, destroying explosive, reactive, and ignitable wastes. Wastes sent to the TTF included ammonium perchlorate. The limited written records made available show that the TTF was periodically active for 24 to 48 hours per month every month in 1959 and 1960. Hydrocarbon disposal by open burning was prohibited by Ventura County Air Pollution Control District in 1969. However, Rocketdyne regularly applied for permission to use the burn pit with reduced volumes of waste. In 1980, the facility was permitted as a waste pile (ATSDR, 1999). Mixtures of fuels, solvents, water, and other materials were routinely burned at the burn pit (Rockwell International, 1992a; GRC, 1993; Rocketdyne, 1959–1989 [Annual Site Environmental Reports], 1959, 1960 [inter-office letters]). Among the chemicals burned at the TTF were hydrazine and hydrazine compounds, sodium pentaborane, kerosene-based fuels (e.g., RP-1, JP-4), lithium powder, nitrogen tetroxide, waste oils, TCE, solid propellants (with perchlorate as an oxidizer), chlorine trifluoride, and alcohol mixtures (Rocketdyne, 1958-1960; Rockwell International, 1992a; GRC, 1993). Disposal records indicate that burning or venting of waste materials at the TTF was conducted by the SSFL fire department, which developed and observed the disposal protocols (Rocketdyne, 1958-1960).

In 1982, the burn pit was cleaned under the Ventura County Department of Health Services' (DHS) authority (DHS, 1991). The county DHS rescinded permission for open-pit burning disposal in November 1990, after discovering logs documenting destruction of volumes of waste larger than permitted (DHS, 1991)—specifically, a slurry containing solvents and fuel. (The logs inspected by Ventura County DHS dated to April 5, May 17, and September 26, 1990; the daily limit exceeded was 5 pounds for flammable liquids.) This waste consisted of 0.6 pounds of slurry waste; 61.4 pounds of acetone, ethanol, and ethyl acetate; 27 pounds of explosives and flammable solvent mixture; and 5.14 pounds of solid explosives on the same day (April 15, 1990).

3.2.4 Stripping Towers

Carbon-adsorption/air-stripping towers are used to treat contaminated groundwater as a part of the onsite groundwater extraction and treatment program. The treatment system includes six packed tower aeration systems (at five locations) with vapor phase carbon treatment and two ultraviolet/hydrogen peroxide units. Air stripping systems were located at water supply well 9A (Delta area, Area II; 200 gallons per minute), deep well RD-1 (Happy Valley, Area I), water supply well 6 behind Alpha (Area IV; 400 gallons per minute), water supply well 9 (Bravo Area, Road I, Area I; two towers), and the Systems Test Laboratory IV (STL IV, Area II). The strippers' capacities were 40 gallons per minute except where noted (Techlaw, 1990). Permits for the operation of the strippers were limited to yearly emissions of 0.5 tons per year of reactive organics. It is noted that the VCAPCD reported that no TCE was detectable in the air stream effluent from these towers (VCAPCD, 1989). However, the UCLA study team did not receive documentation of the effectiveness of stripping treatment and the associated impact on groundwater remediation.

3.2.5 Emission of Radionuclides

Radionuclide emissions came from three sources in Area IV of SSFL: the Radioactive Material Disposal Facility (RMDF), the Hot Laboratory (HL), and the Nuclear Materials Development Facility (NMDF). The RMDF consists of several buildings where radioactive wastes are decontaminated and packaged for offsite disposal. The HL was used principally to examine and prepare radioactive waste for reprocessing. It was licensed by the Nuclear Regulatory Commission (NRC) under Special Nuclear Materials License SNM-21 and continued to work with irradiated nuclear fuels until 1988. The NMDF was constructed for research and production work involving highly radioactive fuels. It was also licensed by the NRC, but the license was rescinded after the facility was shut down in 1986 (DOE, 1989). Emissions of radioactive particulates at the three facilities were controlled by high-efficiency particulate air (HEPA) filters. There is a community concern that there may have been accidental radioactive air emissions (Appendix E).

3.2.6 Chemical Emission Estimates

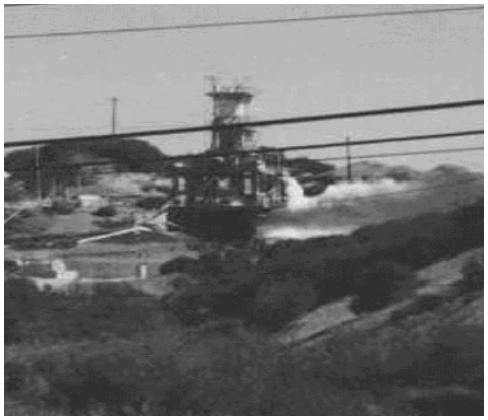
To estimate emissions of toxic organic and toxic metal air emissions over the span of SSFL's operations, the audit team developed an air toxic emission inventory by:

- Reviewing documents detailing SSFL activities involving air toxics and associated emissions of specific hazardous air pollutants (HAPs).
- Estimating an air toxic emission inventory for each source of relevant HAPs at SSFL.
- Allocating total air toxic emissions by source activity as a function of time (from the late 1940s to the present).

EPA lists 188 pollutants or chemical groups as HAPs, commonly referred to as "air toxics," that cause or are suspected of causing cancer or other serious human health effects. HAPs are emitted from thousands of sources, such as electric power utilities and industrial manufacturers, dry cleaners and gasoline service stations, and automobiles and airplanes. As shown in Figure 3-2, some of these sources are localized at individual facilities (e.g., RET), while others are ubiquitous (e.g., located at sites scattered throughout urbanized communities).

Major questions addressed in this part of the study were: What level of toxic emissions occurred over the life of this facility? What is the history of emissions at the facility? What are the most significant sources (in terms of annual release) of toxic air emissions? To guide the estimation of HAP emissions from the SSFL facility, the study team visited SSFL several times to personally observe source activity, requested available HAP air emissions information from SSFL staff, and conducted a literature review to identify and obtain other sources of SSFL emissions data. (See Appendix S for a complete emission inventory.) Information requested from SSFL included specific reports on activities identified through the literature review. A number of relevant prior studies have been identified as sources of useful information on potential emission sources and emission rates (CH2M Hill, 1993; ABB Environmental Services, Inc., 1992; Rockwell International, 1992a, 1992b; Rocketdyne, 1960).

Figure 3-2. HAP Emissions from SSFL Activities (Left) and Urban Settings (Right)



The study team identified four potentially significant sources of toxic organic and toxic heavy metal air emissions: (1) rocket engine exhaust; (2) pre- and post-degreasing of rocket engines; (3) storage tanks, STs, and other evaporative sources of toxic organic emissions; and (4) open-pit burning of waste material. The team then estimated emissions of 18 chemicals (listed in Table 3-1) by cross-referencing information about emission source types at the SSFL and the EPA HAP list (again, see Appendix S).

Table 3-1. Chemicals Analyzed for Emissions

Organics	Metals
Benzene	Arsenic
1,3-butadiene	Beryllium
Hydrazine[a]	Cadmium
TCA—methyl chloroform	Chromium
TCE—trichloroethylene	Lead
Toluene	Manganese
Xylene	Mercury
	Nickel
	Selenium
	Copper
	Zinc

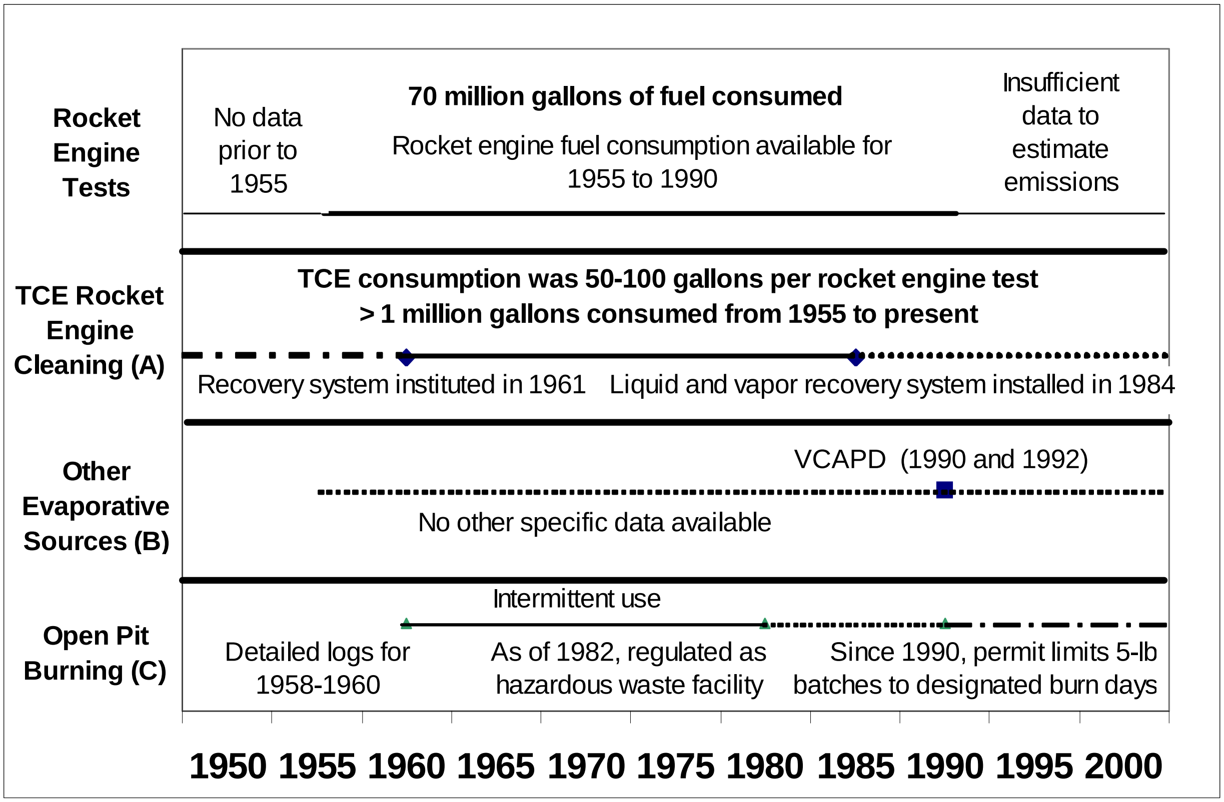
[a] The hydrazine derivatives monomethyl hydrazine (MMH) and unsymmetrical dimethylhydrazine (UDMH) were also combusted during rocket engine testing in the rocket engine testing areas.

3.2.7 Summary of Emission Estimates

The study team estimated toxic organic and toxic heavy metal air emissions, from the four sources mentioned above (Section 3.2.6), for the late 1940s to the present (Appendix S). Emissions from most activities at SSFL were intermittent and have varied over time as a consequence of the changing level of activity at the facility, the introduction of control measures, and permit restrictions.

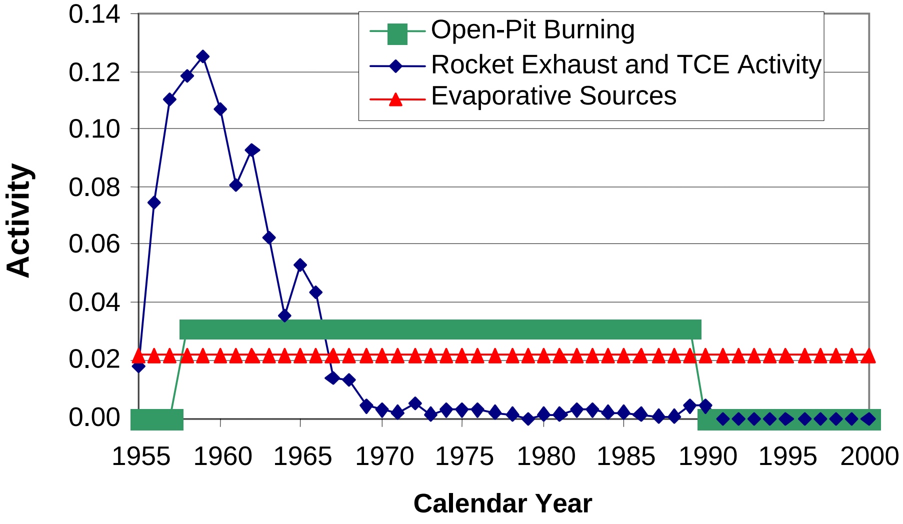
The majority (88%) of rocket exhaust emissions occurred from 1955 to 1965 (Figure 3-3). Open pit burning activity was assumed uniform from 1959 through 1989. From 1955 to 1990, cumulative toxic organic and metal emissions were about 4775 tons (including hydrazine derivatives) and 9 tons, respectively. The largest source of toxic metal emissions is rocket engine exhaust. Evaporated TCE from the cleaning of rocket engines were the largest source of toxic organic emissions to the air (Figure 3-4). Other evaporative sources (Figure 3-4) constituted the second largest source.

Figure 3-3. Timeline of Available Activity Reports for SSFL



(A) Estimated to be the largest source of HAP air emissions.
(B) Estimated to be the second largest source of HAP air emissions.
(C) Not estimated to be a significant source of HAP air emissions.

Figure 3-4. History of Emissions Activity from Selected Source Types at SSFL as a Percent of Total Lifetime Activity



The available data (Appendix S) suggest that, on a weight basis, liquid kerosene was the fuel most often combusted in RET (more than 60%) from 1955 to 1990 (Table 3-2). The second most common fuel used at SSFL was liquid hydrogen (35%). Combustion of lesser amounts of isopropyl alcohol (1.4%), hydrazine derivatives (0.5%), and pentaborane fuel (0.006%) also took place. Analysis of the available fuel use data revealed that the vast majority (more than 80%) of fuel use took place before 1970; 80% of kerosene fuel use took place from 1956 through 1969, 80% of unsymmetrical dimethylhydrazine use took place between 1956 and 1965, and 96% of pentaborane use took place in 1963. The study team could not obtain fuel use data for 1948 to 1954, or for the years after 1990. Therefore, air toxic emissions resulting from fuel combustion from 1948 to 1954 and 1991 to the present could not be reliably estimated. The available documents on rocket testing at SSFL (Sullivan, 1999) did not contain fuel use data for periods before 1955 or beyond 1990. However, a review by ATSDR suggests that ethanol, kerosene, and hydrazine fuels were combusted in engines before 1955 and ethanol, kerosene, and MMH (hydrazine derivative) fuels were combusted in engines after 1990 (ATSDR, 1999; Appendix S).

Table 3-2. Reported Fuel Use at SSFL from 1955 to 1990

Fuel Name	**Tons**
Kerosene	173435
Liquid hydrogen	98351
Isopropyl alcohol	3765
Hydrazine and derivatives	1491
Pentaborane	16

Source: Sullivan, 1999. No data were reported for beryllium, ethanol, or any fuels from 1948 to 1954 and after 1990.

Review of SSFL documents indicates that RET at SSFL (Appendix S) has taken place at least 10 different locations; as mentioned above, there were STs in six locations and one TTF (which consisted of an open-pit burning area). Waste generated from the North American Kindleberger

Atwood Laboratory, or NAKA (in Area I, like the TTF) was sent to the TTF from 1958 to as late as 1992 (Rockwell International, 1992a). Waste generated at NAKA included HMX, RDX, nitrocellulose, nitroglycerin, and ammonium perchlorate. Other wastes sent to Area I TTF were "strong oxidizers," hypergolic propellants (i.e., chlorine pentafluoride, tetrafluorohydrazine, and "limited quantities" of solvents and kerosene (Rockwell International, 1992). Surface water from Area I TTF can run off into the Perimeter Pond, which is part of SSFL's reclaimed water system. It is noted that, during rainfall events, the Perimeter Pond overflows into NPDES Outfalls 001 and 002 to the south of the facility, which in turn is discharged into Bell Canyon Creek (Rockwell International, 1992a).

For air dispersion modeling purposes, the study team grouped these sources into eight RET sources (modeled as either point or area sources), six ST sources, and one TTF source. These 15 consolidated sources are summarized in Table 3-3.

Table 3-3. SSFL Emissions Sources Used in Dispersion Modeling

No.	Type	Name	SSFL Area	UTMX (m)	UTMY (m)	Point Source	Area Source
1	RET	Delta (1A, 1B, 2A, 3A, 3B)	II	343125	3788455	✓	✓
2	RET	Coca (1, 2, 3)	II	343681	3788486	✓	✓
3	RET	Bowl (PS1, VTS1, VTS2, VTS3, HTS)	I	345095	3788775	✓	✓
4	RET	Canyon	I	345383	3789055	✓	✓
5	RET	STL-IV	III	342488	3788771	✓	✓
6	RET	Bravo (1A, 1B, 2, 3)	II	343585	3789120	✓	✓
7	RET	Alfa (1, 2, 3)	II	344080	3789328	✓	✓
8	RET	APTF	I	345421	3789369	✓	✓
9	ST	Delta	II	342706	3788351	✓	
10	ST	Happy Valley	I	345509	3789109	✓	
11	ST	Alfa	I	344158	3789213	✓	
12	ST	Bravo	II	343516	3789050	✓	
13	ST	Area I Road	I	345292	3789159	✓	
14	ST	STL IV	III	342651	3788841	✓	
15	TTF	TTF	I	344318	3788324	✓	

Details of the emissions estimated from RET are summarized in Appendix S1, and estimates of TCE emission associated with engine cleaning are provided in Appendix S2. Other evaporative sources of toxic organic emissions, such as storage tanks and stripping towers, were also assessed to estimate levels of relevant air emissions (Appendix S3). Details of emissions from the TTF are provided in Appendix S4.

Table 3-4 summarizes the major cumulative air emissions of organic chemicals and metals for 1955 through 1990. TCE air releases from engine flushes are estimated to amount to about 67% of the total toxic organic emissions and about 80% of the total TCE emissions. Other evaporative losses represent about 30.5% of the total toxic organic emissions. The organics with the highest specific compound emissions in this category are TCA and TCE (46% and 54%, respectively, of the total). Emissions from RET and the TTF accounted for 2% and 0.5%, respectively, of the total emissions of toxic organics; the major compounds released were benzene, hydrazine and hydrazine derivatives, 1,3-butadiene, toluene, and xylene. The most significant source of heavy metal emissions is kerosene rocket engine tests, with zinc, copper, and manganese constituting the largest fraction of metal emissions.

Table 3-4. Cumulative 1955–1990 Toxic Organic and Heavy Metal Emissions (Tons)

Pollutant	Kerosene Rocket Engine Tests	Hydrazine and Solid Rocket Engine Tests	TCE Engine Flushes	Other Evaporative Activities	Thermal Treatment Facility	Total
Toxic organic	**95.0**	**2.3**	**3,196**	**1,457**	**25**	**4,775**
Benzene	54.0				2.72	56.7
1,3-butadiene	18.0					18.0
Chloroform	0.04					0.04
Vinylidene chloride	0.01 (ND)					0.01 (ND)
Methylene chloride	0.01 (ND)					0.01 (ND)
Hydrazine/UDMH/MMH		2.3			20.4	22.7
Toluene	14.0				2.72	16.7
TCA				673		673
Trichloroethylene[(a)] (TCE)	0.36		3,196	784		3,980
Vinyl chloride	0.01 (ND)					0.01 (ND)
Xylene (total)	9.0					9.0
Heavy Metals	**9.2**	**0.0**				**9.2**
Arsenic	0.03 (ND)					0.03 (ND)
Beryllium	0.06 (ND)	0.0004				0.06 (ND)
Cadmium	0.17					0.17
Chromium (total)	0.24					0.24
Chromium (hexavalent)	0.05 (ND)					0.05 (ND)
Copper	3.1					3.1
Lead	0.03					0.03
Manganese	1.0					1.0
Mercury	0.02					0.02
Nickel	0.6					0.6
Selenium	0.03 (ND)					0.03 (ND)
Zinc	3.9					3.9

(a) TCE emissions from the subsurface are discussed in Section 5.0.

As mentioned above, the vast majority of rocket fuel use occurred from 1955 to 1969, and TCE engine cleaning activity was similar to rocket exhaust activity. The use of TCE for cleaning of rocket engines was the largest source of toxic organic emissions to the air. The second largest source was other evaporative sources (stripping towers, degreasing activities, storage tank breathing losses, chemical fume hoods). The largest source of toxic metal emissions was rocket engine exhaust.

The emission inventory developed in the present study provides a reasonable framework for assessing the magnitude of chemical emissions from SSFL. Such information was used to evaluate potential hot spots of exposure in the areas surrounding SSFL (Chapter 6). It is important to recognize that the analysis was based on incomplete reporting of chemical usage, site activities, accidental discharges, and emissions. For example, SSFL hydrazine and beryllium rocket engine emission measurement tests are believed to be insufficient to accurately characterize emissions and thus emissions were estimated from fuel combustion information. Air toxic emissions from fuel combustion of ethanol and isopropyl alcohol were not available and thus not included in the emission inventory. Information on accidental spills was inadequate and therefore emissions due to accidental spills of TCE, for 1955 though 1974, were estimated by data extrapolation. Annual emissions of TCA from 1955 to 1990 were assumed to be equal to that reported for 1990. No data were available from which to estimate emissions from RET before 1955 and after 1990, even though testing did occur during these periods. Finally, radioactive releases were not estimated due to lack of data; radioactive contamination was assessed based on available monitoring data.

3.2.8 SSFL Air Toxic Emissions, 1990 Through 2002

Rocketdyne provided a series of Toxic Release Inventory documents detailing estimate emissions of toxic metals and organics for 1990, 1992, and 2003, as well as parts of 1994 and 1997 (Rocketdyne, 1992, 1994a–c, 1997, 1998, 1999c, 1999d, 2003). A summary of the emission inventory data is provided in Table 3-5. Analysis of toxic metal emissions from 1990 and 2002 reveals the following:

- The annual toxic metal emissions declined over the 1990–2002 period from 9.7 to 2 pounds (about a 79% decline). Note that Rocketdyne applied lower emission factors in estimating the 1990 inventory than for the 2002 inventory, so the actual change in toxic metal emissions over the 1990–2002 period remains uncertain.

- From 1990 to 1992, total annual toxic organic emissions declined by about 10% (from 44,785 to 40,838 pounds per year); from 1990 to 2002, total annual toxic organic emissions declined by about 98.5%. This suggests a linear decline in emissions between 1990 and 2002. Four chemicals (TCA, glycol ether, methanol, and methylene chloride) accounted for 84% of the total 1990 organic emissions. TCA accounted for 75% and 62% of the air toxic organic inventory for 1990 and 1992, respectively, while there were no reported emissions in 2002. Glycol ether and methanol emissions for 1990 were reported as 1184 and 1578 pounds, respectively, with no emissions reported for 1992 and 2002. Methylene chloride emissions were 1732 and 1072 pounds for 1990 and 1992, respectively, with no emissions reported for 2002.

- Similarly, hydrogen fluoride (an inorganic species) emissions were reported in 1990 and 1992 but not in 2002. It is noted that cyclohexane was not emitted in 1990 or 1992, but was emitted in 2002. The reasons for the unexpected presence of cyclohexane in the 2002 inventory and the absence of hydrogen fluoride and methylene chloride emissions from the 2002 inventory have not been provided to the UCLA team.

The partial inventory data for 1994–1997 revealed that 1994 was the year in which TCE usage as a degreaser in RET was reportedly terminated. In the 1997 inventory, also partial, ammonia was the largest reported source of toxic inorganic and organic emissions (99.6%). Benzene and formaldehyde were not emitted in 1997, though emissions were reported for these two compounds in 1990 and 1992. It is also noted that the toxic emission inventory data reported for the 1990–2002 period are incomplete, and the reliability of the data is of concern given apparent inconsistencies that are not addressed in the Rocketdyne inventory documents.

Table 3-5. SSFL Air Toxics Emission Inventory from 1990 to the Present

Chemical	**Emissions (lb/yr)**												
	Total 1990	**Other 1990**	**RET 1990**	**Total 1992**	**Other 1992**	**RET 1992**	**1994**	**Add'l 1997**	**Total 2002**	**Other 2002**	**Alfa 2002**	**Bravo 2002**	**APTF 2002**
1,2,4-Trimethylbenzene										10			
1,3-butadiene	172		172	76		76		0	15	11	3.6400	0.63400	0.0057900
Acetaldehyde				36	1	34		2	1		1.2200	0.22100	0.0019400
Acetone				1030	1030				0				
Acrolein								0		1			
Ammonia				549	549			12074					
Benzene	568	49	519	141	92	49		0	65	52	11.0000	1.90000	0.0175000
Carbon tetrachloride	305	305		0	0				2	2			
Chloroform	58	58		1		1			0		0.0081	0.00140	0.0000129
CFC-113									0				
Cyclohexane				0	0			4	207	207			
Ethylene dichloride	526	526											
Formaldehyde	309	2	307	72	36	36		1	41	33	6.3800	1.10000	0.0101000
Gasoline vapors	228	228											
Glycol ethers	1184	1184		0	0			5	0				
Hydrogen fluoride	29	29		35	35				0				
Isoproply alcohol				3851	3851				349	349			
Methanol	1578	1578						5					
Methylene chloride	1732	1732		1072	1072				0		0.0025	0.00040	0.0000040
PAH				213	213			0	0				
Phenol	1051		1051	91	91				21		17.7000	3.08000	0.0282000
sec-butryl alcohol				536	536				0	0			
TCA	37399	37399		25467	25467				0				
TCE	4305	1497	2808	7756	7756		0		0		0.0735	0.01280	0.0001170
Toluene	261	129	132	72	59	13		13	3		2.7800	0.48600	0.0044200
Xylene	159	70	89	50	50			15	2		1.8600	0.32300	0.0029600
Vinylidene chloride				0	0	0			0		0.0024	0.00042	0.0000038
Vinyl chloride					0				0		0.0025	0.00043	0.0000039
Total	49864	44785	5078	41047	40838	210	0	12117	719	666	44.6690	7.75944	0.0710516
Arsenic			1.7E-02						4.E-03		0.0040	0.00004	0.0000063
Beryllium			3.2E-02						7.E-03		0.0066	0.00042	0.0000106
Cadmium			1.1E-01						3.E-02		0.0342	0.00005	0.0000544
Chromium			1.5E-01						1.E-03	5.1E-04	0.0004	0.00004	0.0000007
Copper			1.7E+00						6.E-01		0.5990	0.00004	0.0009520
Lead			2.3E-01						6.E-01		0.5990	0.00042	0.0009520
Manganese			6.2E-01						2.E-01		0.1920	0.00085	0.0003040
Mercury			2.5E-02						3.E-03		0.0034	0.00003	0.0000054
Nickel			3.940						1.E-01		0.1220	0.00255	0.0001940
Selenium			3.2E-02						7.E-03		0.0066	0.00042	0.0000106
Zinc			2.4E+00						8.E-01		0.7630	0.00255	0.0012100
Chromium VI			0.402						8.E-04		0.0008	0.00000	0.0000013
Total			9.749						**2**	0.0005	2.3311	0.00742	0.0175000
	24-Feb-94			8-Jun-94			22-Jul-94			1-Feb-98			
	31-Jul-97		From Nov. 1996 to Apr. '97						13-Oct-92	Less than ABB estimates			
	4-Sep-03												

3.3 Air Dispersion Modeling

3.3.1 Overview

Spatial patterns of contaminant concentrations resulting from SSFL emissions were assessed by numerical air dispersion modeling. The first objective was to decide whether available meteorological data were representative of meteorology during the years SSFL has been operating (1948 to the present). The second objective was to model air dispersion of emissions from RET, cleaning solvents, stripping towers (STs), and open-pit burning at the TTF. Estimated concentration patterns were then used, along with various exposure scenarios, to identify areas of potential exposure concern surrounding SSFL. Review of the available climatological data suggests that the available meteorological data from 1994 to 1997 are reasonably representative of the period of historical operations at SSFL (Appendix I).

3.3.2 Meteorology

The use of a few years of meteorological data for to assess dispersion modeling relevant for longer time periods is a reasonable approach, provided that the few meteorological years selected are consistent with the longer climatological data history. In order to assess the suitability of the four years (1994–1997) of available on-site meteorological data for representing the historical time period, precipitation and temperature data in the four available meteorological years were compared with climatological precipitation and temperature data during the period of 1948 through 2002. The precipitation assessment is briefly described below low and the temperature assessment is discussed in Appendix I. The study team also sought to assess the diurnal variations of on-site winds at SSFL. Understanding the wind flow directions is relevant as emissions follow the wind direction pattern.

The nearest meteorological station to SSFL with long-term annual precipitation totals is in Canoga Park, California at a distance of only 15 kilometers (9.3 miles) southeast of SSFL. The proximity of the above station to SSFL provides a reasonable justification for considering precipitation data at Canoga Park to be representative of the yearly precipitation pattern at SSFL. At Canoga Park, the annual average rainfall of 16.2 inches during 1949-2002 (Figure 3-5) is 10% less than the 17.0 inches for the 1994-1997 period. The standard deviation of the annual average rainfall of 9.1 inches for 1949-2002 is 13% higher than for the 1994-1997 period. Given that the annual and standard deviation precipitation statistics for the 1948-2002 period and the meteorological data period (1994-1997) deviate by at most 13%, the SSFL on-site data for 1994-1997 seem appropriate for representing the longer air quality study period.

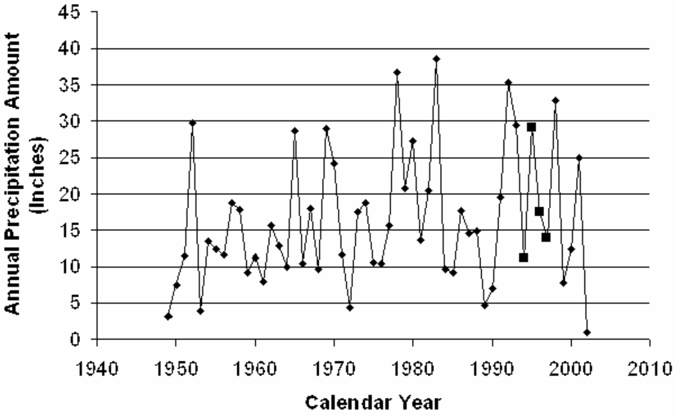


Figure 3-5. Annual Precipitation Totals from 1948 to 2002 at Canoga Park, California

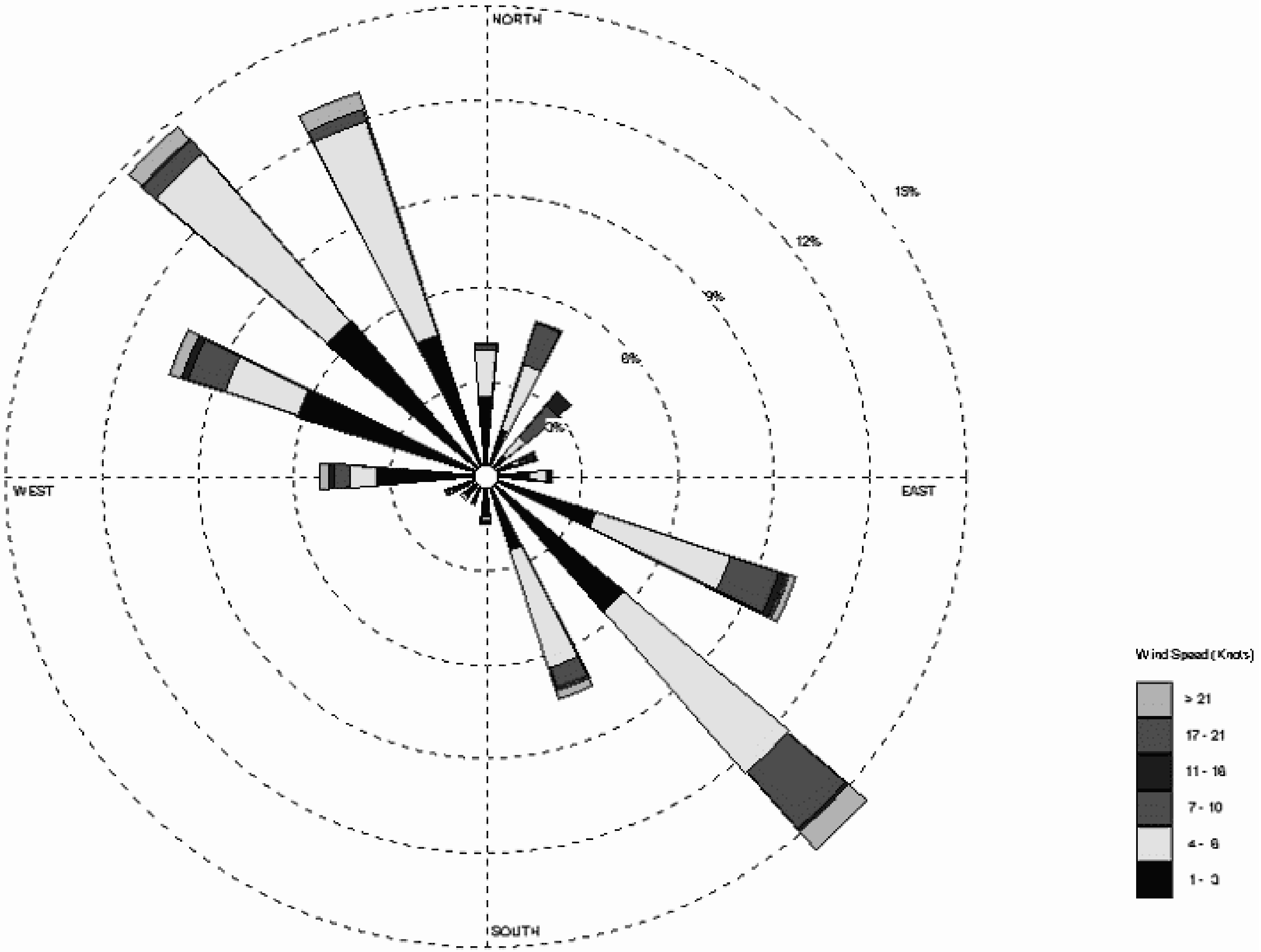
The frequency of wind speeds and wind directions[3.1] measured in SSFL Area IV (Figure 2-2) from 1994 to 1997 by 16 compass directions by time of day are illustrated using three wind rose plots. A wind rose diagram shows the frequency of measured wind speeds and wind direction. A wind rose plot contains a center circle from which 16 thick lines emanate. The length of each line corresponds to the frequency of measured winds in that compass direction. The average wind pattern across all hours of the day from January 1994 through December 1997 is shown in Figure 3-6. Most winds (85%) flow from the northwest to the southeast and in reverse. This is nearly the same wind pattern followed from 7 a.m. to 8 p.m. (0700 to 2000 PST) (Figure 3-7). Wind flow from the southwest and northeast quadrants were significantly less at 3% and 12% of the time, respectively. Therefore, using this SSFL wind data continuous and daytime into late evening air emissions should result in similar surrounding air impact patterns. According to the wind direction pattern, the highest impacts will be southeast and northwest of SSFL emission sources. Figure 3-8 shows a different wind pattern for the time period 11 a.m. to 8 p.m. (1100 PST to 2000 PST) from January 1994 through December 1997. Winds are mostly from the northwest. Therefore, SSFL sources of air emissions emitted only or predominately in this time period should result in surrounding air impacts highest southeast of SSFL emissions. This time period from 11 a.m. to 8 p.m. is when most emissions from SSFL RETs probably occurred (S. Laflamm, personal communication, 1994). These facts suggest SSFL RETs and TCE flushes are likely to have resulted in the highest surrounding air impacts southeast of the SSFL. These wind patterns are consistent with main flow directions in the region and local terrain.

Like all local wind data, the Area IV wind data were most accurate for the local area of the measurement. Study team members personally observed that SSFL Area IV wind directions were consistent with those in SSFL Areas II and III but not with Area I. To better understand the inconsistent wind directions in Area I compared with Areas II, III and IV the following is noted. SSFL collected wind data in Area I are rotated about 22 degrees counterclockwise compared with Area IV wind data. The 22 degree wind rotation in Area I is consistent with a downward directional slope of the dominant ridge in that area. Therefore, this wind rotation in Area I is likely present only south of this dominant local terrain ridge[3.2]. This variation in flow pattern often occurs in light winds when terrain effects dominate and cause upslope and downslope flows. Analysis of the light winds frequency revealed that surface winds were less than 2 knots 25% of the time and less than 4 knots 45% of the time. Therefore, upslope and downslope weather patterns may have occurred at least 25% and possibly as often as 45% of the time. This bidirectional wind flow behavior was not incorporated in the model simulations, since wind data for Area I were not available for the same periods as the Area IV data. A complex computer wind field model that includes the detailed site topography could in principle be used to evaluate this bidirectional wind flow. Such an endeavor was beyond the scope of this study, for which the present approach is believed to be sufficiently conservative to identify the locations of potential exposure concern.

[3.1] Precise Environmental Consultants reviewed the preprocessed meteorological data and noted a systematic scaling error (Suder, 1999). The data were corrected and compared to other meteorological data collected in Area I (see Figure 2-2) for October 1998 through April 1999. The corrected winds from Area IV were found to be consistent with the winds from Area I. These corrected wind data from Area IV were used in the present modeling work.

[3.2] Emission sources south of this ridge include the TTF and five RET areas (the Bowl, Canyon, APTF, Coca, and Delta areas).

Figure 3-6. Wind Rose Plot of Surface Wind Data from SSFL Area IV: All Hours, Years 1994–1997



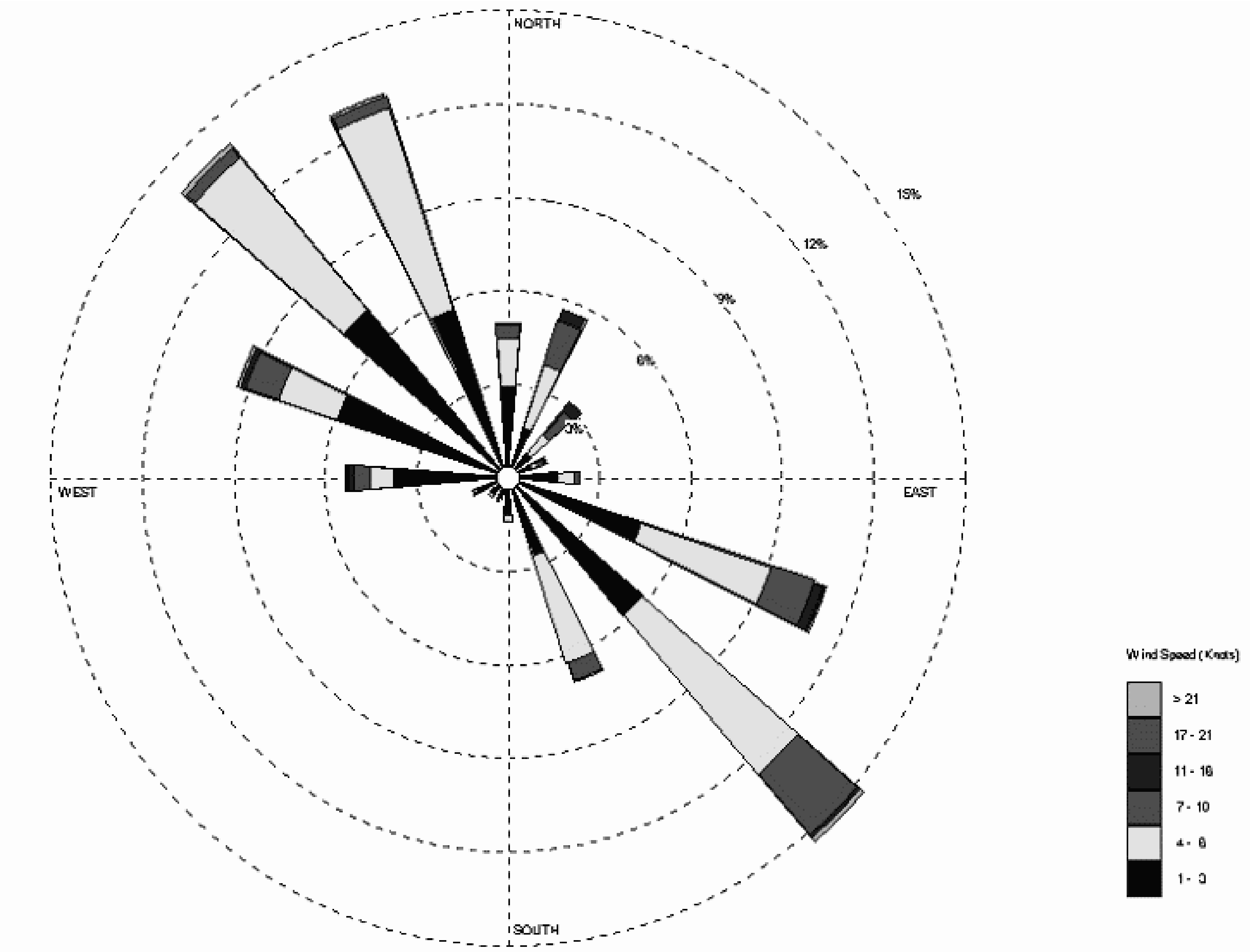


Figure 3-7. Wind Rose Plot of Surface Wind Data from SSFL Area IV: 0700–2000 PST, Years 1994–1997

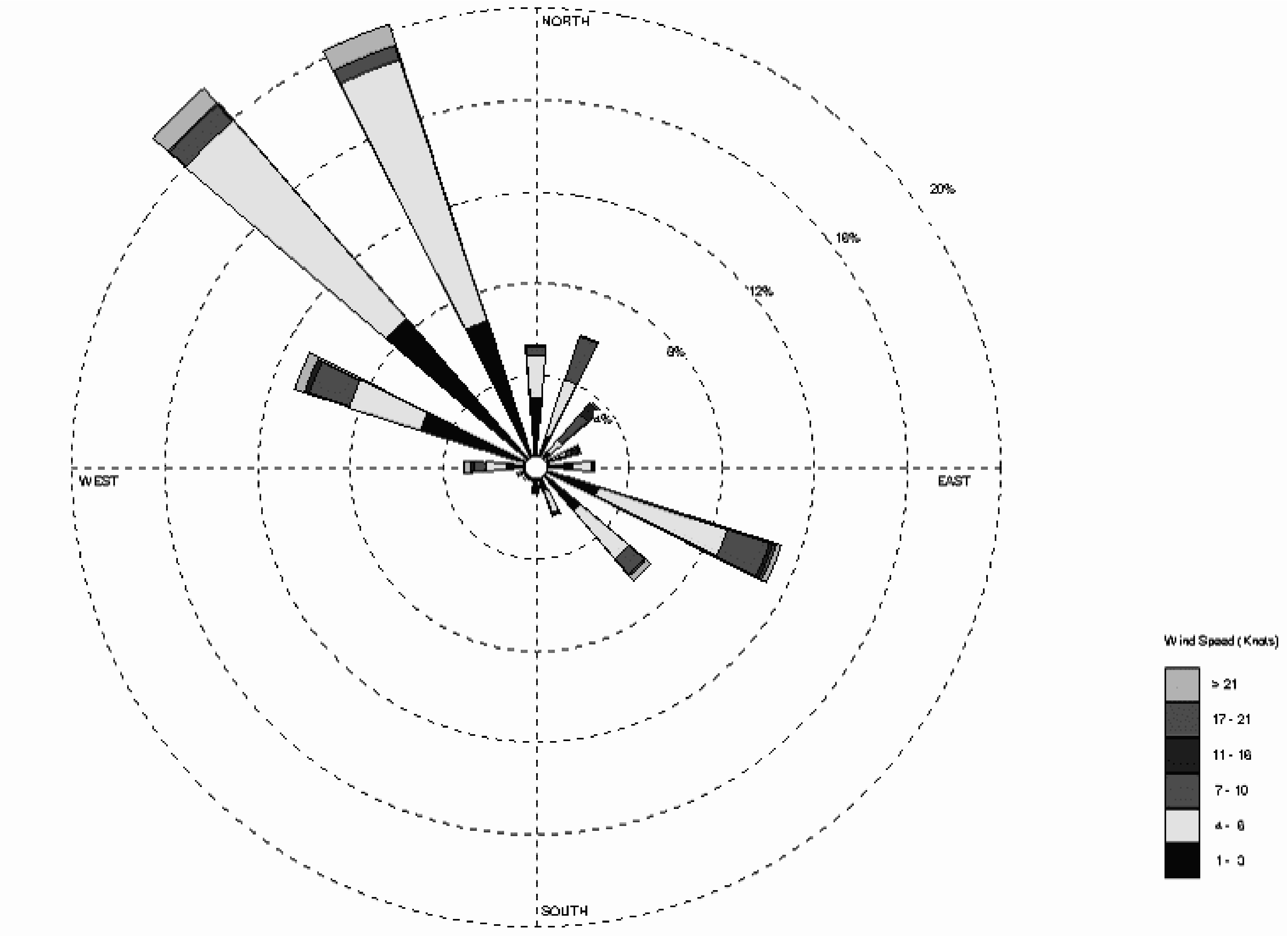


Figure 3-8. Wind Rose Plot of Surface Wind Data from SSFL Area IV: 1100–2000 PST, Years 1994–1997

3.3.3 Air Dispersion Modeling Approach

Dispersion of SSFL emissions into the atmosphere and the resulting outdoor concentrations in various communities surrounding the SSFL were estimated using the CALPUFF air quality model (EPA, 1995c, 1998, 2001). CALPUFF is an EPA approved model that is capable of predicting airborne concentrations of multiple species simultaneously. The CALPUFF model requires input of receptor coordinates at which to predict ambient air concentrations. In the CALPUFF model, receptors can be specified in an organized polar or rectangular grid or as discrete receptor locations. Meteorological data are input as hourly averages. Model input data for CALPUFF include source characteristics, meteorological data, and topographical data.

Meteorological data for the period 1994-1997 from SSFL Area IV were prepared into the single height data format for use in CALPUFF. This data format is identical to that used in the EPA ISC steady state Gaussian model (EPA, 1995). CALPUFF predicted concentrations were obtained at locations spaced 1000-meters (about 0.6 miles) apart extending to a distance of 50 km (~ 31 miles) radially from SSFL. This gird enabled estimates of airborne concentrations within various communities (Fig. 2-9) within 31 miles of SSFL. CALPUFF simulations were also carried out with locations spaced 100 meters (~ 0.06 miles) apart to provide refined coverage near the SSFL property. The terrain elevations of the various receptor locations are provided in Appendix I.

CALPUFF simulations were carried out for 39 different emission scenarios (Appendix I, Table I-8):

- Thirty-two (32) simulations were run to predicted airborne concentration patterns resulting from RETs. Four simulations were carried out for each of the eight RET locations. The four simulations at each location consisted of two simulations of RET emissions and another two simulations of the TCE emissions that resulted from degreasing the rocket engine equipment. The two simulations of RETs and TCE degreasing emissions used a constant and a best-estimate of the daily variation in emissions. The best-estimate was derived from anecdotal evidence and safety issues, which suggested that RET occurred almost only during daylight and dusk. It is believed that for safety reasons engines were tested on the same day they were prepared for testing. This suggested that, when averaged over all days in the historic period, the number of engine tests increased from morning to dusk. The study team used this “best estimate” in the modeling study for the RET emissions. As a sensitivity study, the ambient impact of RET emissions was also examined assuming testing took place uniformly throughout the day and night. It is noted that the best-estimate and uniform emission scenarios represent two extremes of emission alternatives.
- Six simulations were conducted for the STs (one for each ST source). Organic emissions from air stripping were assumed constant and diurnally invariant. This is consistent with the assumption of continuous use of the equipment.
- One simulation was made for the TTF source. In this simulation it was assumed that open pit burning occurred only during the daytime (due to safety reasons) and at a constant uniform rate.

The diurnal profiles used to model emissions from RET, ST, and TTF sources are give in Table I-8 (Appendix I). Detailed building geometry data over the lifetime of the SSFL facility were not available, so it was not feasible to include downwash in the model simulations. it was not possible to include downwash accurately in the RET simulations. Therefore, this study treated dispersion simulations of RET emissions conservatively without significant buoyancy.

Additional simulations were made to evaluate the sensitivity of predicted concentrations to atmospheric degradation and rain scavenging. Both of the above processes lead to reduced airborne concentrations of the emitted air toxics. It is noted that winds were less than 2 knots about 25% of the time. Therefore, it was possible for emitted air toxics to be transported a distance of less than 2 miles (about 3 kilometers) in an hour for only about 25% of the time. This implies that since the atmospheric chemistry half-lives of the COCs (except for the secondary species 1,3-butadiene) is above 1-hour, atmospheric degradation was not a relevant factor in the near field (except for 1,3-butadiene). Removal of air toxics from the atmosphere by rain scavenging is an episodic process. However, since rainfall occurred less than 2.1% of the total annual hours, rain scavenging would have a negligible impact on the long-term average atmospheric concentrations of air toxics emitted at SSFL. Therefore, the team omitted the effect of rain on reducing airborne concentrations.

All CALPUFF simulations were accomplished using a source specific "unit emission rate"[3.2] of 1 milligram a second. Specific air toxic concentration fields were estimated from this information as follows. For each specific air toxic, the CALPUFF results by source location were multiplied by the specific air toxic emission rate (in milligrams a second) for that source. Added together were the specific air toxic airborne concentrations predicted from the individual sources to calculate the air toxic combined effect from all SSFL emission locations. CALPUFF output was in the form of outdoor concentrations for short (1-hour) periods and four-year averages, for the various receptor locations, with post-processing performed to obtain get long-term (annual or multi-annual) averages.

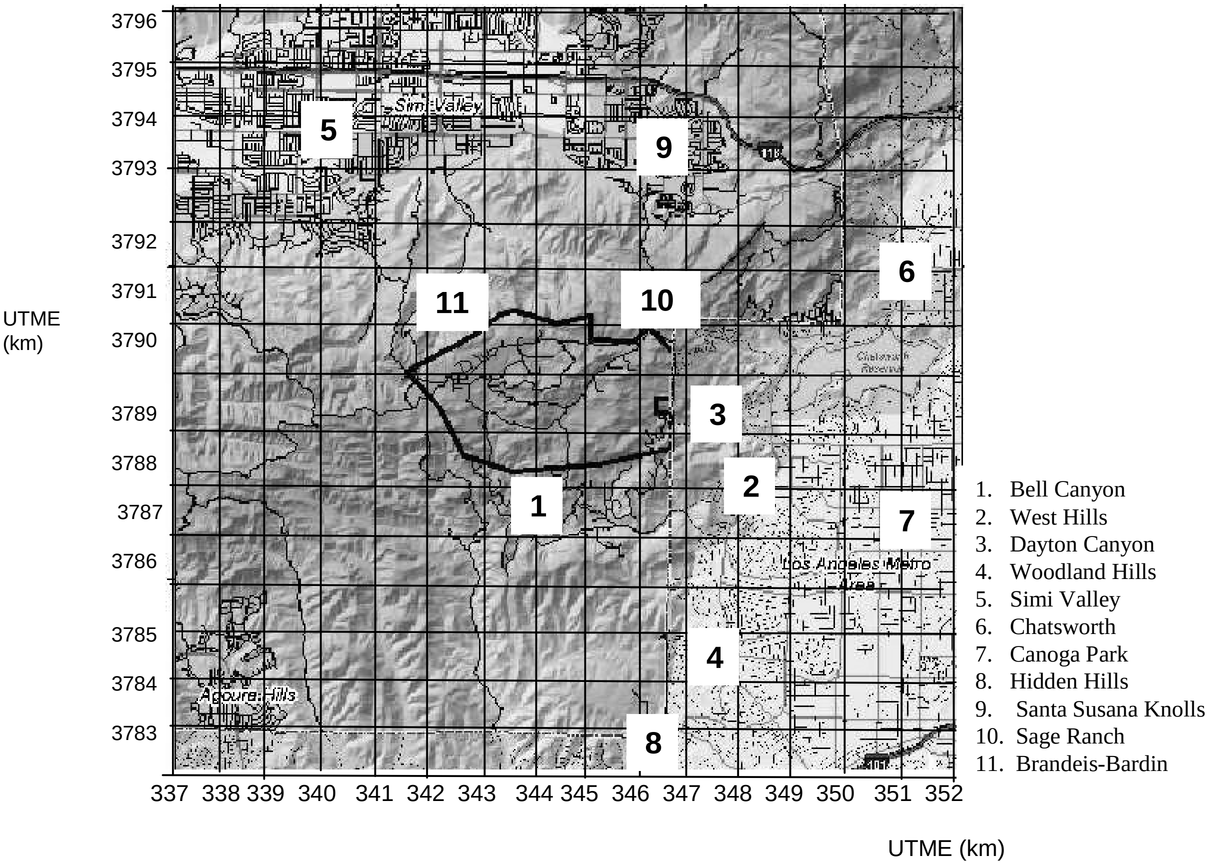
The concentration fields obtained from the various simulations served to identify locations of peak predicted concentrations at or beyond the SSFL property boundary. For each of these peak concentrations, the corresponding meteorological date (month, day, year) and time (hour of day) were identified along with the emission source that represented the highest contributing to each of the peak concentration. In order to assess the upper limit of the emission impacts, the highest concentration location on the SSFL property boundary was also identified. The average concentration by hour-of-day averaged over the four-years of hourly predicted concentrations was calculated at this location. A review of these hour-of-day averages identified the time of day when exposure at such location was expected to be highest and lowest. Finally, to assess how air toxic concentration, on any single day during the four years modeled, might vary from the AAC, the highest daily average concentration (DAC) was calculated at the SSFL property boundary to provide a frequency distribution of DACs.

[3.2] For example, to estimate concentrations for an emission rate of 1 ton per year, the modeled concentration at 1 gram per second would need to be multiplied by 907,185 grams and divided by 31,536,000 seconds, which in this case would be about 3% of the concentration at 1 gram per second.

3.3.4 Modeled Concentration Fields Resulting from Air Dispersion of Chemicals Released from SSFL

Dispersion modeling results are summarized in contour plots overlaid on a map of the area surrounding SSFL (Figure 3-9). These contour plots illustrate the historical ambient air concentration pattern predicted by CALPUFF to have occurred around the SSFL facility from each source activity. As a reference, the figure shows the locations of a number of selected communities on the area map with the corresponding receptor grid coordinates. Each of the concentration fields plotted in Figures 3-10 to 3-15 covers an area of approximately 15 by 15 kilometers, centered over SSFL. (The boundary of the SSFL is outlined in white at the center of each plot.) To visually reflect this predicted behavior, the CALPUFF predictions are plotted using log normal contours that change in multiples of 10 (e.g., 10^{-3} µg/m^3, 10^{-2} µg/m^3, 10^{-1} µg/m^3, 1 µg/m^3, 10 µg/m^3). In other words, contours are plotted at intervals of 0.2 orders of magnitude, which means that every fifth contour reflects a factor-of-10 change in concentration.

Figure 3-9. Receptor Coordinates of Communities



3.3.4.1 Concentration Fields Associated with Rocket Testing Emissions

Figure 3-10 depicts the AAC pattern for all RET point sources using the best-estimate diurnal emissions profile (Section 3.3.3). The pattern shows the highest concentrations within the boundaries of the SSFL and extending predominantly southeast toward the city of Canoga Park. A secondary lobe of high concentrations extends northwest toward Simi Valley. These results are consistent with the surface wind climatology for the SSFL during daylight hours.

The AAC pattern for all RET point sources using the uniform diurnal emissions profile is shown in Figure 3-11. This pattern demonstrates the sensitivity of predicted concentrations to the diurnal emissions profile used. The general pattern is similar to that predicted using the best-estimate diurnal profile, but the highest concentrations are more uniformly distributed to the southeast and northwest. In addition, secondary maxima are seen to the west-southwest and northeast. These results are consistent with the SSFL surface wind climatology for all hours.

Figure 3-12 shows the AAC pattern for all RET area sources using the best-estimate diurnal emissions profile. This pattern represents the potential impact from emissions associated with solvent (i.e., TCE) use near the RET stands. The pattern is similar to that for RET point sources (Figure 3-11), but concentrations are generally higher.

The AAC pattern for all RET area sources, using the uniform diurnal emissions profile, is shown in Figure 3-13. This pattern demonstrates the diurnal meteorological sensitivity of the predicted concentrations, assuming no diurnal variation in emissions. It also represents the potential impact from emissions associated with solvent use near the RET stands. As with the RET area source simulations with best-estimate diurnal emissions, the concentrations are generally higher than for the corresponding point source cases. However, secondary concentration maxima, as seen to the west-southwest and northeast in the corresponding point source case, are not evident.

Simulations for the best estimate diurnal emission profile from RET sources (Appendix I) demonstrated that the locations of the peak hourly concentrations are along the northeast and eastern edges of the SSFL property boundary. At the SSFL boundary line, the scenario of daily increasing emission correspondingly yielded AACs that increase during the day from 0600 to 1900 PST. The peak predicted annual average concentration was about six times greater than the AAC and occurred at 1900 PST. Note that emissions from the APTF RET stand were identified as contributing the most to the peak hourly concentration (PHC) at the SSFL property boundary.

Figure 3-14 shows PHC contours from a single RET point source (the APTF) for the best-estimate diurnal emissions profile. These concentrations are the maximum hourly concentrations for each receptor during the four years modeled and are approximately three orders of magnitude higher than for the AACs. The pattern is less defined than for the AACs, with higher concentrations in all directions. The highest concentrations outside SSFL are north of Canoga Park, toward the Chatsworth Reservoir. This pattern is likely a result of shifting wind directions when vertical mixing decreases and emissions are highest: from 1600 to 2000 PST. February 4, 1995, was identified as having the highest PHC of all days in the four years modeled. This worst-case scenario was assessed by carrying out a simulation for the above date, for a single rocket test, from 1800 to 1900 PST (winds were mostly from the West). The simulation results (Figure

3-15) indicate a concentration decline downwind of the SSFL property boundary. The downwind PHC decreases rapidly in the first 3.7 kilometers, where the PHC would be less than 10% of that at the property boundary. Beyond 3.7 kilometers, the decreases in PHC become uniform; the PHC at 31.1 kilometers is only 1% of that at the property boundary.

3.3.4.2 Concentration Fields Associated with Stripping Towers and Thermal Treatment Facility Emissions

The AAC pattern for all ST point source emissions, using the best-estimate uniform diurnal emissions profile, is shown in Figure 3-16. The pattern is similar to that obtained by modeling the RET point sources with the uniform diurnal emission profile. The AAC pattern for all TTF sources using the best-estimate (daylight only) diurnal emissions profile (Figure 3-17) is similar to that for the RET point sources using the best-estimate diurnal profile. However, it is centered over the TTF, and the maxima to the northwest and southeast are more balanced. This behavior is expected, since winds at SSFL tend to increase in strength from the northwest later in the day.

Figure 3-10. Average Concentration Pattern for all RET Point Sources Using the Best-Estimate Diurnal Emissions Profile

Figure 3-11. Average Concentration Pattern for all RET Point Sources Using the Uniform Diurnal Emissions Profile

Figure 3-12. Average Concentration Pattern for all RET Area Sources Using the Best-Estimate Diurnal Emissions Profile

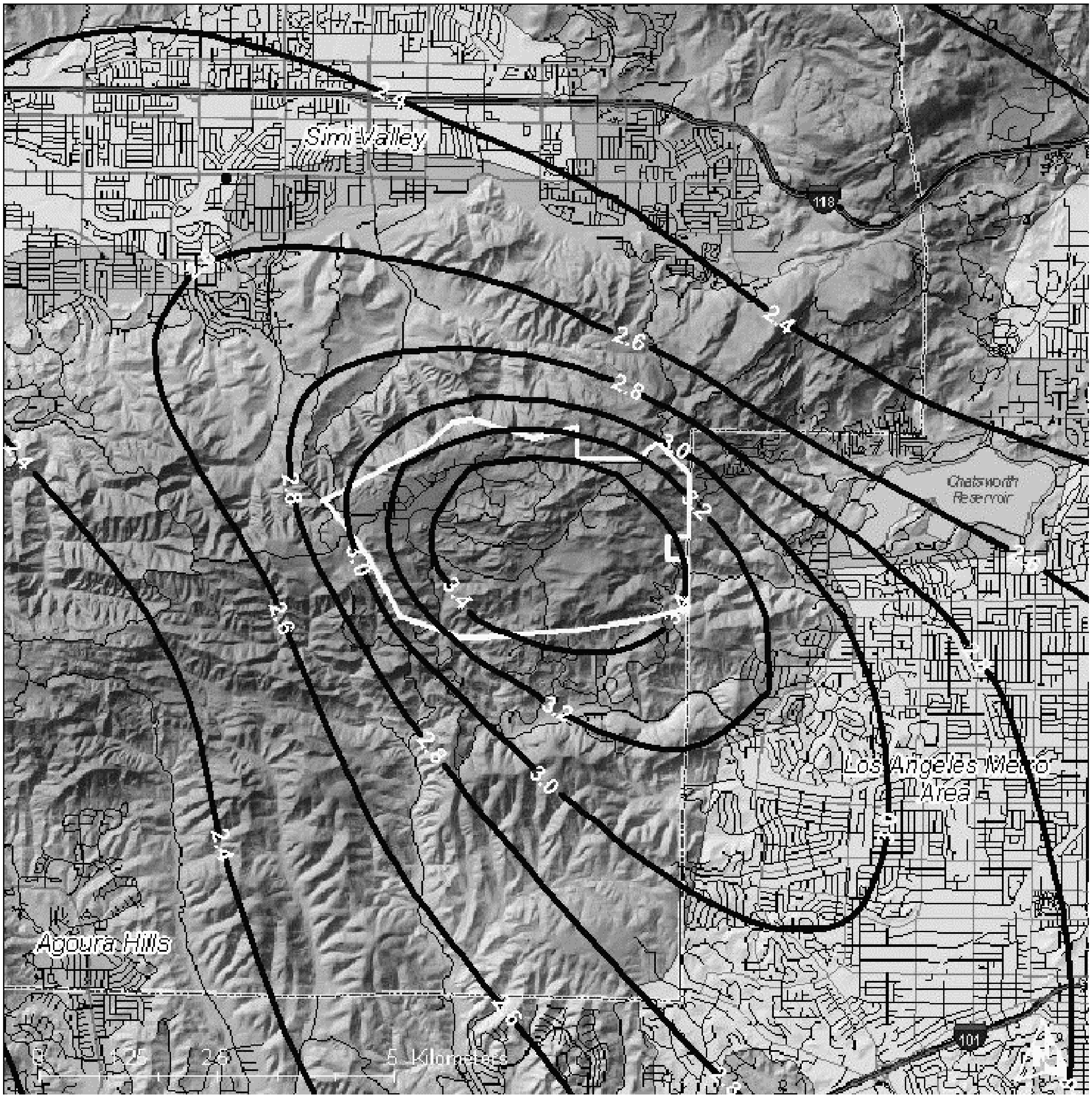


Figure 3-13. Average Concentration Pattern for all RET Area Sources Using the Uniform Diurnal Emissions Profile

Figure 3-14. Contours of Locations of Highest Concentrations for the APTF Point Source Using the Best-Estimate Diurnal Emissions Profile

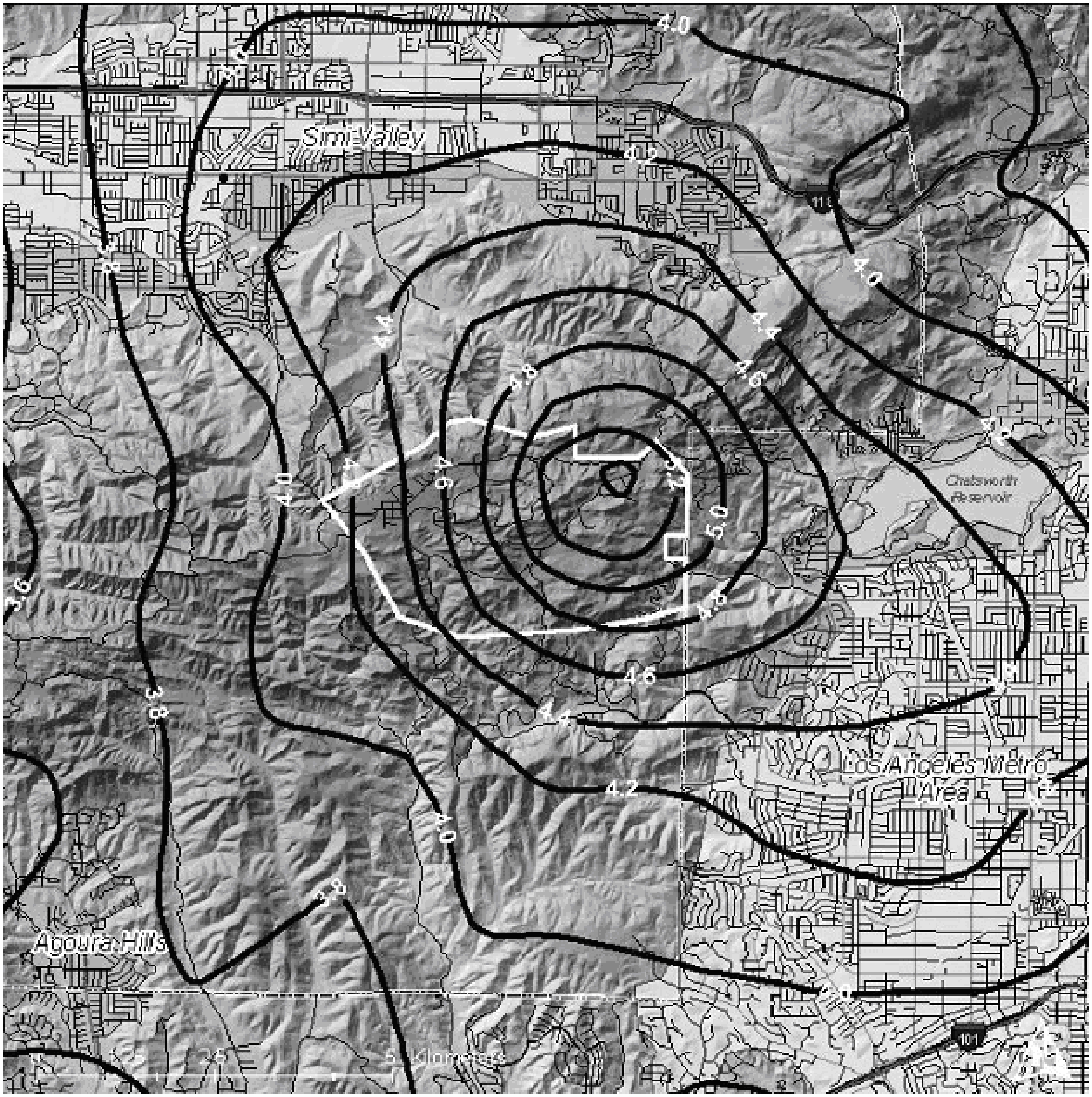


Figure 3-15. Change in the Peak Hourly Concentrations Downwind of the SSFL Property Boundary

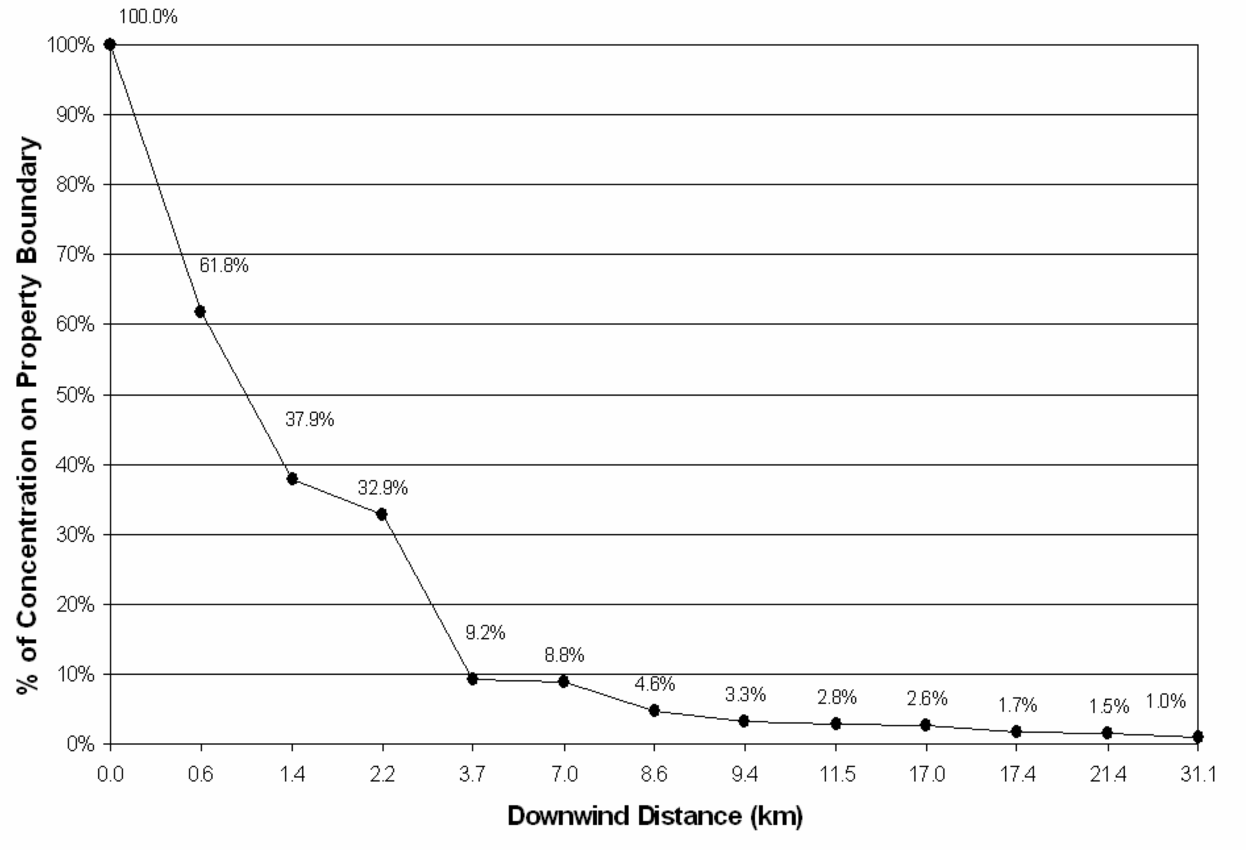


Figure 3-16. Average Concentration Pattern for all ST Point Sources Using the Best-Estimate Uniform Diurnal Emissions Profile

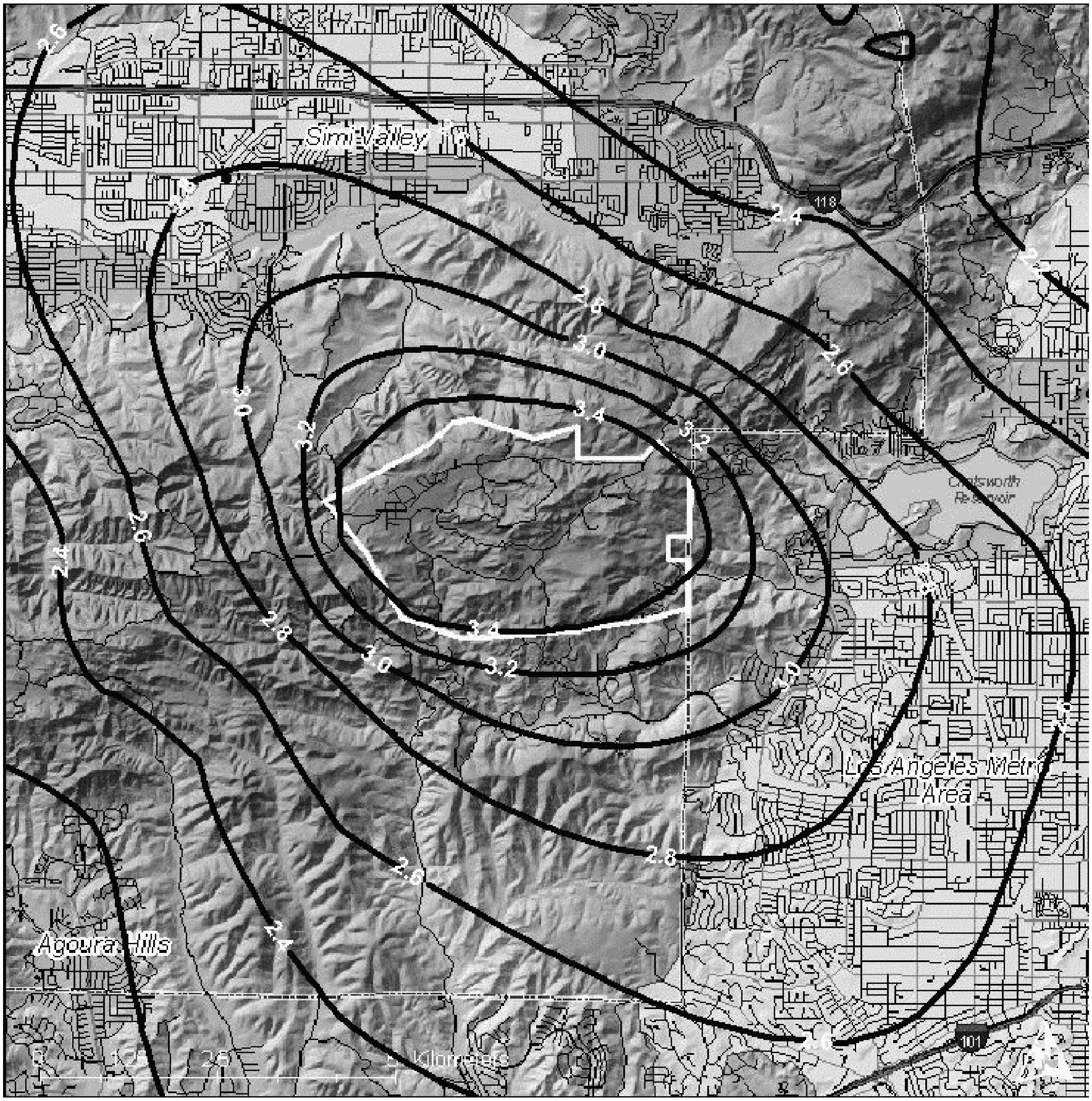


Figure 3-17. Average Concentration Pattern for all TTF Point Sources Using the Best-Estimate (Daylight Only) Diurnal Emissions Profile

3.3.5 SSFL Concentration Profiles from Air Dispersion Modeling of Emissions

It is instructive to display the chemical concentrations profile on a linear trajectory from the source to the receptor of interest. Such a concentration profile displays the concentration decay as one moves away from SSFL. Accordingly, a series of concentration profiles were calculated based on the concentration fields obtained for the different source emission scenarios (TCE/rocket engine degreasing; TCE/storage tank releases and stripping towers; and hydrazine and derivatives/open-pit burning). For each scenario, concentration-distance profiles are presented for the northwest, northeast, and southeast directions, which cover the nearest populated areas and the zones with the expected highest concentrations.

Four different profiles were determined for each of the above cases (Figures 3-18 through 3-29). The first profile is for the annually averaged concentrations, based on the air dispersion simulations for the estimated maximum annual emission rate as given in Appendix S. The second profile is for the annually averaged concentrations, based on the air dispersion simulations for the average annual emission for the 1995–1990 period for TCE and the 1959–1989 period for hydrazine. The third profile depicts the peak hourly concentration decay, based on dispersion simulations for the estimated maximum annual emission rate. Finally, the fourth profile is for the peak hourly concentration based on the dispersion simulations for the average annual emission. In the present analysis, concentration profiles were calculated based on the average concentrations for each type of emitter (e.g., the average of the eight RET stands). Note that for a given point source and climatic conditions, the concentration, at a given receptor location, is directly proportional to the emission rate. Therefore, it is convenient to present the annually averaged concentration profiles as derived from air dispersion simulations for average and maximum emission rates on the same figures. These two profiles will coincide when they are depicted in the same figure with different but properly scaled coordinate axes (Figures 3-18, 3-20, 3-22, 3-24, 3-26, and 3-28). Similarly, the peak hourly concentration profiles (Figures 3-19, 3-21, 3-23, 3-25, 3-27, and 3-29), for both average and maximum emission rates, for each chemical activity and direction, are plotted with the coordinate axes scaled so that profiles are coincident.

3.3.5.1 TCE Concentration Profiles Associated with Rocket Engine Degreasing

The averaged annual TCE concentration profiles in the northwest, northeast, and southeast directions are provided in Figures 3-18 through 3-20. The concentration on the left axis corresponds to the average during 1959, when the estimated emission rate was at maximum (~387 tons/year), while the right ordinate axis corresponds to the average concentration corresponding to the simulations at the average emission (~89 tons/year) for 1955 through 1990. For the year of maximum emission rate, the average annual concentration decreased from 17.2 $\mu g/m^3$ at the source to 1 $\mu g/m^3$ at a distance of 2.4 kilometers northwest of SSFL (Figure 3-18) and a distance of 2.0 kilometers northeast (Figure 3-20). In the southeast, the concentration decay is less pronounced, with the concentration slightly above 1 $\mu g/m^3$ even at the distance of 10.6 km away from SSFL (Figure 3-22).

The peak hourly concentration profiles in the northwest, northeast, and southeast directions are shown in Figures 3-19, 3-21, and 3-23, respectively, for the maximum emission rate (387 tons per year) and the average emission rate (~90 tons per year). These variations in the peak concentrations with distance are less sensitive to the different directions than the annual average concentrations. The profile along the northeast direction (Figure 3-21) shows a local maximum approximately 8 kilometers from the emission point, where the region topology induces a significant concentration pattern variation—as shown in the contour plot, Figure 4-8, of the *Dispersion* report of Sonoma (Appendix I). This apparent local maximum anomaly is also shown in Figure 3-27 for the TCE emissions from storage tanks and stripping towers.

3.3.5.2 TCE Concentration Profiles Associated with Storage Tank Releases and Stripping Towers

The average annual concentrations in the northwest, northeast, and southeast directions, for the maximum and average emission rates, are depicted in Figures 3-24, 3-26, and 3-28, respectively. For the maximum emission rate, the concentration decreases from the maximum value of about 20 µg/m^3 at the source to 1 µg/m^3 approximately 2 kilometers away from SSFL for all the three directions, as can also be seen in Figure 3-16. The weak direction-dependence of the concentration decay is also observed in Figure 3-12. The corresponding peak hourly concentrations are shown in Figures 3-25, 3-27, and 3-29.

3.3.5.3 Hydrazine and Derivatives Concentration Profiles Associated with Open-Pit Burning

The annual average concentration-distance profiles for hydrazine, based on a uniform daytime emission rate from the TTF (Section S) are provided in Figures 3-30, 3-32, and 3-34. Note that a more gradual concentration decline is observed in the southeast, relative to the northeast and northwest, as can also be seen in the concentration contour plots shown in Figure 3-17. The concentration declines from about 0.039 µg/m^3 at SSFL to about 5×10^{-3} µg/m^3 2 kilometers to the northwest; the same concentration decline is observed 1.4 kilometers northeast and 3.6 kilometers southeast. The peak hourly concentration profiles, Figures 3-31, 3-33, and 3-35, all show similar concentration decline profiles irrespective of direction.

Figure 3-18. Average TCE Concentration Associated with Rocket Engine Degreasing. Profile from SSFL to UTM coordinates (338, 3796) for the estimated maximum annual emission (387 tons/year) and for the estimated average emission from 1955 to 1990 (88.7 tons/year).

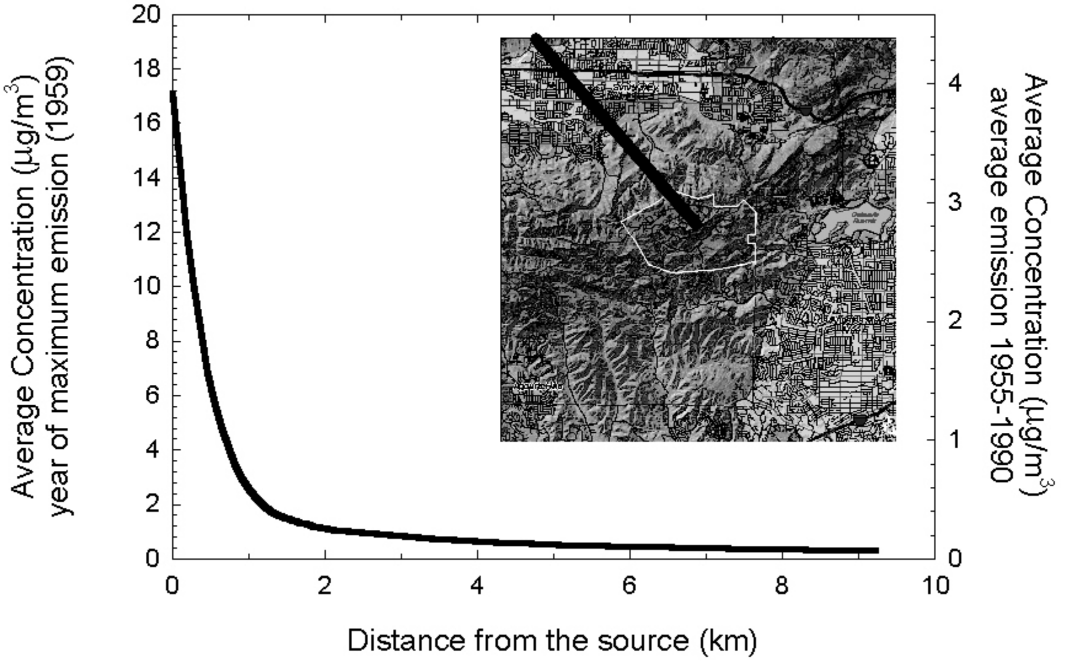


Figure 3-19. Peak Hourly TCE Concentration Associated with Rocket Engine Degreasing. Profile from SSFL to UTM coordinates (338, 3796) for the estimated maximum annual emission (387 tons/year) and for the estimated average emission from 1955 to 1990 (88.7 tons/year).

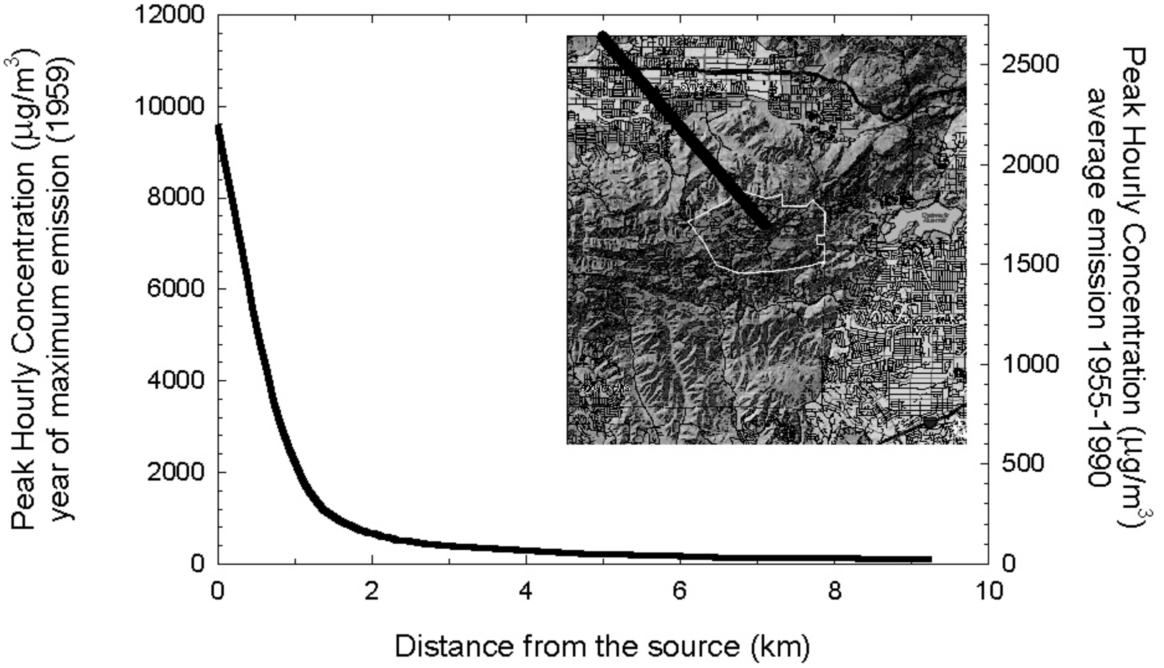


Figure 3-20. Average TCE Concentration Associated with Rocket Engine Degreasing. Profile from SSFL to UTM coordinates (351, 3796) for the estimated maximum annual emission (387 tons/year) and for the estimated average emission from 1955 to 1990 (88.7 tons/year).

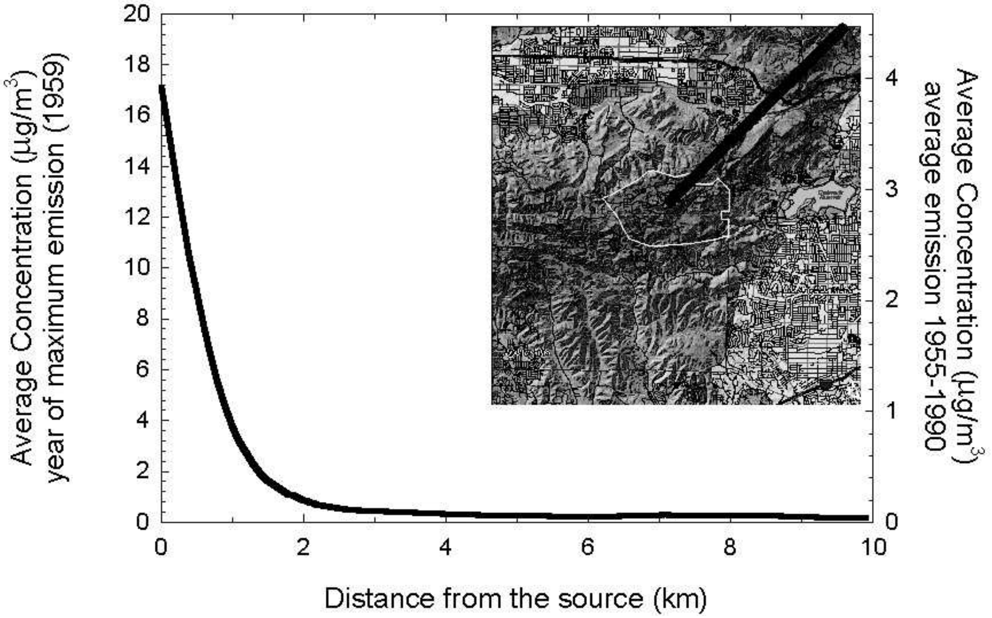


Figure 3-21. Peak Hourly TCE Concentration Associated with Rocket Engine Degreasing. Profile from SSFL to UTM coordinates (351, 3796) for the estimated maximum annual emission (387 tons/year) and for the estimated average emission from 1955 to 1990 (88.7 tons/year).

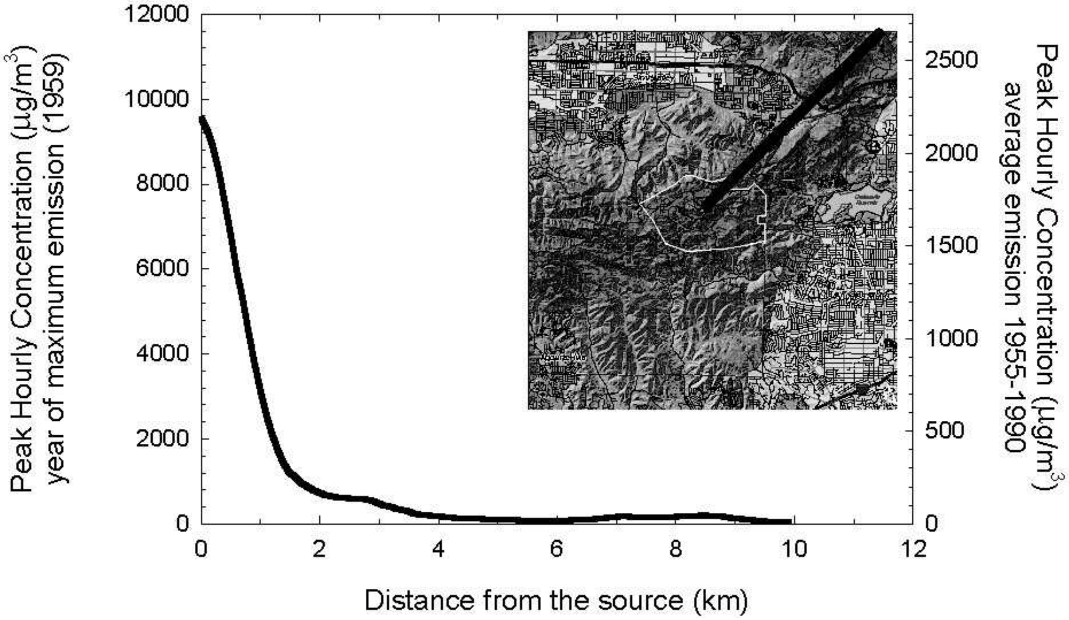


Figure 3-22. Average TCE Concentration Associated with Rocket Engine Degreasing. Profile from SSFL to UTM coordinates (351, 3781) for the estimated maximum annual emission (387 tons/year) and for the estimated average emission from 1955 to 1990 (88.7 tons/year).

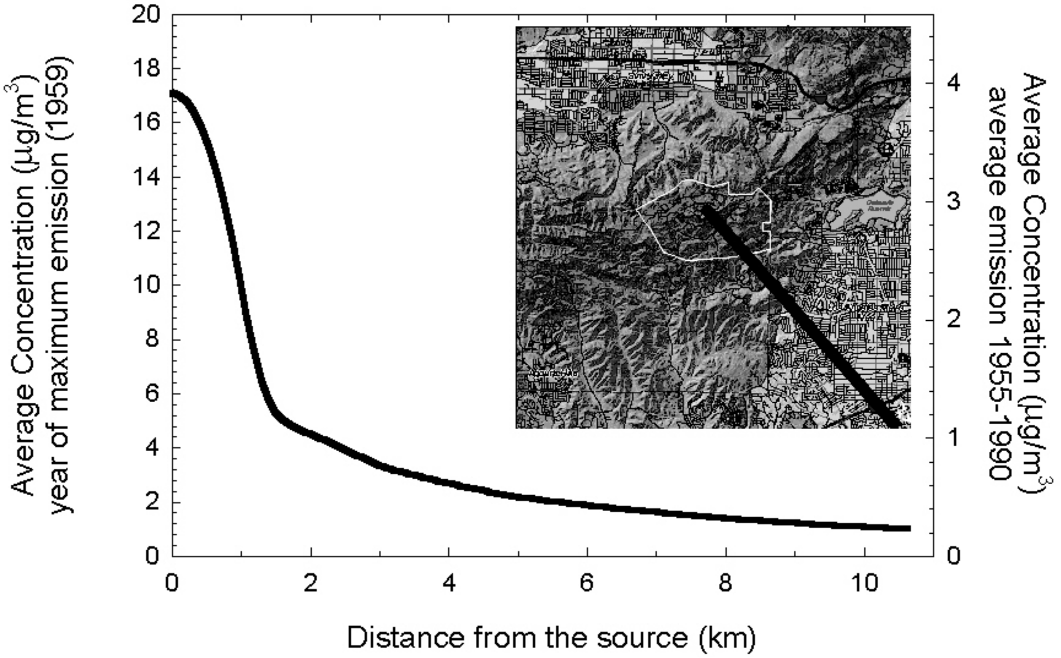


Figure 3-23. Peak Hourly TCE Concentration Associated with Rocket Engine Degreasing. Profile from SSFL to UTM coordinates (351, 3781) for the estimated maximum annual emission (387 tons/year) and for the estimated average emission from 1955 to 1990 (88.7 tons/year).

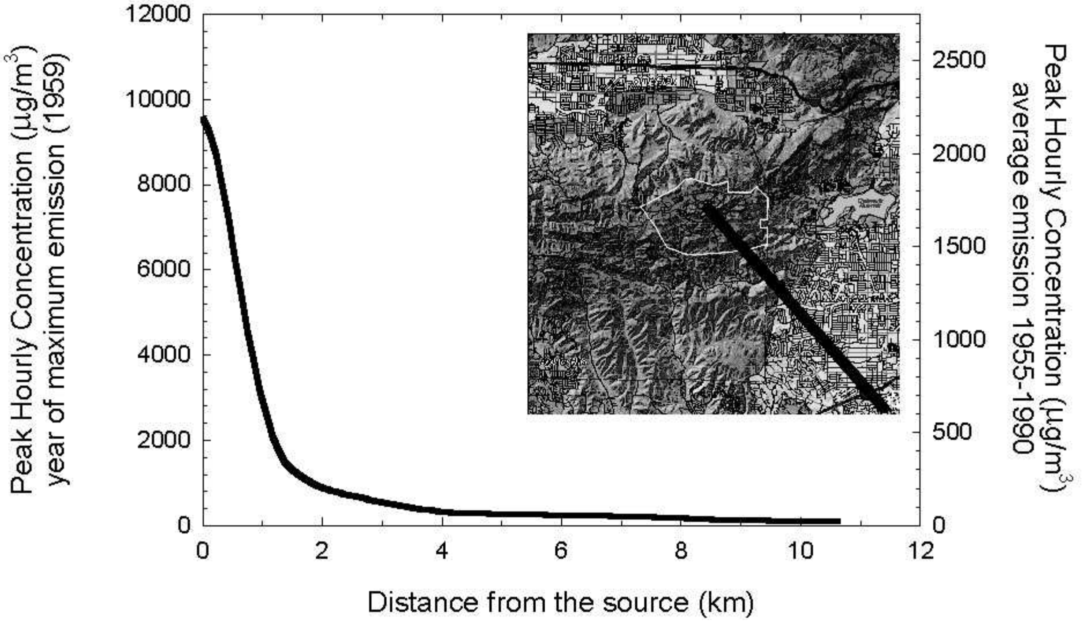


Figure 3-24. Average TCE Concentration Associated with Storage Tank Releases and Stripping Towers. Profile from SSFL to UTM coordinates (338, 3796) for the estimated maximum annual emission (91.8 tons/year) and for the estimated average emission from 1955 to 1990 (21.8 tons/year).

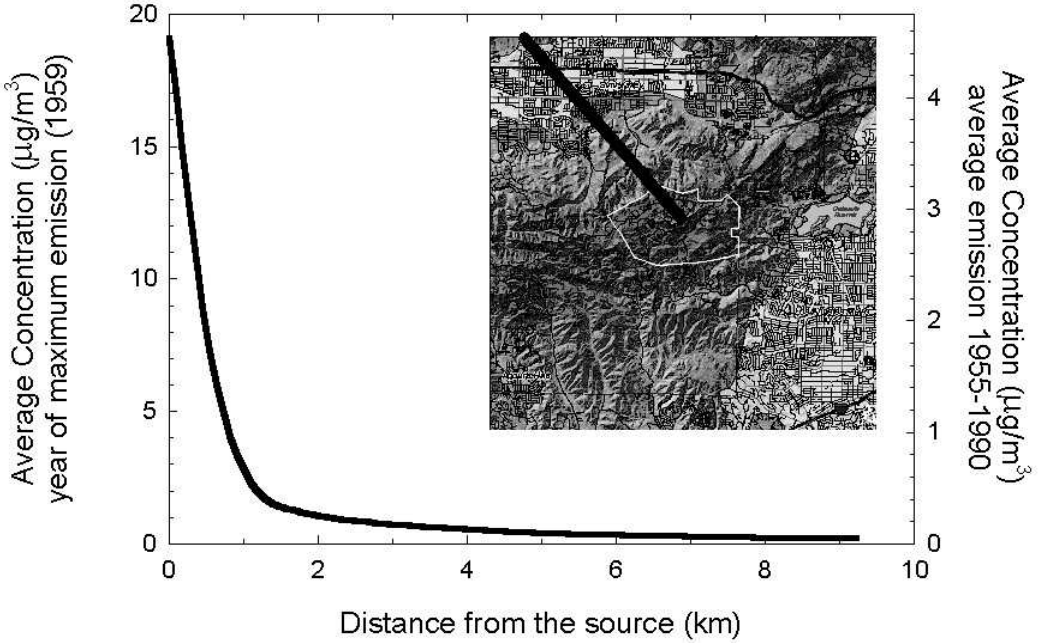


Figure 3-25. Peak Hourly TCE Concentration Associated with Storage Tank Releases and Stripping Towers. Profile from SSFL to UTM coordinates (338, 3796) for the estimated maximum annual emission (91.8 tons/year) and for the estimated average emission from 1955 to 1990 (21.8 tons/year).

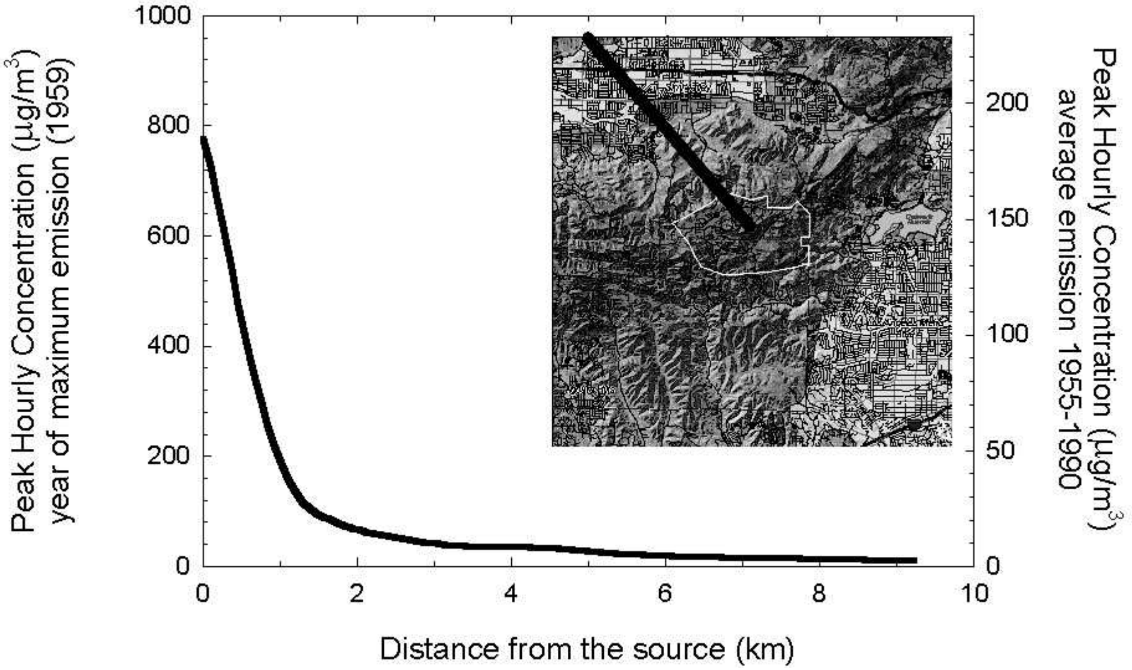


Figure 3-26. Average TCE Concentration Associated with Storage Tank Releases and Stripping Towers. Profile from SSFL to UTM coordinates (351, 3796) for the estimated maximum annual emission (91.8 tons/year) and for the estimated average emission from 1955 to 1990 (21.8 tons/year).

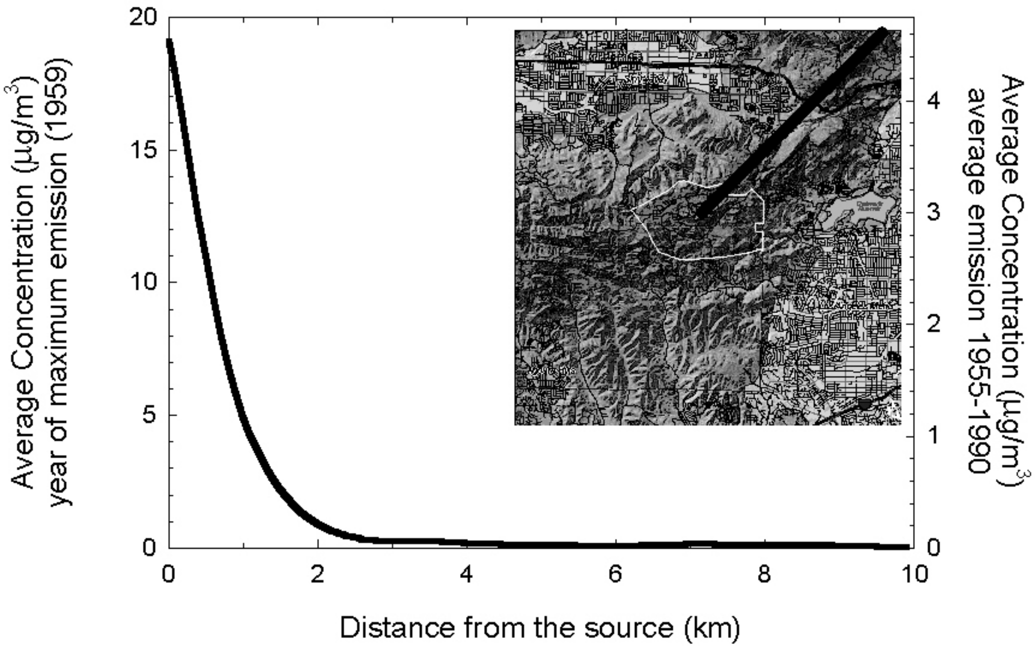


Figure 3-27. Peak Hourly TCE Concentration Associated with Storage Tank Releases and Stripping Towers. Profile from SSFL to UTM coordinates (351, 3796) for the estimated maximum annual emission (91.8 tons/year) and for the estimated average emission from 1955 to 1990 (21.8 tons/year).

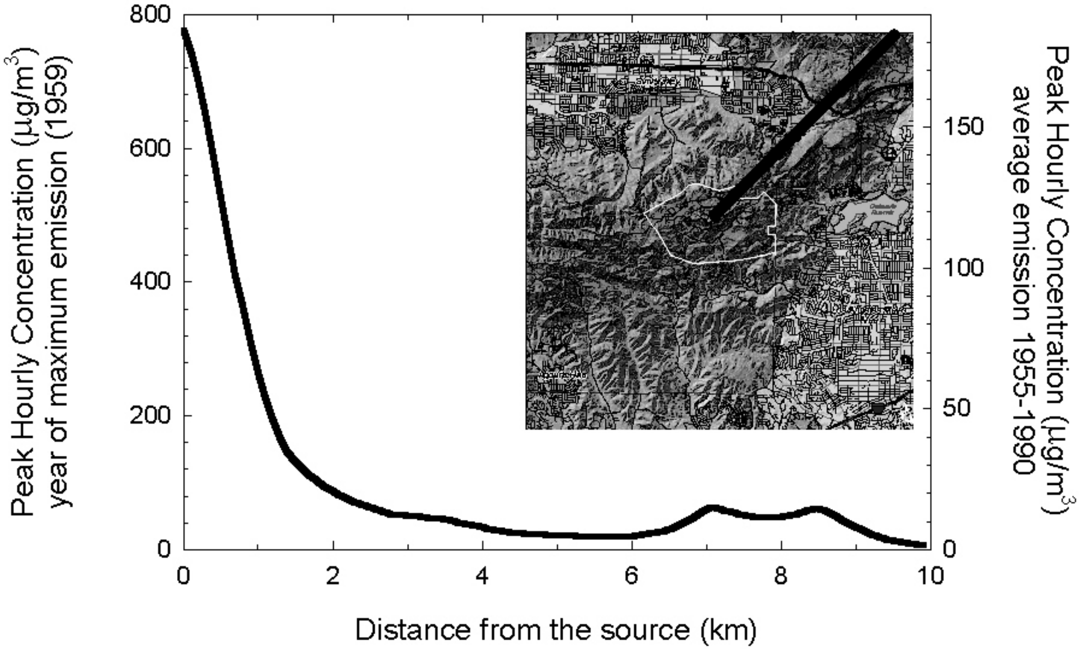


Figure 3-28. Average TCE Concentration Associated with Storage Tank Releases and Stripping Towers. Profile from SSFL to UTM coordinates (351, 3781) for the estimated maximum annual emission (91.8 tons/year) and for the estimated average emission from 1955 to 1990 (21.8 tons/year).

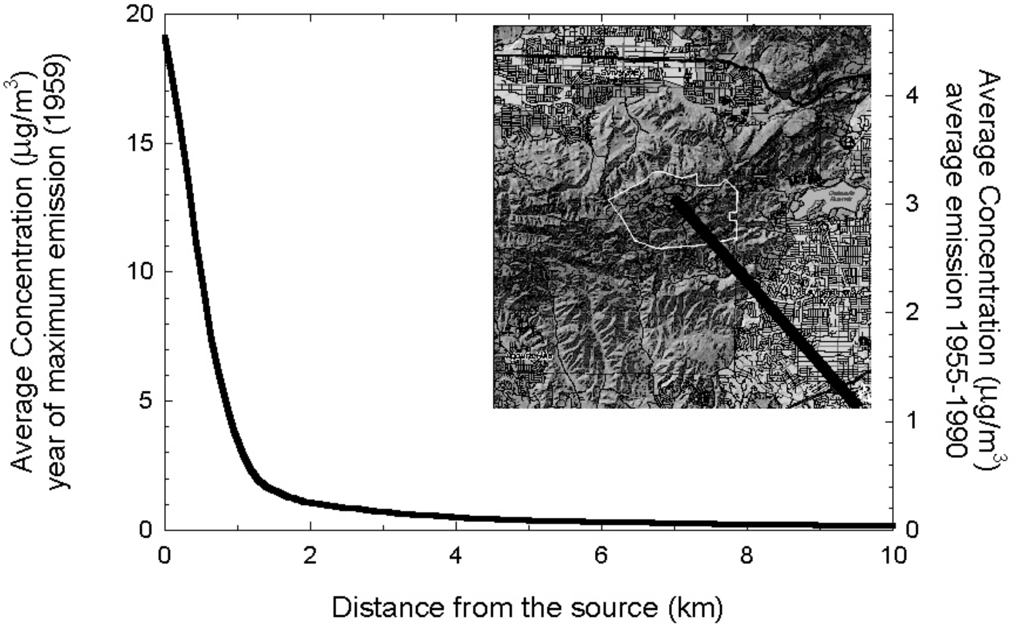


Figure 3-29. Peak Hourly TCE Concentration Associated with Storage Tank Releases and Stripping Towers. Profile from SSFL to UTM coordinates (351, 3781) for the estimated maximum annual emission (91.8 tons/year) and for the estimated average emission from 1955 to 1990 (21.8 tons/year).

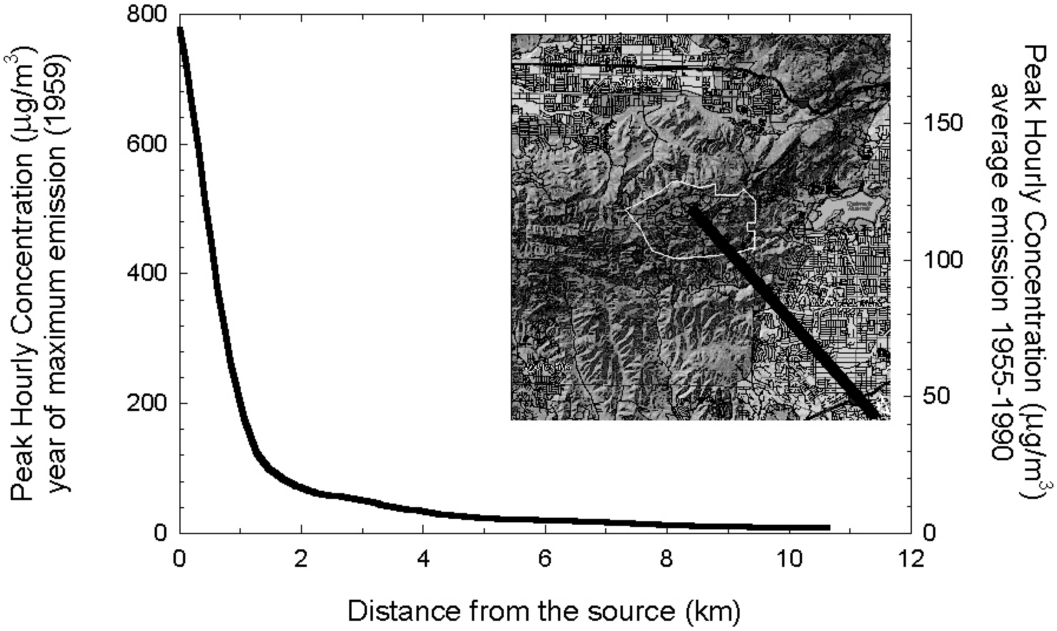


Figure 3-30. Average Hydrazine and Derivatives Concentration Associated with Open-Pit Burning. Profile from SSFL to UTM coordinates (338, 3796) for the estimated uniform emission (0.658 tons/year).

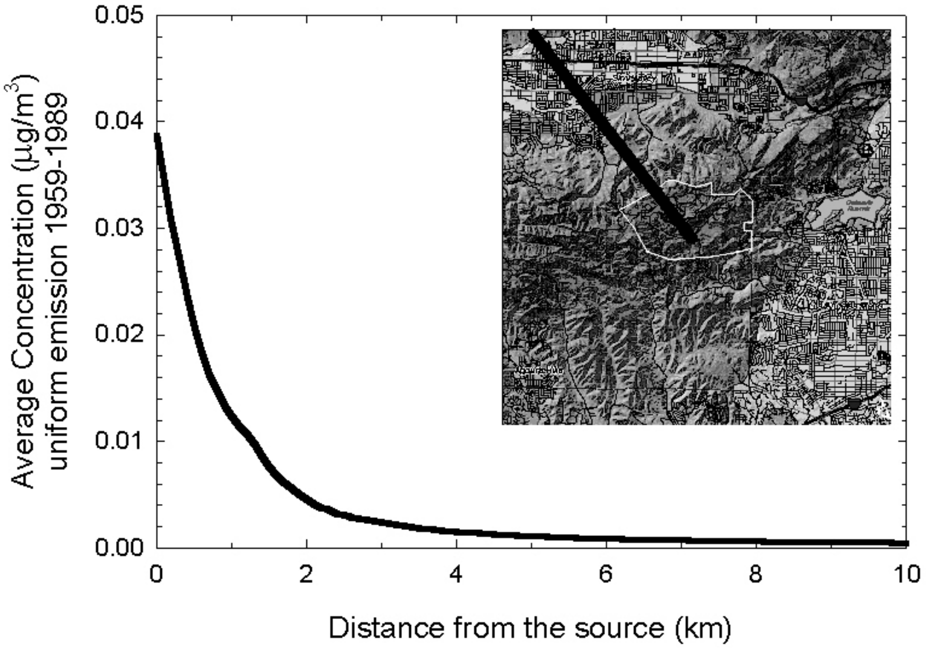


Figure 3-31. Peak Hourly Hydrazine and Derivatives Concentration Associated with Open-Pit Burning. Profile from SSFL to UTM coordinates (338, 3796) for the estimated uniform emission (0.658 tons/year).

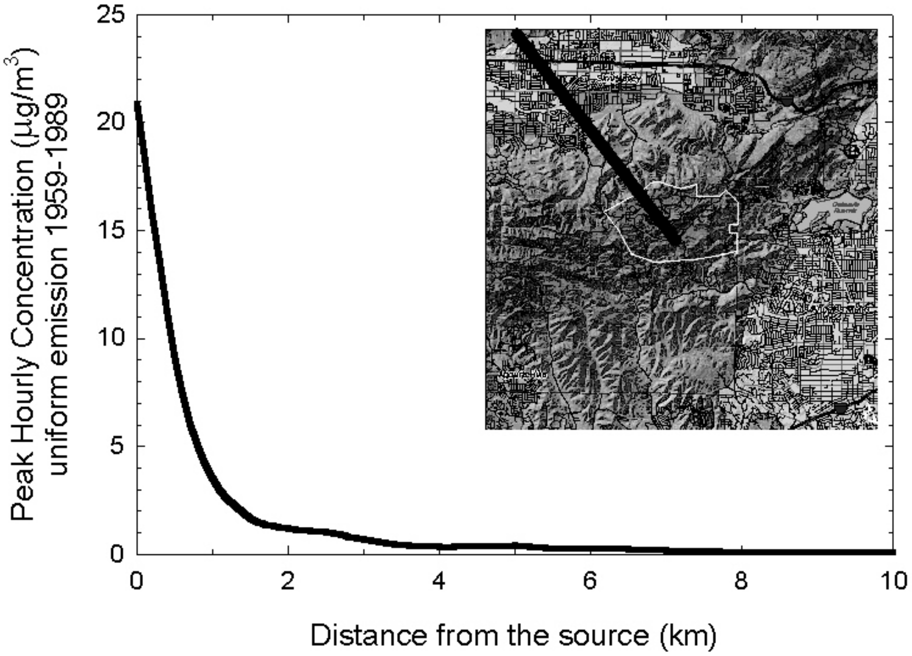


Figure 3-32. Average Hydrazine and Derivatives Concentration Associated with Open-Pit Burning. Profile from SSFL to UTM coordinates (351, 3796) for the estimated uniform emission (0.658 tons/year).

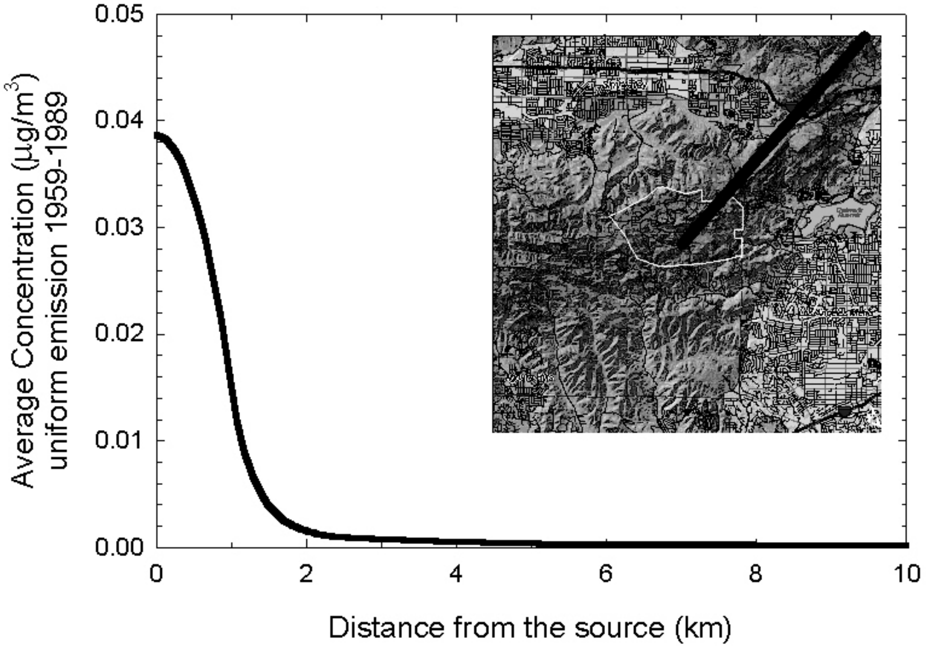


Figure 3-33. Peak Hourly Hydrazine and Derivatives Concentration Associated with Open-Pit Burning. Profile from SSFL to UTM coordinates (351, 3796) for the estimated uniform emission (0.658 tons/year).

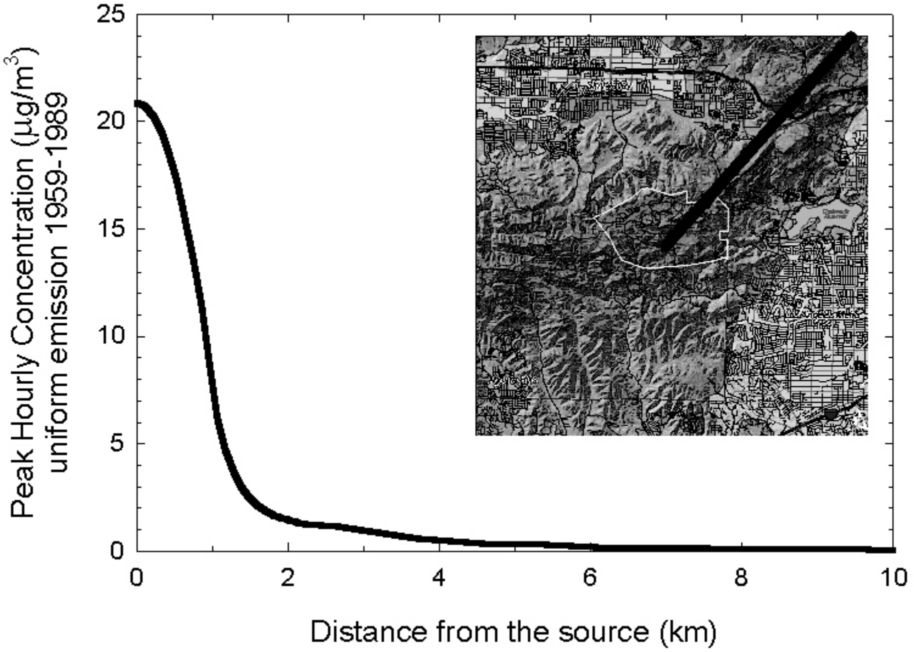


Figure 3-34. Average Hydrazine and Derivatives Concentration Associated with Open-Pit Burning. Profile from SSFL to UTM coordinates (351, 3781) for the estimated uniform emission (0.658 tons/year).

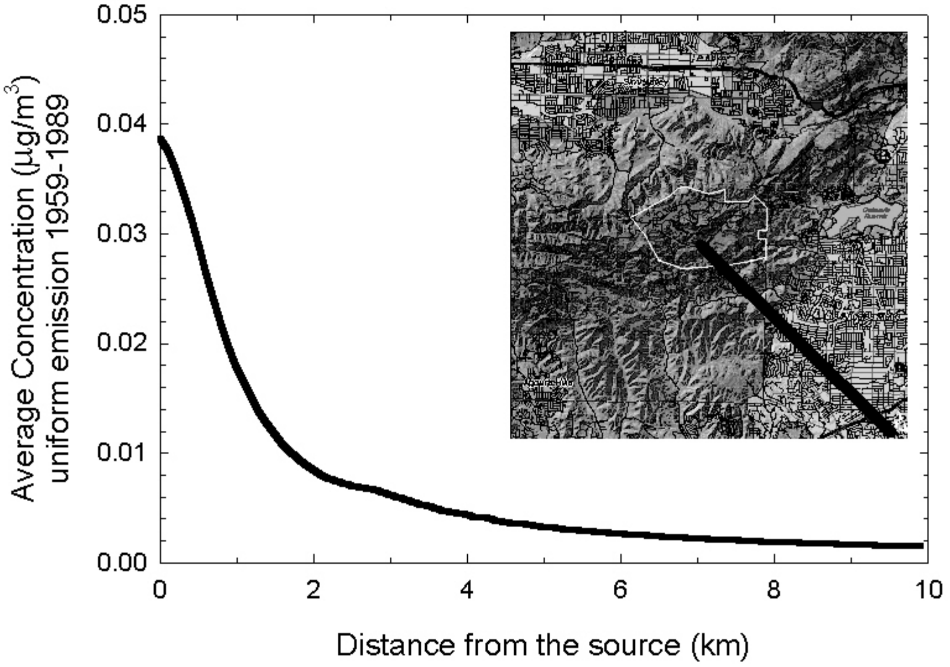
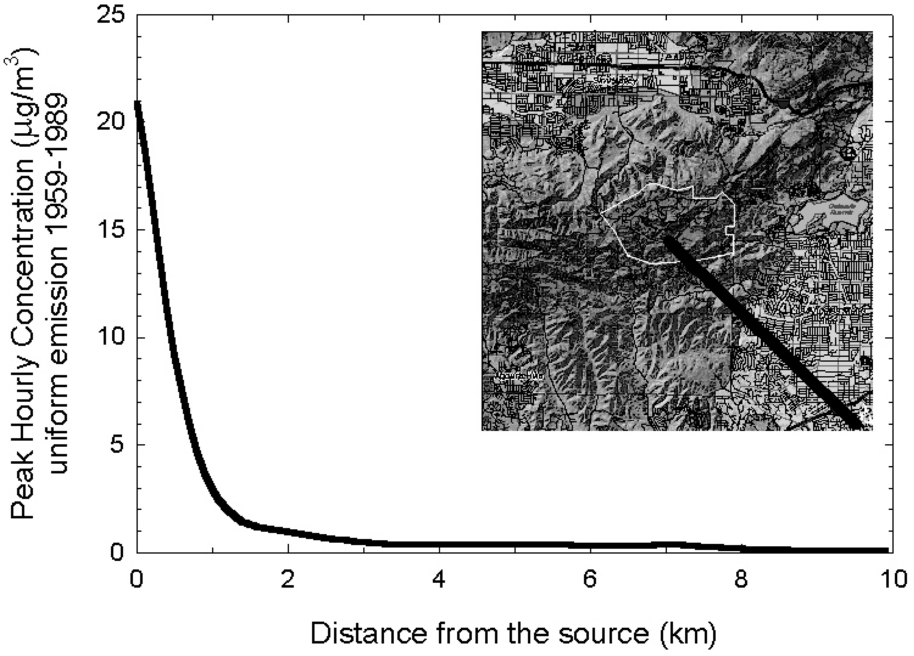


Figure 3-35. Peak Hourly Hydrazine and Derivatives Concentration Associated with Open-Pit Burning. Profile from SSFL to UTM coordinates (351, 3781) for the estimated uniform emission (0.658 tons/year).



3.3.6 Sensitivity Studies

The estimated airborne concentrations of SSFL emitted chemicals in populated areas surrounding SSFL were calculated following U.S. Environmental Protection Agency (USEPA) modeling guidance[3.3]. In this approach all four-years of Area IV on-site meteorological data were utilized to estimated hourly average atmospheric concentrations of air toxics associated with SSFL emissions. Long-term averages were also obtained in addition to 1-hour and 24-hour maximum concentrations. The estimated of air toxic concentrations did not consider atmospheric chemical degradations, dry deposition and rain scavenging. The above simplification was justified given the following argument. The reaction half-life for most organics is longer than their time of travel from SSFL across the study area. The rate of dry deposition of particle-bound chemicals is sufficiently slow and thus the impact on estimated concentrations within the study area would be small. Moreover, the particle size distributions from rocket engine tests are not known and thus could not be accurately incorporated into the model simulations. Wet deposition is episodic and given the low annual rainfall, rain scavenging of chemicals would have a negligible effect on the annual average long-term concentrations. It is emphasized that the consequence of neglecting atmospheric degradation and dry and wet deposition is a conservative (i.e., overestimate) estimate of atmospheric concentrations of SSFL emitter chemicals. A detailed discussion of the sensitivity studies conducted to assess the impact of the above model simplifications is provided in Appendix I.

While the various simulations discussed in Chapter 3 focus on annual averaged concentrations, these estimates do not identify the extent of potential exposure to significantly higher or lower concentrations in a single year. In order to identify the specific periods and level of highest exposure concentrations, there is need for accurate data regarding the number and timing of rocket tests and the meteorology associated with those tests. Unfortunately, the meteorology associated with individual tests may be difficult to reconstruct lacking routine nearby meteorological measurements from the start of testing (1948) to present (2004). The highest exposure concentrations for the population surrounding SSFL would be at the SSFL boundary. As suggested by the sensitivity studies (Appendix I), concentrations at the SSFL boundary could be up to a few orders of magnitude higher than the average airborne air toxic concentrations to which the population surrounding SSFL was exposed.

[3.3] Appendix W of 40 CFR 51.

4.0 GROUNDWATER AND SURFACE WATER PATHWAYS

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4.0 GROUNDWATER AND SURFACE WATER PATHWAYS

4.1 Overview

The groundwater system and surface water streams in the SSFL area and its immediate vicinity are a linked integrated system. The movement of groundwater is affected by the rate of recharge through precipitation, subsurface fracture systems, and groundwater pumpage by onsite water supply and remediation wells. Groundwater elevations at the SSFL site are significantly higher than elevations at Simi and San Fernando Valleys, with groundwater emerging from a number of springs and seeps in the canyons leading from the site into the valleys (GRC, 1987).

Groundwater monitoring studies have revealed significant groundwater contamination at the SSFL site, above health-based standards and regulatory levels (Appendix H; CHDS, 1999) McLaren/Hart, 1993, 1995; GRC, 1990a, 2000; Rocketdyne, 1958-1960, 1959-1989). There is also concern that chemicals and radionuclides have migrated away from SSFL via both groundwater and surface water pathways.[4.1] In order to identify groundwater and surface water contaminant migration pathways, as well as water COPCs (Appendix C), the study team reviewed NPDES releases, disposal and leakage from surface impoundments, site hydrogeology, groundwater pumping, and the extent of migration of subsurface contaminants.

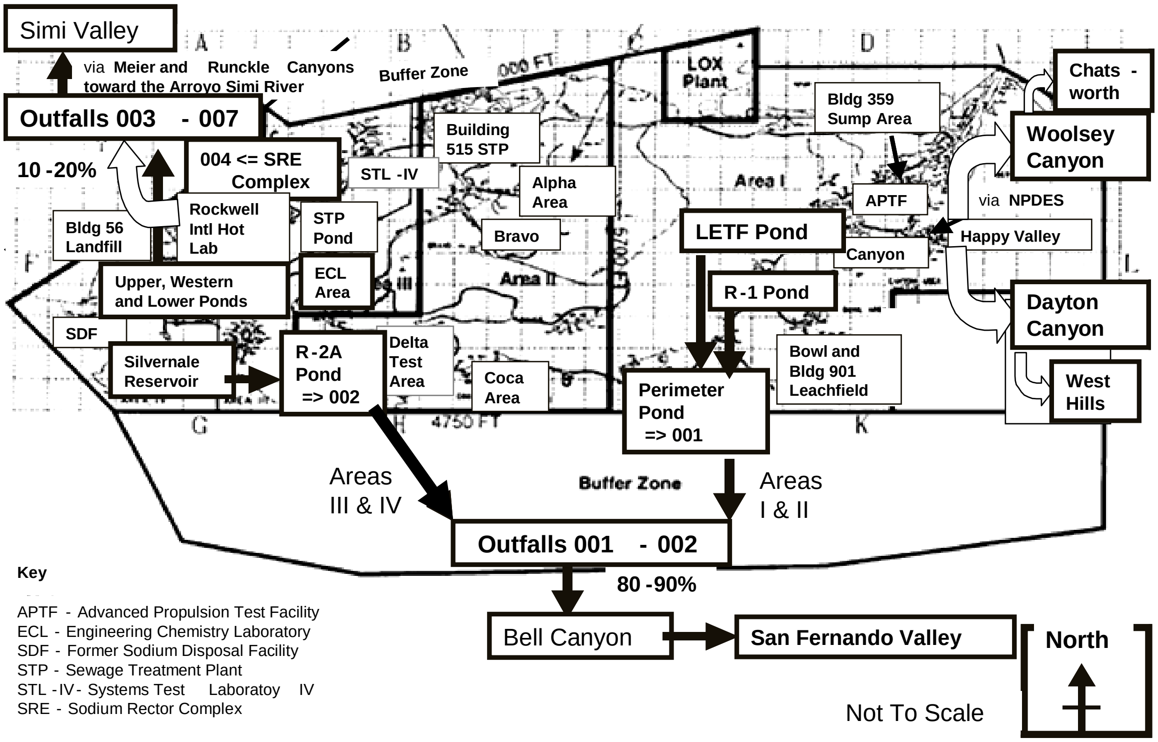
4.1.1 NPDES Releases

SSFL has a National Pollutant Discharge Elimination System (NPDES) permit[4.2] allowing it to discharge up to 160 million gallons of treated water per year (about 90% of the facility's surface water discharge). There are two NPDES outfalls (Figure 4-1): NPDES 001 (Perimeter Pond) and NPDES 002 (R2A) located near the undeveloped area south of SSFL and upstream (north) of the residential area of Bell Canyon (and Bell Creek) (Rockwell International, 1987; Boeing, 2003). These two onsite drainage channels join to form the headwaters of Bell Creek in the southern buffer zone of SSFL. Land south of SSFL is borderland and gated but easily accessible (see Chapter 6). South of this gated border zone is the Bell Canyon neighborhood, which extends essentially to the fence line. Chemical contamination above health-based standards has been reported in the Bell Creek headwaters (Table 4-1). The remaining 10 percent of treated water flows from Area IV into Outfalls 003 through 007 and drains north into the Simi Valley via Runckle and Meier Canyons.

[4.1] Techlaw consultants (1990) reported that "a number of ponds were not lined and are situated in a drainage eroded along a fracture or fault" (Techlaw, 1990). See Figure 4-1 for pond locations.

[4.2] NPDES Permit No. CA0001309 (Rockwell International, 1987; Boeing, 2003).

Figure 4-1. Locations of NPDES Drainage



4.1.2 Disposal and Leakage from Surface Impoundments

The SSFL water reclamation and contamination control system is formed by a series of surface impoundments (about 28 between 1963 and 1988) designed to collect cooling water, rinse water, stormwater runoff, and accidental spills. Waste collected in these impoundments consisted primarily of organic solvents, hydrazine fuels, oxidizers, and kerosene-based fuels (GRC, 1986). According to the Hydrogeologic Assessment Report by GRC (1987), approximately 870 tons of wastes were deposited in the impoundments from 1963 to 1988. It has been reported that a significant number of impoundments had either inadequate linings or no linings. The concrete linings in the older ponds were inadequately maintained, and cracking was reported (GRC, 1988a). Note that leachate recovery systems were not installed at the impoundments before 1988 (GRC, 1988a).

In 1991, the RWQCB sent a letter (RWQCB, 1991) to Rockwell International regarding the results of the 1990 GRC study, in which it was stated that: “Based on the analyses of disposal data at the facility and water elevation data [e.g., groundwater level is about 100–300 feet below surface in the vicinity of the SDF pond], it is apparent that hazardous waste constituents have migrated from the unlined pond at the Sodium Disposal Facility (SDF) to the vadose zone, Shallow Zone, and Chatsworth Formation groundwater system. It is also possible that migration is likely to continue.” The above early evaluation and evidence of groundwater contamination (Appendix H) beneath the SSFL site (GRC, 1990) suggest that there is a high likelihood that migration of contaminants, from leaky surface impoundments, has contributed to groundwater contamination (Table 4-1).

4.2 Hydrogeology

Groundwater and surface water flows determine the migration and dispersion of contaminants from SSFL via the water pathway. Therefore, it is instructive to review the hydrogeology at SSFL. Groundwater at SSFL is found in two systems: the shallow zone and the Chatsworth Formation. The shallow zone alluvium overlies the Chatsworth Formation, which is a Cretaceous marine turbidite sequence of sandstone interbedded with siltstone/mudstone and conglomerate lenses (Colburn et al., 1981). Zones of weakness, some of which have eroded to canyons infilled with alluvium, are formed by fractures, faults, or siltstone/claystone outcrops. Runoff from precipitation events flows in canyon bottoms and infiltrates in channels eroded along these zones of rock weakness (fractures and faults) (Techlaw, 1990).

General groundwater and surface water flow patterns are shown in Figure 4-2. Surface water and groundwater flow towards lower elevations in the north (Simi Valley), east (San Fernando Valley), and south (Bell Canyon) (GRC, 1987). Surface flows at SSFL drain to the north, northeast, south, southwest and east. Water level contours indicate a west to northwesterly component of groundwater flow in the northwestern portion of the facility and a southerly component of groundwater flow in the southwest portion of the facility (Rocketdyne, 1988). Connectivity of groundwater and surface water flows is hampered by low precipitation in the region. The mean annual precipitation from 1960 to 1986 (from the Simi-Hills/Burro Flats station) was reported to be in the range of 18.6 to 21.5 inches (Techlaw, 1990). A mean annual precipitation of 22.5 inches was reported for the period of 1978 to 1985 (GRC, 1987). Because of the low precipitation level in the region, there are only intermittent surface water runoff flows downhill from SSFL; this has resulted in limited offsite runoff water sampling, thereby preventing sufficiently detailed chemical and radiological characterization of surface water runoff.

Source: RWQCB

Figure 4-2. Surface Water (Light Lines) and Groundwater Flows (Bold Lines)

The shallow groundwater zone occurs within the thin (0 to 20-foot), discontinuous superficial alluvium found along canyon drainages and in underlying zones of weathered sandstone and siltstone (Techlaw, 1990). It comprises a heterogeneous mixture of gravel, sand, silt, and clay and is estimated to have a hydraulic conductivity of 0.001 to 0.1 gpd (gallons per day)/ft^2 (Techlaw, 1990). This zone is distributed primarily in the Burro Flats area (Area IV) and along ephemeral drainage features (Techlaw, 1990). The shallow zone may be saturated along ephemeral drainages and in the southern part of Burro Flats (Techlaw, 1990). Some portions of the shallow alluvium are saturated only during and immediately following the wet season. Groundwater in this zone flows under unconfined conditions. The thickness of the saturated portion of the shallow zone ranges from less than 1 foot to as much as 10 feet. The surface of the saturated portion of the shallow alluvium is a subdued expression of the topographic surface. Water in the shallow zone may move laterally to an area of discharge or downward into the underlying Chatsworth Formation via connecting fractures (Techlaw, 1990).

The principal groundwater aquifer is within the Chatsworth Formation (Techlaw, 1990). The Chatsworth Formation may be as thick as 6,000 feet at the facility, and is overlain in places by the Martinez Formation and by Quaternary alluvium. Fractures occurring in the Chatsworth Formation may be associated with bedding planes, jointing,[4.3] and faulting.[4.4] A number of faults are present at the site. These have two general orientations: the North, Coca, Burro Flats, Woolsey Canyon and Happy Valley Faults generally strike east/west, while the Shear Zone and Skyline Fault generally strike northeast/southwest. All faults appear to dip nearly vertically. There is disagreement as to whether the unfractured portions are permeable. Montgomery-Watson presented a model in which the “fracture network is interconnected, and groundwater flow is compartmentalized by the presence of lower permeability shale units and faults” (Montgomery Watson, 2000a). A report from Groundwater Resources Consultants (GRC) suggested that almost all water flow is in zones of fractures and that the unfractured portions are virtually impermeable (GRC, 1999). However, a 1999 letter from Ventura DHS to Rocketdyne warned that “The term virtually impermeable is misleading and wells constructed in unfractured areas still produce groundwater” (DHS, 1999).

The fracture subsurface system in the SSFL area makes it difficult to predict groundwater movement. Multiple methods have been used to derive estimates of the bulk hydraulic conductivity of the Chatsworth Formation. These methods show that the overall bulk hydraulic conductivity is likely to be in the range of 1×10^{-5} cm/s to 5×10^{-5} cm/s (MWG, 2003). Permeabilities in this fractured formation range from approximately 0.01 to 1,000 gpd/ft^2; this wide range in permeability can be attributed to the fractured nature of the formation. The inflow into the groundwater system was estimated to be approximately 2 inches per year (MWG, 2003. Outflows from the groundwater system include discharges through springs and seeps, groundwater extraction for interim remedial measures, and discharge to the surrounding groundwater system (MWG, 2003).

To summarize, it appears that in some areas of SSFL the two groundwater systems are connected hydrologically. In others, the shallow zone aquifer is separate and distinct from the Chatsworth Formation groundwater, as evidenced by vastly different groundwater elevations and contaminant concentrations. Even in those areas, though, it is likely that the shallow zone transmits groundwater and contaminants to the underlying fractured Chatsworth Formation (GRC, 1986).

[4.3] A joint is a divisional plane or surface that divides a rock along which there has been no visible movement parallel to the plane or surface.

[4.4] A fault is a fracture or fracture zone along which the two sides have been displaced relative to one another, parallel to the fracture.

4.2.1 Groundwater Pumpage

Onsite groundwater withdrawals, which commenced in October 1948, have reduced water levels at wells northeast of the facility (on and off site) (Rocketdyne, 1988). This has caused partial groundwater stagnation in certain areas around SSFL. As early as 1957, heavy pumping around the northeast corner of SSFL induced groundwater to migrate toward that quarter of the facility; pumping there was conducted primarily because that quadrant had the best yielding wells (Rocketdyne, 1988). This practice of heavy pumping in the northeast quadrant has continued from the 1950s to the present time. Since at least the early 1980s, groundwater extractions have been limited exclusively to that quadrant (Rocketdyne, 1988). It has been suggested that pumping at offsite wells northeast of the facility (i.e., wells RD-38A and OS-24) may have been responsible for the TCE plume's migration off site along the northeast boundaries of SSFL (ERD, 1992). The offsite wells appear to be located along major interconnected fracture systems (Rocketdyne, 1988). In recent years, substantial additional characterization efforts have focused on the above area (Montgomery Watson Harza, 2003a).

Because the pumping has lowered the groundwater table at SSFL overall (not just in the northeast), several existing wells were deepened and recycling and reuse of industrial water had to be implemented (Rocketdyne, 1988). As pumpage volumes continued to increase with time (from 1964 to 1988) and groundwater levels decreased, Rocketdyne was required to turn to imported water from Callegas Municipal Water District to supplement onsite drinking water (Rocketdyne, 1988). The ratio of imported water to water from well extractions, since 1984, has been approximately 2:3 (Rocketdyne, 1988).

4.2.2 Extent and Migration of Subsurface Contamination

In various offsite locations, groundwater contaminants have been detected at levels above health-based standards (see Table 4-1 and Figure 4-3). The detection of contaminants associated with SSFL off site, within 1 to 2 miles, suggests that—if these contaminants have originated from SSFL—migration pathways must exist. These pathways include surface water runoff (controlled and natural) in the northwest and south, as well as migration via groundwater in the northeast and northwest. Migration via surface water away from the site is associated primarily with manmade channels (e.g., NPDES outfalls), although natural surface flow can also take place during periods of heavy rainfall.

Table 4-1. Offsite Water Contaminants Detected Above Health-Based Standards

Chemical	Concentration (µg/L)		Date Detected	Location/Sample Identification	Sample Location, Sample Type, Factor by Which Detected Levels Are Above Standards or Comments	Ref
	Monitored Level[a]	Regulatory Standard[b and c]				
Chromium	75	50 [b]	1/28/93	NPDES Outfall 002	South	2
Nickel	130	100 [b]	12/6/94	NPDES Outfall 002	South	2
Lead	40	12 [b]	1/9/95	NPDES Outfall 001	South	2
Chromium	390	50 [b]	3/94	RD-32	Northeast (Sage Ranch)	3
Lead	50	12 [b]	12/94	RD-43	East (Woolsey Canyon)	3
Chloromethane	19	1.5 [c]	4/10/86	OS-5	12x > TWSL; livestock well	2
Bis(2-ethylhexyl) phthalate (DEHP)	66	6 [b]	1/13/90	SBP1	Surface water	2
Bis(2-ethylhexyl) phthalate (DEHP)	109	6 [b]	1/13/90	SBP2	Surface water; EPA priority analysis	2
Bis(2-ethylhexyl) phthalate (DEHP)	170	6 [b]	1/17/90	SBP1	Surface water	2
Fluoride	4,600–5,400	2,000 [b]	1/90-2/90	OS-2	Livestock well	1
Bis(2-ethylhexyl) phthalate (DEHP)	70	6 [b]	2/17/90	SBP1	Surface water	1
Bis(2-ethylhexyl) phthalate (DEHP)	97	6 [b]	2/17/90	SBP2	Surface water; EPA priority analysis	1
TCE	10	5 [b]	3/11/92	SMMC: well by gate	Groundwater	1
PCB-1254	120	0.5 [b]	2/4/94	Outfall 005	240x > MCL	7
PCB-1254	92	0.5 [b]	2/4/94	Outfall 006	184x > MCL	7
Lead	210	12 [b]	2/17/94	Outfall 003	14x > MCL	3
Vinyl chloride	64	0.5 [b]	3/94	RD-56A	128x > MCL	6
TCE	670	5 [b]	8/94	RD-38A	134x > MCL	6
Benzene	3.8	1 [b]	11/94	RD-38A	Groundwater	6
Carbon tetrachloride	4.5	0.5 [b]	2/95	RD-59A	> 9x MCL; northwest (west of Area IV RMDF)	6
Lead	30	12 [b]	1/3/95	Outfall 006	Northwest	5
Beryllium	8	4 [b]	5/15/95	Outfall 006	Northwest	5
Chromium (total)	240	100 [b]	5/15/95	Outfall 006	Northwest	5
Lead	45	12 [b]	5/15/95	Outfall 005	Northwest	5
Benzene	5.6	1 [b]	5/15/95	Outfall 005	Northwest	5
Lead	16	12 [b]	5/15/95	Outfall 003	Northwest	5
Lead	45	12[b]	5/15/95	Outfall 003	Northwest	5
Lead	75	12 [b]	5/15/95	Outfall 006	Northwest	5
Nickel	170	170 [b]	5/15/95	Outfall 006	Northwest	5
Beryllium	5	4 [b]	1/31/96	Outfall 006	Northwest	5
Lead	47	12 [b]	1/31/96	Outfall 006	Northwest	5
Cadmium	5	3.7 [b]	1/31/96	Outfall 006	Northwest	5
Zinc	420	110 [b]	1/31/96	Outfall 006	Northwest	5

Chemical	Concentration (µg/L)		Date Detected	Location/Sample Identification	Sample Location, Sample Type, Factor by Which Detected Levels Are Above Standards or Comments	Ref
	Monitored Level[a]	Regulatory Standard[b and c]				
1,1-DCE	19	6 [b]	5/96	RD-38A	Groundwater	6
Trans-1,2-DCE	38	10 [b]	5/96	RD-56A	Groundwater	6
1,1-DCA	6.5	5 [b]	11/96	RD-38A	Groundwater	6
Cis-1,2-DCE	27	6 [b]	11/96	RD-38A	Groundwater	6
TCE	250–570	5 [b]	8/9/95–2/2/97	RD-38A (NE of Area I off site, Sage Ranch)	9 samples	4
Perchlorate	5	2-4 [b]	8/98	RD-59A	Northwest (west of Area IV RMDF)	6
Perchlorate	4.26	2-4 [b]	5/5/98	Outfall 006	Northwest	6
TCE	130–570	5 [b]	8/7/97–8/18/99	RD-38A (NE of Area I off site, Sage Ranch)	6 samples	4
Cis-1,2-DCE	75–630	6 [b]	3/18/84–2/4/99	RD 56 A N of Area III	19 samples	4
Trans-1,2-DCE	22–82	10 [b]	3/18/84–2/4/99	RD 56 A N of Area III	18 samples	4
TCE	330–900	5 [b]	3/18/84–2/4/99	RD 56 A N of Area III	19 samples	4

[a] Concentrations represent single reported values (unless a range is given) from measurements (not averages) taken in the indicated locations; they represent all contaminant detections above health-based standards.

[b] MCL = U.S. EPA Maximum Contaminant Levels allowed in drinking water. Note: there is a debate regarding the standard for perchlorate.

[c] TWSL = Region 9 Tap Water Screening Level.

Notes:

Abbreviations: IDM = insensitive detection method; DEHP = bis(2-ethylhexyl)phthalate; SMMC = Santa Monica Mountain Conservancy; BBI = Brandeis-Bardin Institute

Wells: RD-32 and 43= Sage Ranch and Woolsey Canyon Wells, respectively; OS-2 and -5 = offsite wells used for livestock NW of SSFL at BBI; RD56A and RD-38A = SSMC wells; RD-59A= deep well located on BBI property.

References: 1. McLaren/Hart, 1993. 2. Boeing, 1990–2003. 3. CHDS, 1999. 4. GRC, 2000. 5. Rocketdyne, 1959–1989. 6. Boeing, 2002. 7. Rocketdyne, 1995.

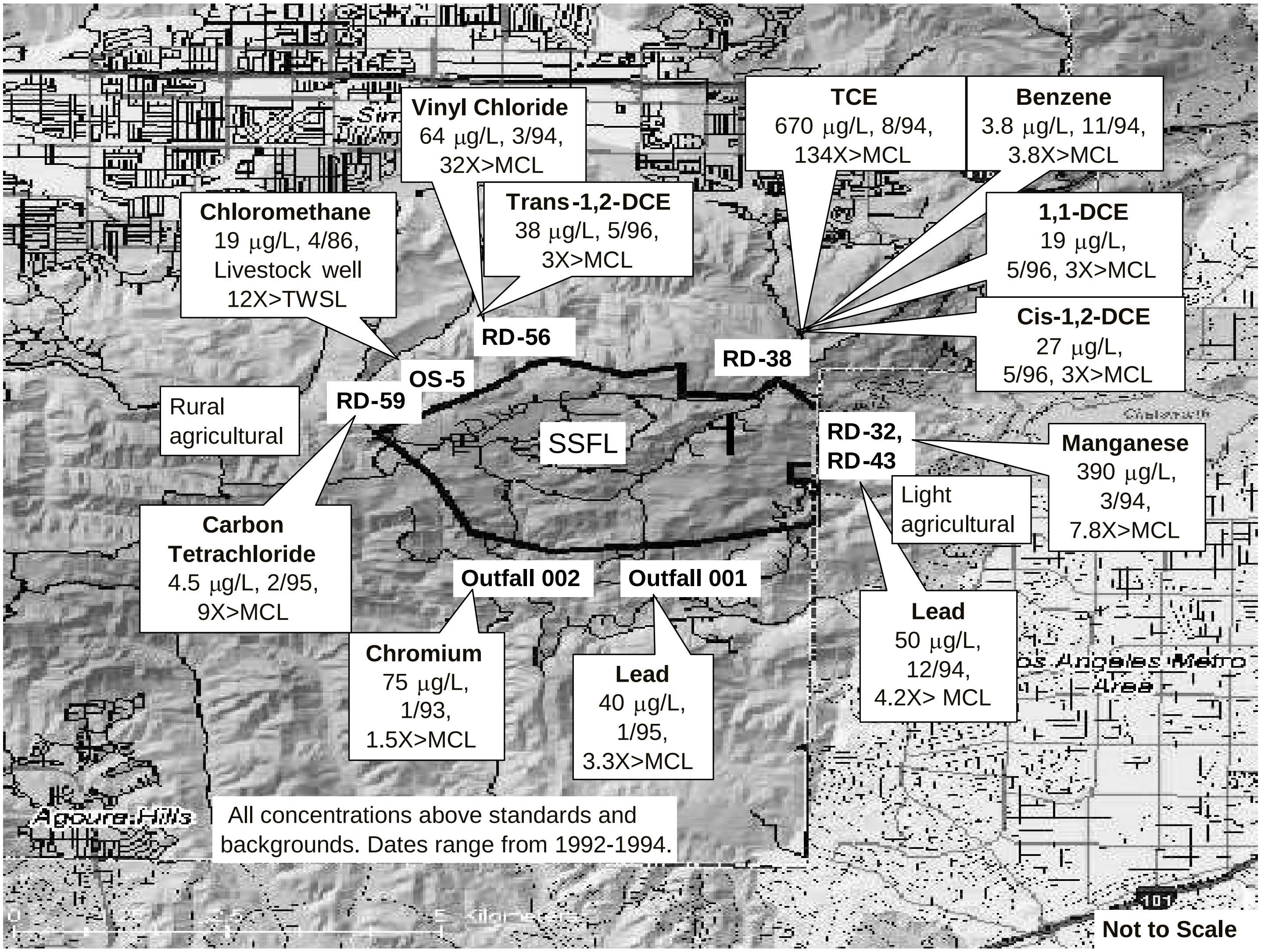


Figure 4-3. Offsite Locations of Selected Groundwater Contaminants of Concern Detected at Levels Above Health-Based Standards. All offsite water contaminants (surface water and groundwater) were compared to MCLs, or Maximum Contaminant Levels (EPA-suggested drinking water standards). The identified contaminants are listed with their offsite detection levels, their dates of sampling, and the factors by which their concentrations were found to be above the MCLs. Contaminants were detected above health-based standards in groundwater northeast, northwest, and east of the facility, as well as in NPDES outfalls on the northeast and south borders of the facility.

4.3 Groundwater and Surface Water Exposure Issues

4.3.1 Private and Public Wells

The presence of contaminants in groundwater can pose a health risk if there is direct or indirect exposure to the contaminated water and if these contaminants are or may have been present above levels of health concern. Indeed, community concerns have been expressed regarding potential exposure to contaminants in private wells (ATSDR, 2000; Appendix G). Accordingly, the potential for community exposure to contaminated groundwater (via groundwater well use) and surface water is discussed in Chapter 6.

Exposure to groundwater can take place if groundwater is used for irrigation of edible crops, or as a source of drinking water for people or livestock. Therefore, it is essential to evaluate the locations of groundwater wells and groundwater use around SSFL. Table 4-2 provides a partial listing of offsite domestic and irrigation wells in the SSFL area, identifying the wells' locations, use, and detected contamination. The locations of selected wells in the immediate vicinity of SSFL are also indicated in Figure 4-3. An expanded discussion of potential exposures to contaminants in groundwater wells is provided in Chapter 6, and a brief account of well usage in the SSFL area is provided below,

An early assessment in 1988 identified 400 private domestic wells and one municipal well within 3 miles of the SSFL facility (GRC, 1988 a and b). Most of the private domestic wells are located in the Santa Susana Knolls community and the unincorporated areas outside the city of Simi Valley. It is unknown if privately owned wells in Santa Susana Knolls and Simi Valley have been affected by chemicals from SSFL. Note, however, that three domestic wells were identified within 2,000 feet to 1 mile of Area II (towards Santa Susana Knolls), serving an estimated population of 12 (GRC, 1988b). Between 1 and 2 miles from Area II, there are approximately 100 domestic wells serving an estimated population of 400; between 2 to 3 miles of Area II, there are approximately 300 wells and one municipal well serving an estimated population of 5000 to 10,000 (GRC, 1988b). Information could not be obtained regarding the water quality of this single municipal well, despite attempts to procure such information from the Southern California Water Company (Appendix J). Other entities contacted for well information included the Los Angeles County and Ventura County public works agencies and water resources departments (see Appendix J).

Groundwater wells beneath SSFL were used as potable water sources from the 1940s to the 1970s (Steve Lafflam, 2004). SSFL has 17 water supply wells that were constructed prior to 1960. These wells provided about 58 million gallons of water per year for sanitary, cooling, and other industrial uses. The local potable water supply was supplemented with bottled water after the late 1960s because of a "bad taste" (Lafflam, S., 1993 and 2004).

Table 4-2. Examples of currently or previously active offsite groundwater wells[(#)]

Well ID	**Well Location**[a]	**Well Use**	**Contamination**	**Comment**	**Time Used**	**Vicinity**
1	2N/17W-20H1	Domestic/ irrigation	"Chemical analysis shows basin water is contaminated with solvents." (6/89)		11/87–? Permit ends 2006	On Black Canyon Rd. by Woolsey Canyon
2	2N/17W-20P1	Irrigation	NA		NA	NA
3	2N/17W-21H1	Irrigation (orchards)	NA	477 ft. depth	5/16/54–?	By Sage Ranch Box Canyon Motorway mobile home park
4	2N/17W-21L1	Domestic/ irrigation	"Chemical analysis shows basin water is contaminated with solvents." (1989) "Severe levels of iron—11 mg/L." (10/95)	40 ft. depth	12/2/87–?	0.22 mi. NE of SSFL, #1 Black Canyon Rd.
5	2N/17W-21R2	Domestic	Manganese: 35 ppm	Owner: Chatsworth Mutual Water Co.	5/18/61–?	On road to SSFL
13	2N/17W-28B1	Domestic	"chemical analysis was not available"		5/18/60–?	On road to SSFL
25	2N/18W-20S1	Domestic	Perchlorate: 82 µg/L (2/12/03), *debated;* 140–150 µg/L (5/1/03)	Bathtub well #1; Listed as domestic (reported in other sources as livestock)	NA	Brandeis-Bardin Institute

[a] **Source:** Ventura Public Works Agency, Water Resources and Development Division. The well location identifications were derived from US Geological Survey (USGS) topological maps which the Public Works Agency uses to identify well locations. Latitude and longitude are N and W respectively and the dashed notations identify the map quadrant where the wells are located. This agency does not have records on many private wells and older wells. This table's survey of wells in the area is incomplete because of the lack of official information on the location and use of wells.

[#] - locations correspond to those indicated in Figure 4-4.

NA – information not available

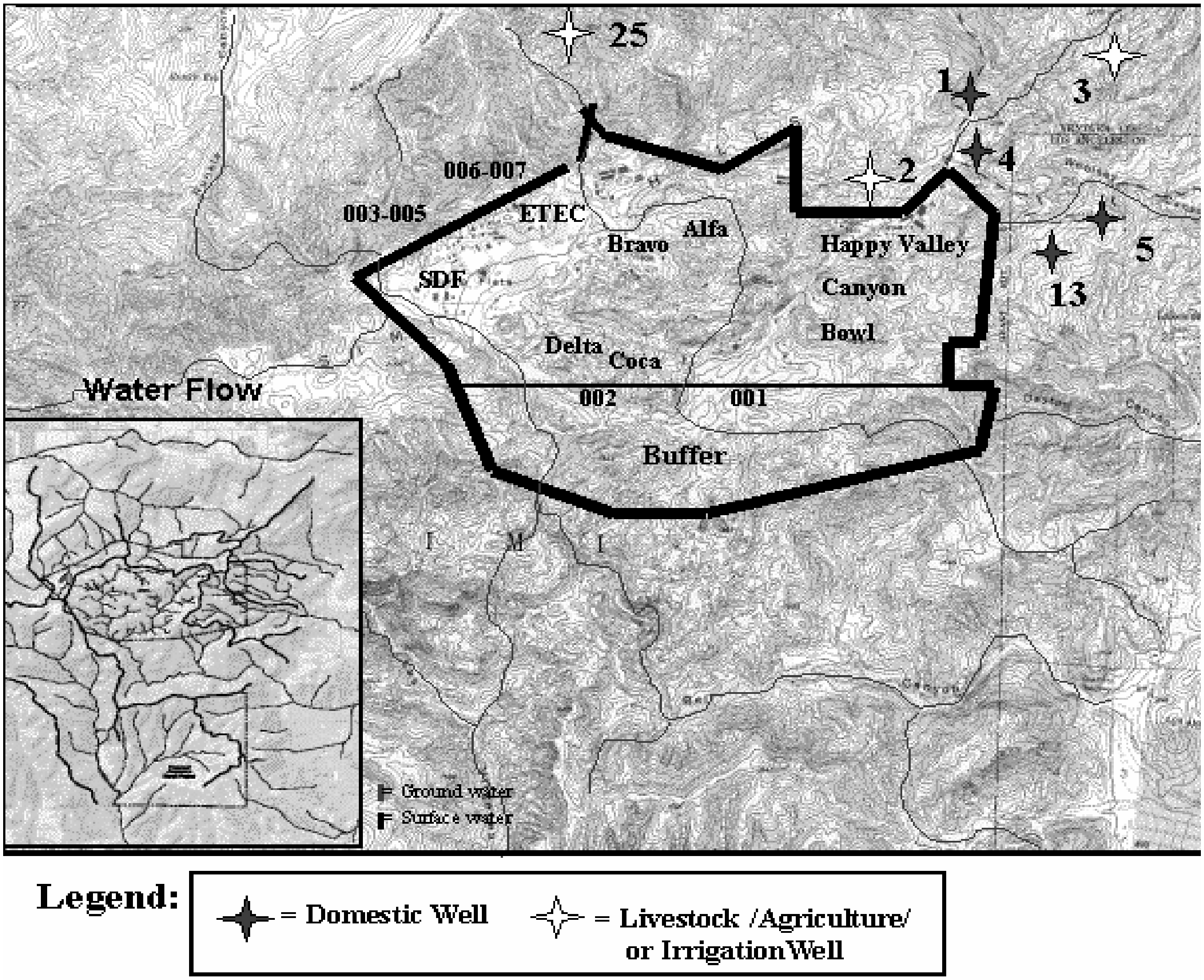


Figure 4-4. Example of Locations of Domestic and Irrigation Wells in the SSFL Area. These wells were identified from the files of the Ventura Public Work Agency's Water Resources and Development Division. Well locations are shown in relation to SSFL surface water pathways. Additional information for the wells in the figure is provided according to the wells' numbers in Table 4-2. An expanded list of offsite well contaminants detected above health-based standards and relevant concentrations is provided in Appendix H. **Note:** The three wells whose present status is unknown, OS-16, OS-17, and OS-18, were identified as domestic wells (ERC, 1990b) on the Los Angeles County side of SSFL (east) near the border.

5.0 SOIL AND SEDIMENT: MONITORING AND CONTAMINANT MIGRATION

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5.0 SOIL AND SEDIMENT: MONITORING AND CONTAMINANT MIGRATION

5.1 Soil and Sediment Monitoring Studies

Soil and sediment monitoring studies were conducted in four main areas off the SSFL site. These include the Brandeis-Bardin Institute (BBI) (McLaren/Hart, 1993; 1995), the Santa Monica Mountains Conservancy (SMMC) (McLaren/Hart, 1993; 1995), Ahmanson Ranch (Klinefelder, 2000), and the Bell Canyon areas (Ogden, 1998a). Samples were analyzed for a variety of chemicals and radionuclides.[5.1] Although sampling in offsite areas was limited, the detection of radionuclide and chemical contaminants in the samples suggests that contaminants migrated from SSFL to these offsite locations (Appendix H).

In the 1995 McLaren/Hart study, soil and sediment samples were collected from BBI, SMMC and along NPDES drainage channels northwest of Area I (McLaren/Hart, 1995). Figure 5.1 depicts offsite soil contamination detected in the vicinity of SSFL for a select number of chemicals. Tables H-6 and H-9 in Appendix H summarize offsite samples in which contaminants were detected above health-based standards from the McLaren/Hart study (1995), as well as the standards used for comparison.[5.2]

Arsenic was detected in soil samples at significant levels above health-based standards (residential soil screening levels or RSSLs) at the SMMC, and the BBI. However, arsenic levels in various California soils are naturally high (McLaren/Hart, 1993, 1995; Appendix H); it occurs in soil and groundwater as a result of releases from erosion of mineral deposits, though human activities can also lead to substantial contamination (ATSDR, 1990). Background concentrations of arsenic in California can be as high as 2.3 to 11 mg/kg (, according to 1986 California soil samples (<2.5 from surface) (Hunter, P., 2005). While SSFL area soil samples contained approximately 1 to 24 mg/kg of arsenic (see Table 6-4), it is still not possible to ascertain whether these levels are comparable to natural background soil conditions or are due to activities associated with SSFL such as waste incineration. The largest anthropogenic sources of inorganic arsenic emissions to the atmosphere are waste combustion and high-temperature processes (ARB, 1998).

Soil contamination by lead, beryllium, and cesium-137 was also detected south of SSFL at the Bell Canyon and Ahmanson Ranch properties (Ogden, 1998a; Klinefelder, 2000; Appendix H). The perchlorate dose ratios (DRs, see Chapter 6) associated with contaminated groundwater in Simi Valley were generally low: they ranged from about 0.05 to 2, even assuming 30 years of exposure at maximum detected levels. See Appendices H and R for offsite levels of perchlorate used in the analysis and the resulting DRs (Table R-5). However, DRs above 1 were determined for inhalation exposure to TCE and hydrazine (and its derivatives) in multiple receptor locations around the SSFL facility (Table 6-6). The implications of the DR values for the identification of areas of exposure concern are discussed in Chapter 6.

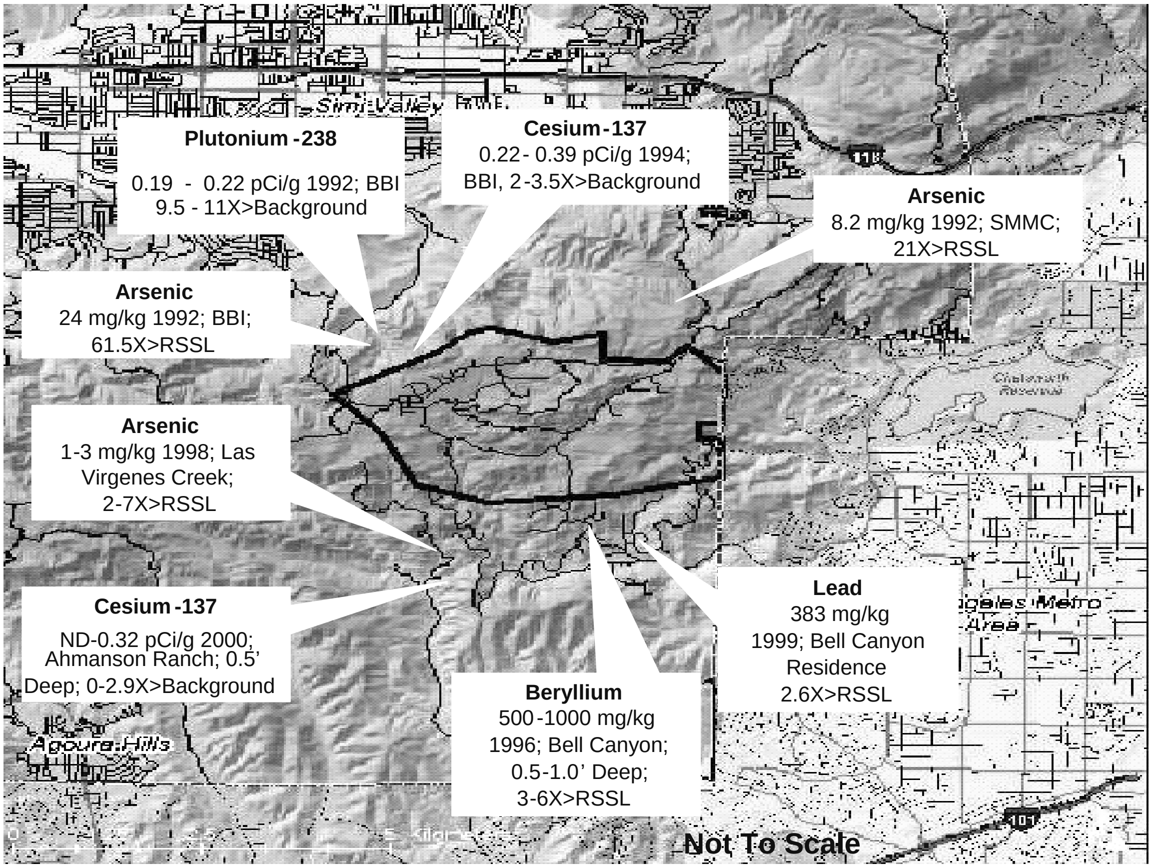
[5.1] See Chapter 2 for a discussion of radionuclide contamination.

[5.2] Note that methylene chloride and toluene were detected in soil samples collected at SMMC but not in background samples collected 2.5 to 12 miles away (McLaren/Hart, 1993, 1995; Appendix H).

5.2 Chemical Migration from Contaminated Soil and Sediment

Soil contaminants can migrate from SSFL in three ways: (1) volatilization from the soil subsurface and subsequent air dispersion, (2) wind re-suspension of contaminated soil particles and subsequent air dispersion and deposition onto offsite soil and (3) surface runoff of soil contaminants from (in SSFL's particular case) NPDES release pathways or natural surface streams with subsequent release to surface water or accumulation in sediment (ATSDR, 1999). Surface water pathways do exist that could be responsible, in part, for offsite transport of soil by intermittent runoff.

Figure 5-1. Offsite Soil Contamination at Levels Above Health-Based Standards and Background Levels



Note: Data collected from 1992 to 1994. Concentration, date detected, location of detection, depth of detection, and exceedence of a health-based standard or background concentration are presented. Depth presented where provided in monitoring reports. (Detections assumed to be at surface level for the purpose of exposure assessment unless otherwise stated in original monitoring report.)

Soil and sediment samples were collected in areas of Bell Canyon that were likely to have been impacted by surface water flow from the SSFL site[5.3] (Ogden, 1998a,b). Note that beryllium was

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[5.3] TCE is discussed in Section 5.3.

detected (up to 1000 mg/kg in soil) above health-based standards (150 mg/kg RSSL) at depths of 0.5 to 1.0 feet (Figure 5-1; Appendix H). Atmospheric deposition is unlikely to have caused contamination at such depths. It is more plausible that the beryllium migrated to offsite areas via runoff and sediment transport during periods of rainfall: at such times, surface water from SSFL flows primarily in (1) a northerly direction via two channels that ultimately discharge at NPDES-permitted outfalls at the northwest property boundary and (2) a southerly direction via two channels that ultimately discharge at two NPDES-permitted outfalls at the southern property boundary (ATSDR, 1999). Note also that soil and sediment sampling along NPDES drainage channels within the BBI and SMMC suggests that PCBs, TCDD (dioxins), and mercury may have migrated in drainages from the Sodium Disposal Facility to offsite areas (McLaren/Hart, 1995).

A clear pattern of topsoil contamination at and away from SSFL would be indicative of potential migration via wind soil re-suspension. However, it is not feasible to establish a clear pattern since there is a concern regarding the adequacy of background samples collected in the late 1990s[5.4] from undeveloped portions of Bell Canyon in areas thought not to be impacted by surface drainage (Ogden, 1998a). Some of these background samples were taken from locations between Bell Canyon and SSFL, in areas which could have been impacted by air dispersion and deposition from SSFL; thus rendering these background samples inadequate for comparison purposes. For example, *n*-nitrosodiphenylamine (NDPA) was detected above analytical reporting limits in background surface soils between SSFL and Bell Canyon at a maximum concentration of 36 µg / kg.[5.5] NDPA is not a naturally occurring substance; it is a man-made chemical that was used in rubber compounding and production. As NDPA was not detected in samples collected along drainage channels, its' presence in background soil samples between SSFL and Bell Canyon suggests that it was transported via air dispersion (Ogden, 1998a; McLaren/Hart, 1993; Boeing, 1990–2003). Indeed, it has been argued that NDPA releases from SSFL would have occurred as air emissions (ATSDR, 1993). Although the concentrations detected off site were all well below the RSSL of 99 mg / kg set by EPA Region 9 (EPA, 1996b),[5.6] offsite detection in areas distant from drainage channels suggests the possibility of migration of soil-bound NDPA particles via air dispersion from SSFL. In support of this possibility, analysis of wind patterns in the SSFL region indicates that the general wind pattern is north-northwest from the ocean during the day.[5.7] Therefore, the potential for wind re-suspended contaminant migration from SSFL cannot be discounted (ATSDR, 1993).

Contaminants found in offsite soil that potentially originated from SSFL and were found in areas of potential exposure include lead, beryllium, arsenic, methylene chloride, toluene, cesium-137, and plutonium-238. These contaminants were found above health-based standards in a number of

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[5.4] Background samples were collected for the following chemicals and radionuclides: As, Ba, Be, Cr, Pb, NDMA, NDPA, PCBs, PAHs, TCDD-TEQ, perchlorate, K-40, Ra-226, Th-228/230/232, H-3, and U-233/234/235/238.

[5.5] The exact location of this sample could not be discerned from the information received, therefore consideration of terrain obstacles to wind dispersion could not be considered in the discussion of background sample appropriateness.

[5.6] EPA has not reported an inhalation reference concentration or an oral reference dose for NDPA. It is not known if exposure to NPDA by breathing or skin contact can affect the health of humans or animals. NDPA has been classified as a probable human carcinogen for exposure via the ingestion route and has been demonstrated to cause adverse health effects in animals (NDPA has a B2 carcinogen listing; EPA, 1995a).

[5.7] The general diurnal winds are predominantly north-northwest, blowing from the ocean; the direction reverses to the east-southeast during the night (Rutherford, 1999).

locations, including residential and recreational areas immediately north and south of the facility (Figure 5.1). Lead and beryllium were detected in soils samples south of SSFL in Bell Canyon, at levels exceeding RSSL standards (Ogden, 1998a). Arsenic and cesium-137 were detected south of SSFL at the Ahmanson Ranch at levels exceeding RSSLs and reported backgrounds respectively (Klinefelder, 2000; Appendix H, Table H-4). Cesium-137, plutonium-238, and arsenic were detected north of SSFL, albeit on border property since purchased by Boeing from the BBI, at levels exceeding background levels and soil standards for arsenic. Background levels for lead and beryllium were not reported with the monitoring data for these chemicals (Appendix H, Table H-4). Background ranges for cesium-137 and plutonium-239 were averaged soil radiation levels in East Ventura and West LA Counties. However, as these background concentrations were derived from Ogden (1998a,b) given the inadequacy of the background sample locations, comparison to these reported background levels may not accurately represent the extent of the radionuclide contamination. Methylene chloride and toluene were detected in soil samples collected at SMMC but not in background samples 2.5 to 12 miles away (McLaren/Hart, 1993, 1995; Appendix H, Table H-6). Although arsenic was detected at significant levels (1-24 mg/kg) above health-based standards in soil samples (2-62x> RSSL) at SMMC, BBI, and Las Virgenes Creek, it is unclear if the arsenic levels were above natural area background levels given that high natural levels in various California soils (2.3-11 mg/kg, Air Force, 2002), and the inadequacy of background samples collected from areas between Bell Canyon and SSFL (McLaren/Hart, 1993; 1995; Appendix H).

In summary, based on information reviewed (McLaren/Hart, 1993, 1995; Ogden, 1998a; Rockwell International, 1992a; GRC, 1993; ICF Kaiser, 1995; ITC, 1999), it is plausible that contaminants that have been detected in offsite soil samples have been transported to offsite locations from SSFL.

5.3 Soil TCE Gas Monitoring and TCE Soil Emission Estimates

5.3.1 Overview of TCE Soil Monitoring Data

A number of studies have been carried out to characterize the SSFL site and assess the extent of TCE contamination and migration (Montgomery Watson, 2000a, 2000b, 2002; GRC, 1986–2000; Ogden, 1999). It is estimated that a significant volume of the TCE used for cleaning rocket engines[5.8] infiltrated the soil and contaminated the aquifer below SSFL (GRC, 1999). When a nonaqueous-phase liquid, such as TCE, migrates through the unsaturated soil zone, a fraction of it remains as a residual phase that adheres to the soil. (Due to the heterogeneous soil formation at SSFL, part of the TCE could be entrapped as free phase in local areas of low permeability.) TCE can volatilize from the soil subsurface, so an assessment of the expected magnitude of the TCE volatilization flux is warranted.

[5.8] It has been estimated (see Section 7.3, particularly 7.3.2) that about 400,000 to 800,000 gallons of TCE were used for washing rocket engines at the SSFL. Estimates of the amount of TCE that has infiltrated the soil range from 139,000 gallons to about 313,000 gallons (CH2M Hill, 1993; Section 7.1).

Monitoring of the soil vapor phase at SSFL[5.9] revealed a significant presence of TCE at various depths surrounding the Instrument and Equipment Laboratories in Area I (Figure 5.2; Ogden, 1999; Montgomery Watson, 2002). The presence of TCE in the soil vapor phase, reported in two separate monitoring data sets (Ogden, 1999; Montgomery Watson, 2002), indicates active transport of TCE in the soil matrix and thus suggests that TCE volatilized to the atmosphere from the above area. The samples were taken from areas northwest of building 301 (Montgomery Watson, 2002), and in an adjacent area south of building 301 (Ogden, 1999). Soil vapor monitoring reported on February 26, 1998 (Ogden, 1999) is presented for TCE concentrations at 18 sampling locations, south of building 301 (Figure 5.2). Data reported in a vapor concentration map dated June 20, 2001, (Montgomery Watson, 2002) provide TCE concentrations at 23 sample locations (Figure 5.2). In each sampling location, TCE concentrations were reported at different depths ranging from 5 to 30 feet. A common characteristic of the data is the high variability of vapor phase concentrations for a given depth at different locations, or for different depths at the same location. In some of the locations, in fact, different concentration values have been reported for the same depth. For example, at sample location identified as ILSV01 (Montgomery Watson, 2002, Map 2), 21 TCE concentration values, ranging from 87 to 220 µg/L, are reported for a depth of 15 feet. The variability in reported TCE vapor phase concentration is illustrated in Figure 5.2. Clearly, the data do not reveal a definitive trend of concentration variation with depth; this suggests that TCE contamination could be distributed throughout the unsaturated soil zone. Note that, for both data sets (Montgomery Watson, 2002; Ogden, 1999), with the exception of one sample, TCE vapor phase concentrations were not reported for the top 5 feet of soil.

5.3.2 TCE Volatilization from the Soil Subsurface

A lower limit of TCE volatilization flux can be estimated if one assumes the top 5 feet of soil to be a TCE-free zone for which TCE monitoring data are unavailable. A reasonable estimate of TCE volatilization flux can be obtained, assuming a homogeneous soil from the surface to a depth of 5 feet, pseudo-steady-state conditions, and that diffusion through the air-soil matrix is the dominant TCE transport mode from a depth of 5 feet to the surface. Given the above approximations, the volatilization flux at the surface, J (µg TCE/m^2 s), can be calculated as

$$J = D_{eff}\frac{C_L}{L} \qquad [5.1]$$

where C_L is the average TCE vapor concentration (µg TCE/m^3) at a depth L (m) below the surface. In Equation 5.1 it is implicit that TCE emission flux is low enough that wind sweeps the chemical as it emerges from the soil, leading to a TCE surface concentration that is several orders of magnitude lower than C_L. The effective TCE diffusion coefficient in the soil void space, D_{eff}, can be estimated as $D_{eff} = \theta_a D_a / \tau_a$, where θ_a is the volumetric air content, $D_a = 8.1 \times 10^{-6}$ m^2/s is the diffusion coefficient of TCE in air (Grifoll and Cohen, 1994), and τ_a is the tortouosity. The tortuosity was estimated from the Millington and Quirk model, $\tau_a = \phi^{2/3} / \theta_a$, where ϕ is the soil porosity (Jin and Jury, 1996). Under dry soil condition, $\theta_a = \phi$ and thus $\tau_a = \theta_a^{-1/3}$.

[5.9] Ogden (1999), Environmental and Energy Services (February 26, 1998), and Montgomery Watson (June 20, 2002) reported analysis of a number of different volatile organics in the soil gas phase.

Following the above approach, the study team estimated the volatilization flux using Equation 5.1 and an average TCE vapor phase concentration (C_L) at 5 feet. This volatilization flux was based on samples analyzed by Ogden (1999) and Montgomery Watson (2002) which are listed in the soil vapor monitoring maps (Ogden, 1999, Map 1; Montgomery Watson, 2002, Map 2). The soil area for TCE volatilization was estimated as the minimum rectangular area that encompasses all locations sampled in each area. The resulting volatilization fluxes, for soil porosity values of 0.15 and 0.3, are given in Tables 5.1 and 5.2. The volatilization flux from the two areas for the porosity range of 0.15 to 0.30 differs by about 30%. The estimated TCE volatilization rate from the two areas ranges from 135 to 345 g/day.

Table 5-1. TCE Volatilization from Soil for Soil Porosity of 0.15

	θ_a	**Average Concentration at 5 Feet (μg/L)**	**Volatilization Flux (g/m^2 day)**	**Surface Area (m^2)**	**TCE Volatilization Rate (g/day)**
Map 1 02/26/98	0.15	274	0.010	6500	65
Map 2 06/20/01	0.15	198	0.0074	9500	70
				Total	135

Although the above TCE volatilization estimates are based on sampling carried out in 1998 and 2001 in the area about building 301, the actual TCE-contaminated area is unknown and could be larger. It is important to note that TCE emission fluxes are proportional to the aerial size of the contaminated area. Given that TCE soil vapor monitoring data are available for only part of the SSFL area, it is not possible, at present, to accurately ascertain the actual TCE volatilization flux or flux changes since the last known monitoring period.

Table 5-2. TCE Volatilization from Soil for Soil Porosity of 0.30

	θ_a	**Average Concentration at 5 Feet (μg/L)**	**Volatilization Flux (g/m^2 day)**	**Surface Area (m^2)**	**TCE Volatilization Rate (g/day)**
Map 1 02/26/98	0.30	274	0.026	6500	169
Map 2 06/20/01	0.30	198	0.019	9500	176
				Total	345

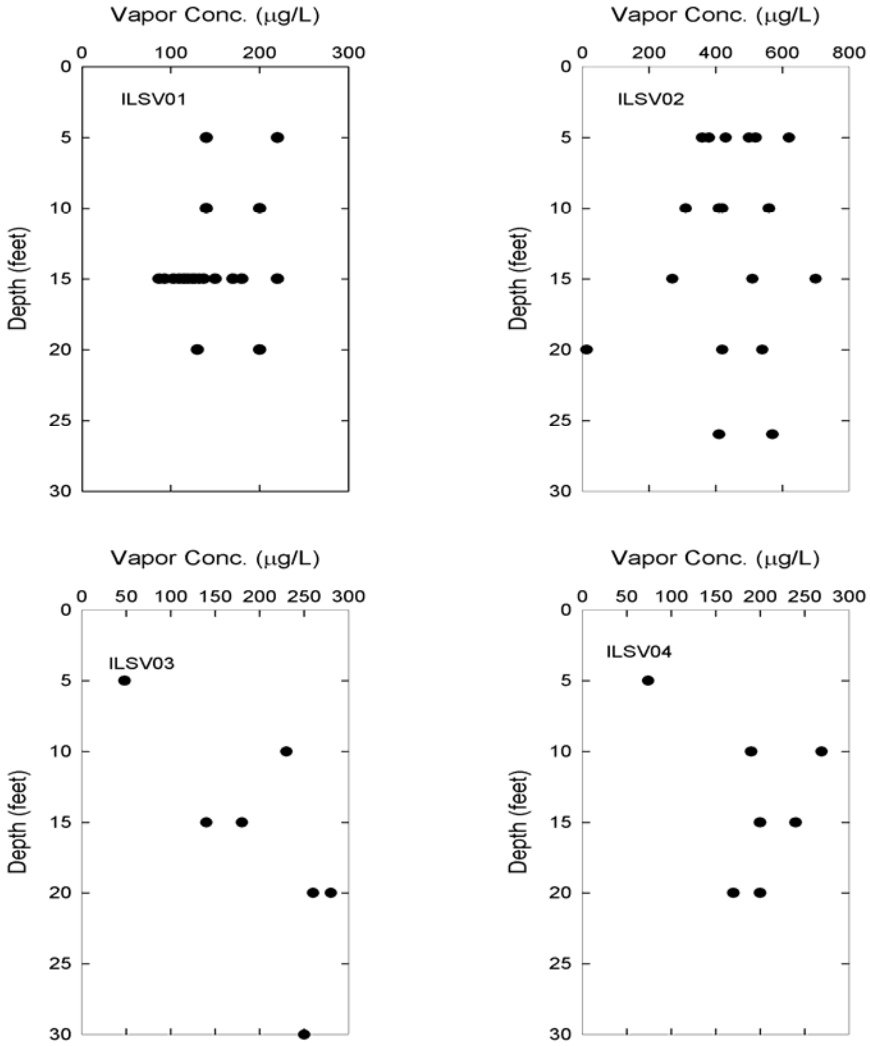
In summary, monitoring data on soil vapor phase in Area I indicate the presence of TCE in the soil vapor at significant concentrations. Cleanup standards based exclusively on gas or soil concentrations have drawbacks, as the distribution of contaminants in the subsurface is not uniform. The American Conference of Governmental and Industrial Hygienists (ACGIH) has created threshold limit values (TLV) or time-weighted averages to express the concentration of a substance to which most workers can be exposed without adverse effects. The ACGIH TLV for TCE is 270 µg/L (270 ppb). This advisory standard is exceeded on site in sample ILSV02 (Figure 5.2) at depths of 5 to 25 feet beneath the surface. Other standards for TCE include Cal-EPA's REL (Recommended Exposure Limit) and ATSDR's intermediate MRL (Minimal Risk Level for 15–364 day exposure). These standards for TCE are 0.6 µg/L and 0.5 µg/L, respectively, and are exceeded in all samples presented in Figure 5.2 below. Finally, the volatilization for TCE and subsequent dispersion via the air pathway is addressed in Chapter 3.

5.4 Soil Exposure Issues

Due to ongoing development and the existence of hiking paths, horse trails, children's camps, and private gardens (see Chapter 6), local residents, visitors, or workers could be exposed to soil contaminants via inhalation, incidental ingestion, dermal contact, and (secondarily) exposure through bioaccumulation and vegetable ingestion. The study team considered these exposures (see Section 6 and Appendices O and T) for contaminants detected in offsite soil (Ogden, 1998a,b; McLaren/Hart, 1993, 1995) above health-based standards. (For the regulatory and advisory standards used, see Appendix N.) In general, the contribution of soil to offsite exposure was found to be low compared to that of other pathways, as discussed in Section 6. The issue of onsite exposure to soil contaminants is nonetheless of greater significance, as soil cleanup is still ongoing.

Contaminants found in onsite soil above health-based standards include lead, mercury, arsenic, chromium, TCE, tetrachloroethylene, PCBs, carbon tetrachloride, 1,2-dichloroethylene, cesium-137, and plutonium-238. Even with effective surface soil cleanup, volatilization of TCE from the soil subsurface is likely to continue. Clearly, assessment of cumulative exposures associated with onsite activities, for single and multiple chemicals and for all exposure pathways, will be of importance especially for areas where mixtures of hazardous wastes were disposed of (Areas I, III, and IV). If onsite land is to be used for residential or even recreational activities, a thorough review of onsite contamination and cleanup targets is warranted, with careful consideration of future land use.

Figure 5-2. TCE Vapor Phase Concentration Profiles in Soil Gas Phase: Area I, Sample Locations ILSV01, ILSV02, ILSV03, and ILSV04



Sources: Ogden, 1999; Montgomery Watson, 2002

CHAPTER 6. EXPOSURE ANALYSIS

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6.0 EXPOSURE ANALYSIS

6.1 Overview

Various SSFL activites have resulted in the release of toxic chemicals toxics into the groundwater, toxics were also carried by surface water beyond the property, and air toxics were released into the atmosphere (Chapters 1-5). The environmental health risk associated with resulting offsite SSFL contamination is a function of the degree of human exposure to those contaminants. Offsite exposure to site-associated chemicals would occur if those chemicals have migrated via various transport pathways (air, water, and soil) from the SSFL to receptor locations where chemical intake can occur via various exposure routes (e.g., inhalation, ingestion, dermal contact).

Given that human receptors continually change their locations and activities, quantifying individuals' potential exposure to specific chemicals in a dynamic environment is generally infeasible. Assessing exposure requires accurate meteorological data, chemical emission source data, geographical data, and population activity patterns. In the present SSFL study, due to significant gaps in data on temporal and spatial chemical releases and concentration monitoring data on chemical concentrations, absolute exposures and health risks cannot be determined. Therefore, it is more meaningful to to establish a range of relative exposures for receptor locations surrounding the SSFL community.

In selecting exposure scenarios, the study team used the standard EPA methodology (EPA 1992) as a basis for potential dose ranges or highest doses. The various corresponding EPA-advised assumptions are summarized in Table 6-3. The pertinent potential exposures to air, water, and soil at receptor locations is discussed in Section 6.2, and details regarding contaminant sources are also provided in Appendix D. The conservative assumptions used to describe exposure scenarios are presented in Section 6.3. Section 6.4 presents the potential exposure doses at various receptor locations, relative to acceptable dose levels derived from EPA's acceptable cancer risks or non-cancer reference doses.

6.2 Exposure and Potential Receptors

This section discusses potential exposure to COCs at various relevant receptor locations surrounding the SSFL, and also evaluates the associated major exposure pathways. Potential exposure pathways were first identified and evaluated based on available information (Appendix O) and site inspections. An exposure pathway was considered as a plausible exposure route provided the following criteria were satisfied:

1. There is a contamination source.[6.1]

2. There is a potential for chemical transport from the source to offsite receptor locations.[6.2]

[6.1] The main sources of potential offsite contamination associated with SSFL include emissions from rocket engine testing and related activities (engine cleaning), open-pit burning at the Area I Thermal Treatment Facility, groundwater stripping towers, NPDES surface water runoff, and DOE-related nuclear research and development activities. Potential contamination sources from SSFL are outlined in Appendix D, as well as Sections 3.2 and 4.1.

3. There are potential receptors (e.g., residential communities) or exposure locations (e.g., specific groundwater wells).

To identify potential exposure pathways, the study team reviewed available records (see the reference section and Appendix O for a list of reviewed documents) and compiled a list of contaminants (onsite and offsite; see Appendix H) detected above health-based standards (Appendix N). Maximum detected concentrations were then run through EPA's Risk Assessment Information System's (RAIS) Human Health Risk Exposure Model[6.3] to eliminate contaminants of no concern from further consideration based on conservative EPA-based exposure assumptions. Moreover, within the context of the present worst case scenario analysis, only contaminants that were present at concentrations that would have resulted in exposure levels leading to dose above acceptable levels were examined further. The team also identified potential exposure locations based on site visits and review of SSFL-related reports and archived documents. For example, assessments of site-related exposure issues, with respect to direct or indirect exposures, were based (in part) on visits to SSFL.

West Hills and Bell Canyon are areas that exemplify potential exposure issues that were revealed by site visits. For example, Dayton Creek flows from SSFL through Orcutt Ranch in West Hills. Orcutt Ranch is used for community gardens that grow flowers, fruit, and vegetables; thus there is a potential for indirect exposure to contaminated crops (via ingestion) if contaminants have migrated through Dayton Creek. The team identified a number of other exposure issues during the site visits to West Hills and Bell Canyon, as documented in Figures 6-1 and 6-2 and the accompanying text.

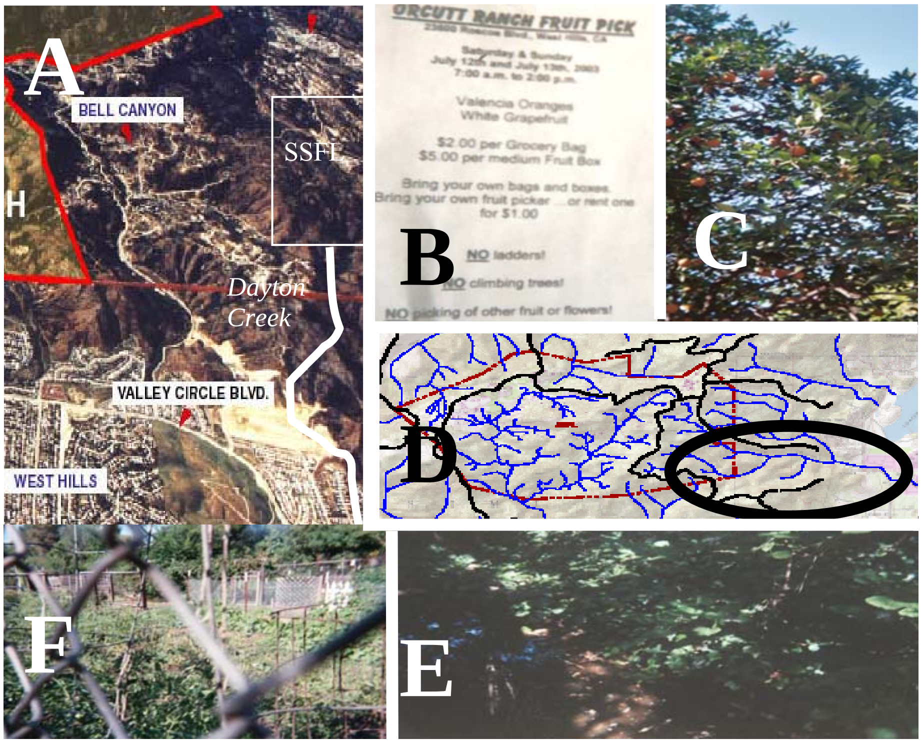
Contaminants found above health-based standards in Bell Canyon include beryllium, lead, and the manmade radionuclide thorium-228 (see Appendix H, Table H-4 and Table H-8). Each of these contaminants was also detected above health-based standards (Appendix N) at SSFL. Beryllium was used at SSFL from 1962 to 1967 and was found in air samples taken onsite from 1964 to 1969 (Appendix H, Table H-1). Lead was detected above health-based water standards in NPDES Outfall 001, which discharges into Bell Creek (Appendix H, Table H-4). Thorium-228, an alloying agent in certain metals used in the aerospace industry, has been detected onsite in Area IV groundwater around buildings T028 and 023 (at the ETEC) (DOE, 1997, 2004).

[6.2] The potential for contaminant transport via air, groundwater, surface water, and soil are discussed in Chapters 3, 4 and 5, respectively. Contaminants from SSFL were detected in offsite soil and groundwater. Areas in which contaminants were detected include the Brandeis-Bardin Institute, Sage Ranch, and Bell Canyon (McLaren Hart, 1993–1995; Ogden, 1998a; Appendix H). Monitoring data were not found for areas directly east of SSFL (Dayton Canyon, Lakeside Park, or West Hills). Contaminants potentially from SSFL (or other locations where Boeing-related activities were carried out) were detected in Simi Valley, Ahmanson Ranch, Chatsworth Reservoir and Canoga Park (MW, 2000, 2002; MWG, 2002; Klinefelder, 2000; Hughes, 1989; DWP, 2004; Lawrence Livermore, 1997). Other contracted sites where Rocketdyne-, Boeing-, and DOE-related operations were conducted include the De Soto site (which generated radioactive effluents; see Lawrence Livermore, 1997) and the Hughes facility in Canoga Park, south of Chatsworth Reservoir (soil and groundwater contaminated with VOCs and radioactivity; Hughes, 1989). The De Soto site's operations terminated in 1995, and Hughes operations terminated in 1976.

[6.3] The Risk Assessment Information System (RAIS) website is comprised of tools for conducting human and ecological risk assessments. The site was last viewed on Jan 17, 2006 at: http://risk.lsd.ornl.gov/homepage/rap_tool.shtml. Information from this website was sponsored by the U.S. Department of Energy (DOE), Office of Environmental Management, Oak Ridge Operations (ORO) Office and the DOE Center for Risk Excellence. The Human Health Risk Assessment tool is located on this site at: http://risk.lsd.ornl.gov/prg/for_sel_data.shtml.

Clearly, surface water transport and air dispersion from SSFL to the Bell Canyon area create the potential for exposure (Figure 6-2) to the above SSFL contaminants. Therefore the study team evaluated various hypothetical exposure scenarios to screen the range of plausible exposures.

Figure 6-1. Exposure Issues in West Hills



ORCUTT RANCH FRUIT PICK
23600 Roscoe Blvd., West Hills, CA

Saturday & Sunday
July 12th and July 13th, 2003
7:00 a.m. to 2:00 p.m.

Valencia Oranges
White Grapefruit

$2.00 per Grocery Bag
$5.00 per medium Fruit Box

Bring your own bags and boxes.
Bring your own fruit picker ....or rent one for $1.00

NO ladders!

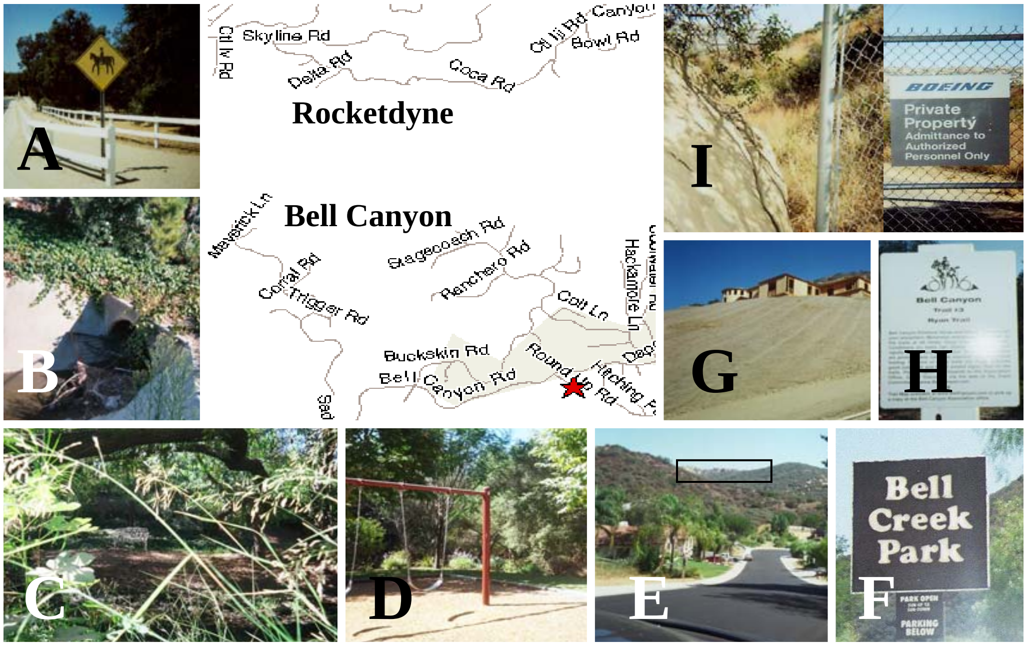
NO climbing trees!

NO picking of other fruit or flowers!

The letter in each element corresponds to an issue described below:

A. Surface water from Area I (Happy Area) flows east via Dayton Creek into West Hills.Note that perchlorate (see Appendix H, Table H-1) has been found on site in Area I, which could potentially contaminate surface water runoff from this area. Note also that one of Dayton Creek's depositories is Orcutt Ranch (located at 23600 Roscoe Boulevard, West Hills, California), which has a community orchard and public-use garden.
B. The Orcutt Ranch Park supervisors organize seasonal fruit picks at Orcutt Ranch, as evidenced by this leaflet (collected by the UCLA study team) from the supervisors.
C. Fruit and vegetables grown at Orcutt Ranch—oranges, lemons, lettuce, etc.—could bioaccumulate certain contaminants. This suggests the need for monitoring.
D. Surface runoff and groundwater emanate from SSFL (Area I) and join to form the headwaters of Dayton Creek.
E. Dayton Creek runs through Orcutt Ranch in unlined channels.
F. Some of the land at Orcutt Ranch was allocated to the community for public-use gardens. Flowers, fruit, and vegetables are grown in these plots.

Figure 6-2. Exposure Issues in Bell Canyon



The letter in each element corresponds to an issue described below:

A. Bell Canyon is a dry canyon with many horse paths, both along Bell Creek and up into the hills where SSFL is located. Resuspension of soil due to horse movement could expose people to contaminants (if the soil is contaminated) via inhalation and ingestion. Note that soil contaminants were detected in this community (Ogden, 1998a; Section 5.1).
B. There are numerous surface runoff channels in the neighborhoods surrounding Bell Creek that are easily accessible to children. Surface water runoff of contaminants from SSFL to Bell Creek was detected in NPDES outfalls that run into Bell Creek (Appendix H). Moreover, it is estimated that about 90 percent of the NPDES treated waste flows (via Bell Creek) through Bell Canyon (Techlaw, 1990).
C. A summer camp sponsors softball activities near Bell Creek and children were observed wading through the creek, which is shallow enough for crossing, to obtain stray balls.
D. A playground is located within 10 feet of the creek. There are no warning signs about water quality in view.
E. Rocket engine testing areas are within 1 or 2 miles of Bell Canyon homes. Although the Delta and Coca, Area II, engine-testing areas are not presently operational, they have been a source of air emissions during past rocket testing activities in these areas.
F. Bell Creek Park is the site of various recreational activities: softball, picnics, summer camp, horse stable with riding trails, and hiking trails are located next to the creek.
G. Residential construction in the area could expose workers and residents to resuspended soil.
H. There are hiking trails and horseback riding in the hills between the community and SSFL where exposure to surface runoff or soil deposited during the rainy season may occur.
I. The SSFL site is not secure and children could easily enter it. This is evident by the unsecured gate between SSFL and Coolwater Road.

In summary, the primary contaminant transport routes associated with SSFL are surface water flows and runoff,[6.4] groundwater transport (Chapter 4),[6.5] and air dispersion (Chapter 3). Sections 6.2.1, 6.2.2, and 6.3 draw on the available data and information from site visits to discuss potential exposures with respect to groundwater wells in Simi and San Fernando Valleys, residences, recreational areas, and community gardens within 2 miles of SSFL.

6.2.1 Exposure to Contaminants in Groundwater and Surface Water

The groundwater and surface water pathways are highly interconnected, as discussed in Section 4.2. Therefore, this section discusses potential exposures associated with both of these media. Potential contaminant sources and associated migration pathways away from SSFL are discussed in Sections 4.1 and 4.2.

6.2.1.1 Groundwater Exposure

Information on the presence and usage of wells in the communities surrounding SSFL is paramount to assessing the potential contribution of the groundwater pathways to exposure to various chemicals associated with SSFL. Contaminated wells could impact both primary exposure via water drinking and secondary exposure linked to crop irrigation wells or livestock wells. Wells surrounding SSFL have been used for drinking water, various household purposes (e.g., showering and garden irrigation), and livestock, agricultural, industrial, or commercial (i.e., potable water distribution) purposes.

Quantitative assessment of exposure to contaminants via groundwater and surface water exposure pathways must consider source releases (e.g., NPDES discharges), onsite and offsite contamination, groundwater well distribution and use, population distribution, recreational facilities and activities, and development- and construction-related activities. Unfortunately, detailed data for the above are lacking for the constantly changing SSFL and its surroundings. Nonetheless, in order to evaluate the potential for exposure via potable water use, it is essential to review available information regarding potable wells in the SSFL area.

Contaminants have been detected offsite (at groundwater wells and NPDES Outfalls 005 and 006; see Appendix H, as well as Sections 4.2, 4.3, 5.1, and 5.2), which suggests that contaminants may have migrated from SSFL to offsite wells. Unfortunately, surveys of drinking water and irrigation wells could not be found and not all responsible agencies have cooperated in providing such pertinent information to the UCLA review team.[6.6] The limited available information indicates that wells have existed within 1 mile of SSFL (Techlaw, 1990). It has been reported that wells were used in areas north, northwest, northeast, and east of SSFL for livestock, irrigation, and/or domestic purposes (Table 6-1; Techlaw, 1990), and groundwater in San Fernando and Simi Valleys is also extensively used as a source of drinking water.

[6.4] Surface water from SSFL (Areas I, II, III, and IV) runs off at multiple locations, including the NPDES outfalls and Dayton, Woolsey, Bell, Meier, Runckle, Black, and Box Canyons.

[6.5] This analysis treats groundwater and surface water as an interconnected pathway (see Section 4). Surface water to groundwater paths exist, as do groundwater to surface water pathways—for example, artesian wells 2,000 feet north of SSFL (Bathtub 1 listed in Table 4-2 is one such artesian well; note that not all potential artesian sources have been adequately characterized).

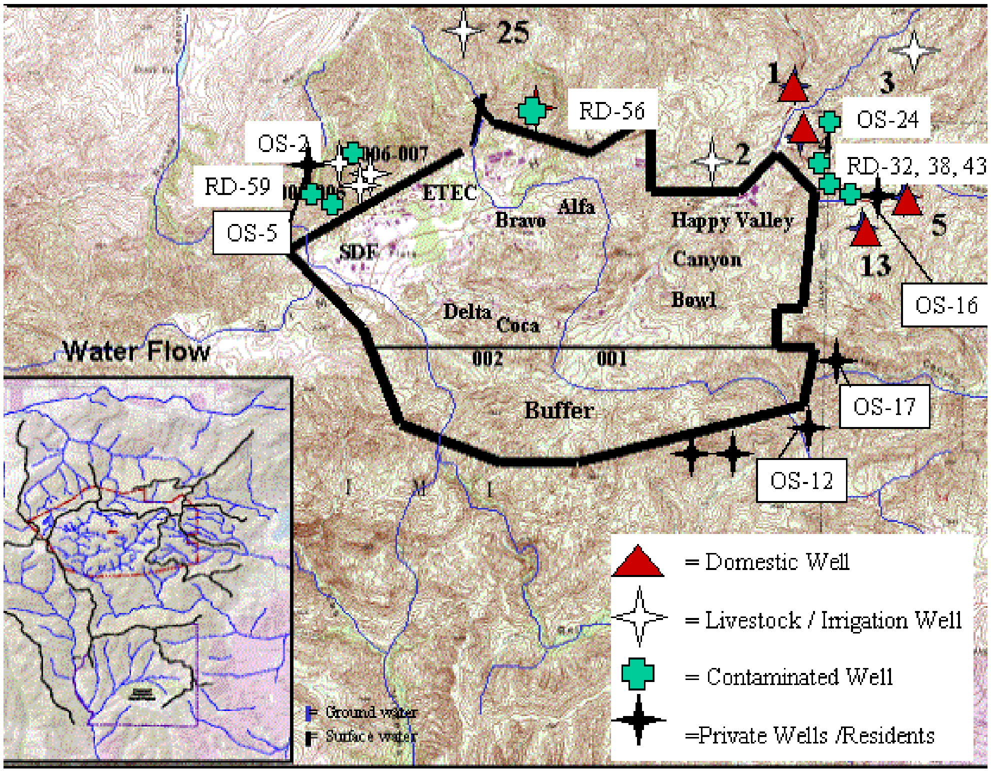
[6.6] See Appendix J for correspondence regarding identification of potable water and irrigation wells.

The extent of groundwater contamination in West Hills, Canoga Park, and Chatsworth is difficult to determine due to the typically low groundwater level in the wells the above areas. Over a decade ago it was suggested that if any of these wells are contaminated they may serve as another potential source of contaminated groundwater for human receptors (ERC, 1990b). However, the transport routes (groundwater and surface water) between these valleys and SSFL must first be clearly identified to establish if there is indeed a connection between contaminants in these offsite wells and contaminants found at SSFL.

The present use and water quality of private wells is unknown and not all offsite wells could be located based on the available information. A list of offsite wells sampled by Rocketdyne (Boeing) and found to be contaminated is provided in Table 6-1. Wells are indicated in Figure 6-3. Wells denoted as 'RD' are Rocketdyne monitoring wells and do not pose exposure risks as the only identified purpose of these wells is to monitor subterranean groundwater flow for potential offsite contaminant migration. Other offsite wells (OS) are domestic, irrigation/livestock, and/or private/residential wells. If contaminants were detected within these wells or in nearby RD wells, exposures to the identified contaminants may have occurred. The closest boundary wells or springs associated with offsite residents are identified in Figure 6-3 (Techlaw, 1990; ERC, 1990b). These include OS-2 and OS-5 (private livestock wells) about 1,000 feet from the northwest boundary of the site), OS-16 (a domestic well about 500 feet east of RD-32 and 800 feet from the northeast boundary [Area I], south of Woolsey Canyon), OS-17 (a domestic well about 200 feet east of the SSFL boundary in an undeveloped buffer below Area I), and OS-12 (a spring southeast of the site). Note that OS-16 and OS-17 have been used for domestic purposes but it is unknown if they are currently in use (ERC, 1990b).

Having reviewed monitoring data, information on groundwater wells, and information from visits to the SSFL and surrounding communities, the study team concluded that exposure to contaminated groundwater should be considered in a conservative exposure analysis. (That is, an analysis that considers exposure to contaminated groundwater even if the affected population is small unless there is clear evidence that wells surrounding SSFL have not been used for drinking, irrigation, or other activities that could lead to direct or indirect contact with contaminated groundwater.) Accordingly, exposures via ingestion, inhalation, and dermal contact—as well as secondary exposure by vegetable ingestion—were considered for various exposure scenarios (residential, occupational, and recreational), as detailed in Sections 6.3 and 6.4. Maximum contaminant concentrations detected in offsite groundwater were used in the exposure analysis. Some of the primary contaminants considered are TCE and its degradation byproducts (1,1-DCE, 1,1-DCA, cis-1,2-DCE, and vinyl chloride), trans-1,2-DCE, perchlorate, carbon tetrachloride, PCBs, benzene, chloromethane, manganese, TCDD-TEQ, lead, arsenic, tritium, thorium-228, radium-226, and cesium-137. The contaminants considered in the analysis (see Appendix H for a complete list) are known to have been produced or used at SSFL (Section 1.2). Potential receptor areas considered in the exposure evaluation include residential areas served by Southern California Water Company and residential locations with private wells within 1 mile of SSFL.

Figure 6-3. Proximity of Private/Residential, Domestic and Livestock/Irrigation Wells to SSFL



Note: Residential / private wells are identified with boxed ID well numbers that correspond to the Well IDs in Table 6-1.

Table 6-1. Locations of Contaminated Offsite Groundwater Wells

Well ID	**Direction from Site**	**Location**	**Comments**	**Contaminant(s)**
OS-2	NW	BBI; Tapo Canyon and Walnut St.; 1,750 feet from NW boundary	Private well: livestock	Fluoride
OS-5	NW	BBI; Los Angeles Ave. and Stow St.; 1,100 feet from NW boundary	Private well: livestock	Chloromethane
OS-24	NE	~750 feet NE of SSFL; closest to RD-38A	Furthest observed offsite TCE migration; Chatsworth Formation well	TCE
RD-32	NE	Sage Ranch		Manganese
RD-38	NE	Sage Ranch near main gate, NE of Area I		1,1-DCE, TCE, 1,1-DCA, cis-1,2-DCE, benzene
RD-43	NE	Woolsey and Canyon Rd., near NE Area I		Lead
RD-56	N	BBI boundary, north of Areas II and III	Currently in undeveloped BBI buffer	TCE, trans-1,2-DCE, cis-1,2-DCE, vinyl chloride
Bathtub well #1	N	BBI	Well closed in 2003; listed as domestic (otherwise reported as livestock)	Perchlorate
RD-59	NW	West of Area IV		Perchlorate, carbon tetrachloride

Note: BBI=Brandeis Bardin Institute

6.2.1.2 Surface Water Exposure

Surface water flow from SSFL (Areas I, II, III, and IV) is known to exist at multiple locations, including the NPDES outfalls as well as Dayton, Woolsey, Bell, Meier, Runckle, and Black Canyons (primarily during heavy rainfall events). Only one major offsite monitoring study of surface water was available at the time of the UCLA study (McLaren Hart, 1992–1995). The McLaren-Hart study assessed surface water and sediments for radionuclides, organic compounds, and priority pollutant metals in two areas north of SSFL: BBI and SMMC.

Surface water runoff can transport contaminants offsite. For example, Dayton Canyon Creek flows from SSFL into Orcutt Ranch and thus represents a concern with respect to contamination of fruit and vegetables grown in the area. The potential impact of NPDES runoff into Bell Canyon Creek also merits consideration with respect to dermal exposure (see Figures 6-1 and 6-3). Surface water from the Area I TTF discharged into the Perimeter Pond, which is part of SSFL's reclaimed water system (Rockwell International, 1992). During rainfall events, the Perimeter Pond can overflow into NPDES Outfalls 001 and 002 to the south of the facility, which in turn discharge into Bell Canyon Creek (Rockwell International, 1992). Any contaminants carried with the NPDES outfall streams could then drain into southern Bell Creek as well as northwestern Meier and Runckle Creeks, which drain into the Arroyo Simi in Simi Valley. Surface water runoff can flow, during heavy rainfall events, from Dayton and Woolsey Canyons (east of SSFL) and Black Canyon (northeast of SSFL).

It is eported that there is some surface water drainage through residential communities (east, northeast, northwest, and south of SSFL) and summer camps in BBI and Bell Canyon. Unfortunately, surface water runoff from ephemeral sources (i.e., rainfall) has not been adequately monitored. The McLaren-Hart study reported that decreasing levels of PCBs, TCDD-TEQ, asbestos, and mercury in samples collected further from SSFL suggested that the above contaminants may have migrated via drainages from the Sodium Disposal Facility (SDF) to offsite areas (McLaren Hart, 1993). However, monitoring for that study was not done in areas downstream of the Sodium Reactor Experiment complex (SRE) and the RD-51 watershed where soil samples were found with radiation levels significantly above background (cesium-137 and plutonium-238). Also, surface water samples were not taken north of NPDES Outfalls 005–007 or the area of Meier Creek downstream of these NPDES outfalls. The study team found no surface water monitoring for Bell Creek and rainfall runoffs.

Given the lack of surface water monitoring data, the study team used data from NPDES outfalls—which have been regularly monitored—in conjunction with the McLaren-Hart study results to assess various scenarios of direct and indirect exposures via surface water (e.g., ingestion, inhalation, and/or dermal exposures), as described in Sections 6.3 and 6.4. The study team considered the following contaminants, detected at NPDES outfalls above health-based standards: chromium, lead, and heptachlor to the south (Appendix H, Table H-4) and chloride, DEHP, PCB-1254, lead, beryllium, chromium, benzene, nickel, cadmium, zinc, perchlorate, radium-225 and -228, and strontium-90 to the northwest (Appendix H, Tables H-6 and H-9).

6.2.2 Exposure to Contaminants in Soil

This section discusses the potential for offsite exposures to contaminated soil. People can be exposed to soil contaminants through dermal contact, inhalation, and incidental ingestion of soil particles. Exposure can also occur via secondary pathways—edible crops that have taken up contaminants. The study team considered various exposure scenarios for offsite soil contamination, as detailed in this section and Section 6.3. (Potential sources of soil contamination are discussed in Chapter 5; the primary routes of transport, air and water, are discussed in Chapters 3 and 4.)

Two offsite monitoring studies reported offsite soil contamination in areas south and north of SSFL (Ogden, 1998a; McLaren-Hart, 1993, 1995). Contaminants detected above health-based standards in these studies included beryllium, arsenic, lead, potassium-40, thorium-228 and -232, tritium, cesium-137, plutonium-238, radium-226 and -228, and strontium-90. Offsite surface soil contamination above health-based standards (residential soil screening levels) was detected northwest of SSFL at BBI (arsenic), and southeast and south (arsenic[6.7] and beryllium[6.8]) of the facility in Bell Canyon. Monitoring data for areas to the west and east were requested but not provided to the UCLA study team.

Exposure to contaminated soil via inhalation, ingestion, and dermal contact could occur when soil is resuspended during residential construction, hiking, horseback riding, gardening, and secondary exposure from exposed livestock and crops. For example, the 1997 Boeing (Rockedyne) NPDES Annual Report noted that livestock had entered the SSFL grounds. As the report states:

> *"It was discovered that livestock from the neighboring property had been entering the RD facility through a break in the fence located by the sampling basin for outfall 006 (northwest). This situation existed for approximately 3 weeks."*

It was also observed by these reviewers that avocado and orange groves exist northwest of SSFL at BBI and that many residents south of SSFL at Bell Canyon have private gardens. Site visits to Bell Canyon also identified alternate routes of exposure to these contaminants. Both of these areas have summer camps (Alonim at BBI and Bell Canyon Summer Camp in Bell Canyon), so consideration of susceptible populations (children) and their outdoor activities is warranted.

6.2.3 Exposure to Contaminants in Air

People can be exposed to air contaminants associated with SSFL if those contaminants, once emitted, are dispersed to certain locations. Unfortunately, ambient monitoring data on hazardous air pollutants associated with SSFL are lacking. Therefore, the study team developed emissions

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[6.7] All soil contains some arsenic. Naturally occurring arsenic is commonly found in southern California soils at levels of 5 to 20 mg/kg (AEHS, 2003). Levels found off site of SSFL are between 1 and 14 mg/kg (south) and 8 and 24 mg/kg (north). Onsite levels vary from 1 to 21 mg/kg. See Appendix H for details.

[6.8] It is important to note that arsenic and beryllium are listed among the EPA's 53 priority PBT chemicals. PBT pollutants are chemicals that are persistent, can bioaccumulate, and are toxic in the environment, and thus pose risks to human health and ecosystems.

estimates for specific COCs. Different emission sources (Appendix S) were considered, including rocket engine testing (RET), TCE emissions from rocket engine cleaning (RET-TCE), thermal treatment facilities (TTF), and air stripping towers (ST). The team estimated chemical-specific emission rates based on information on site activities, reported chemical usage, TRI-reported emissions, rocket engine testing and cleaning, air stripping, open pit burning, and emissions from contaminated soil.

This study's air exposure analysis (Sections 6.2 and 6.3; see also Chapter 3) is a conservative assessment of a range of potential inhalation exposure scenarios. Highly conservative asssumptions were used in these scenarios in order to bracket the upper exposure range and provide a relative ranking of potential doses for various receptor locations of concern. While it would be of great interest to determine each individual's exposure in the SSFL region, lack of monitoring data, emission data, population dynamics and activity patterns makes such an anlysis infeasible.

To be conservative, the present study considered worst-case scenarios based on the maximum emission rates. Air dispersion modeling was performed (see Chapter 3 and Appendix I) and maximum estimated annual emission rates for periods of similar activity were used to estimate contaminant air concentrations at different receptor locations to identify areas of potential exposure concern. The air dispersion analysis considered the impact of emission periods, emission source locations, area topology, and meteorology. The team assessed the maximum contaminant concentrations for potential receptor communities within 50 kilometers, among them Simi Valley, Brandeis Bardin Institute (BBI), Sage Ranch (SR), Santa Susana Knolls, Dayton Canyon, West Hills, Chatsworth, Bell Canyon, Canoga Park, Woodland Hills, and Hidden Hills (Table 6-2; see Appendix T for a complete list of locations and estimation of relative exposure levels for the contaminants of concern presented here).

Table 6-2. Partial List of Potential Air Contaminants and Receptor Locations of Concern

	Contact Location	Time	Chemical	Exposure
1	West Hills, Bell Canyon, Simi Valley, Dayton Canyon, Woodland Hills, Chatsworth, Hidden Hills, Santa Susana Knolls	1959–2004	TCE	Inhalation
2	West Hills, Bell Canyon, Simi Valley, Dayton Canyon, Woodland Hills, Chatsworth, Hidden Hills, Santa Susana Knolls	1959–1994	Hydrazine	Inhalation
4	West Hills, Bell Canyon, Simi Valley, Dayton Canyon, Woodland Hills, Chatsworth, Hidden Hills, Santa Susana Knolls	1955–1976	UDMH	Inhalation
5	Dayton Canyon, West Hills, Bell Canyon, Woodland Hills	1963–2004	MMH	Inhalation

6.3 Exposure Scenarios

An exposure scenario is a set of parameters and assumptions that specify how exposure of a receptor population or an individual takes place. The outcome from assessing an exposure scenario is an estimate of potential lifetime-average exposure dose for the target contaminant, typically in units of mg/kg/day. An exposure scenario generally includes facts, data, assumptions, and inferences pertaining to exposure settings, the exposed population, and intake and uptake routes. In the present analysis, three specific conservative scenarios were established: residential (people living in the SSFL area), occupational (people working in the SSFL area) and recreational (people using recreational facilities in the SSFL area). The various scenarios (Table 6-3) were based on either site-specific conditions when available or the standard EPA-suggested assumptions. The study team used highly conservative assumptions in these scenarios in order to establish the upper exposure range and provide a relative ranking of potential doses for various receptor locations of concern.

All potential exposure pathways were assessed for each of the three scenarios (i.e., residential, recreational, and occupational). For example, residential exposure to TCE was evaluated from all media (soil, water and air) and for each potential exposure route (inhalation, ingestion, dermal, secondary exposure via vegetable ingestion) (Table 6-3). In the most conservative estimate, maximum concentrations found in water, soil, and sediment in each area (north, northeast, northwest, south, southeast, southwest, and east of SSFL) were assumed to be the prevailing concentrations over the period of exposure. In assessing exposure to air contaminants emitted from SSFL, the study team considered the change in concentrations over the years in relation to emissions from SSFL (Appendices R and T). However, the inhalation exposure estimates are conservative in that the highest annual emission rate from a given source was used to represent emissions over periods of similar activity[6.9]. For example, the maximum annual emission rate for hydrazine released during RET at the STL-IV site between 1953 and 1977 was during 1968. This annual hydrazime emission rate from this site was then applied for each year with comparable activity levels (in this case during the entire 1953-1977 period).

Extensive development of the areas surrounding SSFL did not occur until the late 1960s and early 1970s. USGS maps (USGS, 1952, 1967) indicate that fewer than six buildings were present in the areas directly bordering SSFL before 1967, with an approximate near-border population of 20 individuals. Given the above, a 30-year exposure period was assumed to be a reasonably representative period of exposure to soil and groundwater contaminants in communities surrounding SSFL. The exposure period for air contaminants was taken to be the duration for which air emissions were reported. For carcinogens, the average daily exposure was calculated using the standard 70-year lifetime averaging period. For non-carcinogens, the average daily exposure was determined over a 30-year period for soil and water contaminants and the actual reported emission period for air contaminants.

[6.9] Additional details wer provided in Appendix T. Maximum concentrations resulting from unit emission rates for each activity were identified at various receptor locations from all potential emission-specific sources (STL-IV, APTF, Bravo, etc.; see Appendix T, Table T-1.) The above information was then utilized to ascertain, for each activity (e.g. TCE use), which source had the greatest contribution to chemical-specific emissions associated with the exposures for the selected receptor locations. Maximum emission rates for each activity, from emissions during years of similar activity levels (Appendix S), were then identified (Tables T-2) and applied as stated above.

Table 6-3. Scenario Assumptions

Pathways Assessed	Scenario		
	Recreational	**Occupational**	**Residential**
Soil ingestion	Exposure frequency = 75 day/yr Exposure time = 1 hr/day Ingestion rate = 0.0001 kg/day	Exposure frequency = 225 day/yr Exposure time = 1 hr/day Ingestion rate = 0.0001 kg/day	Exposure frequency = 75 day/yr Exposure time = 1 hr/day Ingestion rate = 0.2 kg/day
Vegetable ingestion	—	—	Exposure frequency = 350 d/yr Ingestion rate = 0.2 kg/day
Groundwater ingestion from private wells	Exposure frequency = 45 day/yr Exposure time = 1 hr/day Ingestion rate = 0.05 L/day	Exposure frequency = 225 day/yr Ingestion rate = 0.8 L/day	Exposure frequency = 350 d/yr Ingestion rate = 2 L/day
Groundwater dermal contact from showering	—	—	Exposure frequency = 350 d/yr Exposure time = 0.24 hr/day
Groundwater inhalation during household use	—	—	Exposure frequency = 350 d/yr Inhalation rate = 20 m^3/day
Surface water dermal contact	Exposure frequency = 45 day/yr Exposure time = 1 hr/day	—	Exposure frequency = 45 d/yr Exposure time = 1 hr/day
Air inhalation	—	—	Exposure frequency = 365d/yr Exposure time = 24 hr/day Inhalation rate = 20 m^3/day

Note: An adult receptor (body weight 70 kg) was assumed for all scenarios and pathways to systematize the exposure methodology for comparison and exposure ranking purposes. A 30-year exposure to maximum detected concentrations was assumed for exposure to water and soil contaminants to enable comparative analysis of receptor locations and exposure pathways. This exposure duration is appropriate because major development of the area surrounding SSFL did not begin until the late 1960s and activities such as rocket engine testing declined significantly during the early 1990s. Exposure to air contaminants was estimated over the duration of the emission period for each chemical.

6.4 Dose Estimation and Dose Ratios

6.4.1 Exposure Doses

A conservative estimate of the average daily dose can be obtained as follows (USEPA, 1989):

$$ADD\ (Average\ Daily\ Dose; mg/kg/day) = \frac{\sum_{i=1}^{N}\left(C_j I_j F_E t_E\right)_i}{M_B t_T} \qquad (6.1)$$

in which C_j is the concentration of chemical j in the medium of concern (e.g., mg/m^3 air or mg/L water), I_j is the intake rate of the medium phase (e.g., m^3 air/day or liter water/day), F_E is the frequency of exposure (number of exposure events/year), t_E is the event exposure period (e.g., days) to concentration C_j for the specific exposure event, subscript i designates the exposure year and N is the total number of exposure years, M_B is the total body mass, and t_T is the total time period (measured in days) over which the average daily dose is sought (e.g., lifetime). The lifetime average daily dose (LADD) was calculated from Equation 6.1, applied over the various exposure periods over the number of exposure years and then setting the averaging time period (t_T) to the default EPA standard lifetime assumption of 70 years. In the present analysis, the exposure period for offsite soil and water contaminants was assumed to be 30 years, while the exposure period for air contaminants was taken to be the actual period of emissions as ascertained from reviewing site activities (Chapter 3 and Section 6.3). Three primary routes of exposure to contaminants were considered: inhalation, drinking water, and skin absorption. Exposure via these routes can result from contact with contaminated air, soil, sediment, groundwater, and surface water and from ingestion of contaminated food.

In order to rank potential exposure sites and contaminants of concern, this report presents the dose ratio, DR,

$$DR = LADD / ALADD \tag{6.2}$$

in which ALADD is the acceptable lifetime average daily dose. The ALADD was determined based on the standard assumption of an acceptable disease (e.g., cancer) risk of 1×10^{-6} (see Appendix R, Table -4 and Appendix T, Table T-4). For carcinogens, the ALADD was calculated as the 1×10^{-6} risk divided by EPA's reported cancer slope factor. For non-carcinogens, the ALADD was taken to be EPA's chronic RfD for non-carcinogens. When comparing receptor locations and/or chemicals in terms of the DR, one should note that there are uncertainties with respect to the dose estimate. Thus, such comparisons are only useful as a qualitative means for ranking locations of concern and identifying areas of exposure concern. Note also that DR values are not additive across chemicals or locations.

Dose estimates were based on monitored and estimated offsite concentrations and standard default exposure parameters (see Appendix V). Given that monitoring data were inadequate for the purposes of a quantitative risk analysis, a highly conservative approach was undertaken: the maximum detected point concentrations and the maximum air emission rates for periods of similar emissions activity were assumed to be accurate for the entire exposure period. Doses for residential, recreational, and occupational scenarios were calculated for ingestion, inhalation, and dermal exposures (with EPA-default assumptions as in Table 6-3 above and as discussed in Appendix R).

In the above approach, if a DR falls below 1, one can be reasonably assured that the potential health impacts associated with the specific chemical and receptor location would be of little concern. DRs greater than 1 would suggest that there may be reason for concern and thus for a more detailed investigation to either confirm or rule out the potential for health impacts for the specific chemical and location of concern. Such an investigation would have to consider population dynamics and possibly involve additional field monitoring and retrospective studies. Because the population around the SSFL has changed continually since the facility was established, and because of the lack of adequate continuous offsite contaminant monitoring data, it is not feasible to conduct quantitative site-specific exposure and risk assessments to assess the actual health impact of the SSFL on the surrounding communities. One can, however, assess the potential exposure for various hypothetical scenarios to capture worst cases and to provide a dose-based ranking of chemicals of concern in locations of potential exposure cocnern.

The maximum detected concentrations of specific chemicals in soil and water monitoring data, collected over the lifetime of the facility, were used in dose calculations for the various receptor locations (Appendix H). DRs for soil and water contaminants are relevant for the areas surrounding detection locations, but the study team assumed that maximum detected concentrations were present for 30 years at all detection locations that were accessible to the public. Receptor locations for exposure-based ranking were identified based on the levels of contaminants detected in water and soil at locations of potential exposure concern, the time period of contaminant detections in soil and water, potential exposure routes, and estimates of the size of the potentially affected population (Table 6-4).

Receptor air concentrations were estimated (Chapter 3 and Appendix T) based on air dispersion simulations (Appendix I) using onsite meteorological data (Appendix I) and emission estimates for 1953 through 2004 (Appendix S). Concentrations of air contaminants were estimated at various receptor locations (Table 6-6 and Appendix T) for different emission sources (RET, RET-TCE-associated emissions, TTF, and air stripping towers).[6.] The study team took a conservative approach in which the highest emission rates (g/s) to be used for each source/receptor combination (Appendix S) were first identified[10]. The team then selected the maximum concentrations (µg/m^3) associated with each source for various receptors around SSFL, considering the release scenarios detailed in Appendix I.

The contaminants considered in the analysis are presented in the following Appendices: H (monitoring data), S (air emissions), T (inhalation dose calculations), and R (soil and water dose calculations). The specific locations considered in the comparative (ranking) exposure analysis for soil and water contaminants are marked in Table 6-4 and Figure 6-4. Receptor coordinates for the assessment of the air inhalation pathway are identified using the grid shown in Figure 6-5.

Table 6-4. Potential Pathways of Exposure to Soil and Water Contaminants with Dose Ratios Greater than One for Communities Surrounding SSFL[a]

Exposure or Detection Location[b]	**Year Detected**	**Chemical**	**Potential Media of Exposure**	**Potential Exposure Pathways[c]**	**Toxicity[d]**
Brandeis-Bardin Institute (1)	1992	Arsenic (8–24 mg/kg)	- Air - Soil -Vegetables/fruit	- Inhalation - Incidental soil ingestion - *Crop ingestion*	Carcinogen, cardiovascular, skin, bladder
Northeast of facility (2)	1994	TCE (10–900 µg/L)	- Air - Water wells - Vegetables/fruit	- *Inhalation* - Contact - Water ingestion - Crop ingestion	Carcinogen, liver, kidney, central nervous system
Northeast of facility (2)	1996	1,1-DCE (19 µg/L)	- Air - Water wells - Vegetables/fruit	- *Inhalation* - Water ingestion - Crop ingestion	Carcinogen, liver, kidney, lung
Northeast of facility (2)	1994	Vinyl chloride (64 µg/L)	- Air - Water wells - Vegetables/fruit	- Inhalation - Water ingestion - *Crop ingestion*	Carcinogen, liver, central nervous system
Bell Canyon (3)	1998	Arsenic (1–14 mg/kg)	- Air - Soil - Vegetables/fruit	- Inhalation - Incidental soil ingestion - *Crop ingestion*	Carcinogen, cardiovascular, skin, bladder

[a] Population estimates from Ventura County 75.03 Census Tract at a distance of about 1 mile surrounding SSFL. See Chapter 1 for additional details regarding population density.

[b] Well locations are identified by numbers (in parentheses) corresponding to the locations marked in Figure 6-4.

[c] Dominant potential exposure pathways are indicated in italics. The individual dose ratios for the intake pathways are provided in Appendix R, Table R-5.

[d] "Toxicity" represents the primary target organ of the chemical. It is based on toxicity summaries from ATSDR (2000–2003) and IRIS (EPA, 2004; see Appendix F).

[6.10] Maximum emission rates for each chemical (tons/year) were identified for each source (e.g., RET) from emission inventories (1953–2004) (Appendix T, Table T-2). Maximum emission rates were selected for worst-case scenario analysis.

Specific contaminants and exposure locations of concern at which the DRs were estimated to be above 1 are summarized in Tables 6-5 and 6-6 (analyses details are provided in Appendices R and T). DRs for exposure to soil and groundwater contaminated with TCE, vinyl chloride, and 1,1-DCE were significantly above 1 in the northeast area for the residential exposure scenario (Table 6-5). DRs above 1 were also determined for inhalation exposure to TCE and hydrazine and its derivatives in multiple receptor locations around the SSFL (Table 6-6).

DRs above 1 were also obtained for exposure to arsenic. Arsenic was detected at significant levels at Santa Monica Conservancy, Brandeis-Bardin and Las Virgenes Creek above health-based standards in soil samples (detections: 1-24 mg/kg; RSSL=0.39 mg/kg). This is 2-62 times in excess of health-based residential soil screening limits. However, it is unclear if these arsenic levels were above natural area background levels. Arsenic is naturally occurring in soil and groundwater as a result of releases from erosion of natural minerals deposits,, though human activities can also lead to arsenic contamination (ATSDR, 1990). Background concentrations of arsenic in California can be as high as 2.3 to 11 mg/kg, according to 1986 California soil samples (surface to about 2.5 feet below surface; Hunter, 2002). Unfortunately, the determination of background samplescollected from areas between Bell Canyon and SSFL in the McLaren/Hart studies (1993; 1995) was inadequate. Therefore, it is not possible with the present monitoring data to determine if the present levels of arsenic are indeed above expected background and/or to identify any specific sources of offsite arsenic.

Note also that DRs for perchlorate from contaminated groundwater in Simi Valley were generally low (up to DR=2 for direct groundwater ingestion; Appendix R, Table R-5), even assuming 30 years of exposure at maximum detected levels. However, recent offsite monitoring has detected perchlorate on the eastern side of SSFL (Allwest Remediation, 2005). On June 18 and 20th, plant debris and plant leaves from plants with new growth were collected along side Dayton Canyon Creek (Allwest Remediation, 2005). The results of these analyses demonstrated high levels of perchlorate ranging from 32 to 42 mg/kg on plant leaves, and from 42 to 57 mg/kg in plant debris (Appendix R, Table R-5; Allwest, 2005). If this vegetation had been edible it would have resulted in DRs ranging from 13 to 24 for chronic ingestion. This is of concern as this area has never been adequately characterized, despite the fact that runoff from Happy Valley where perchlorate was used and has since been detected, runs into Dayton and Woolsey Canyons. See Appendices H and R for offsite levels of perchlorate used in the analysis and the resulting DRs (Table R-5).

The range of DR values reflects the uncertainty in the estimates given the variability of the assumed exposure scenarios and associated parameters (see Tables 6-5 and 6-6). For example, in some scenarios it is assumed that residents drink local groundwater. This may be true for a select community east and north of the facility, but not for residents of Bell Canyon, where there are no known potable water wells. Similarly, exposure via ingestion of vegetables only applies to residents growing fruit and vegetables and eating them, whereas incidental ingestion of soil could affect all residents. It is also important to recognize that the DR values are for long-term exposure of residents (>30 years; Table 6-5) in the communities surrounding SSFL, and are based on maximum area-specific concentrations of offsite contaminant contaminants. Thus these DRs may not reflect realistic exposures for all residents. They were estimated for screening purposes and are presented here for the purpose of identification and ranking of areas of potential exposure concern.

Offsite DRs greater than unity suggest the potential for past or continuing community exposure, based on worst-case scenarios, and thus potential for adverse health impacts. Specific chemicals, potential exposure routes, and locations of such concern include:

1. Long-term (>30 years) residential exposure to TCE, vinyl chloride, and 1,1-DCE within SSFL's offsite TCE plume bounds, via extended use of private water wells north and northeast of the facility, soil vapor intrusion and inhalation, or from chronic area-grown crop ingestion.

2. Long-term residential exposure (>30 years) to arsenic (source unknown) via chronic area-grown crop ingestion in Bell Canyon, Brandeis-Bardin, and potentially all areas north and east of SSFL, including Simi Valley, Dayton Canyon, West Hills, and Canoga Park.

3. Long-term (>40 years) residential exposure to TCE via inhalation of emissions from SSFL in West Hills, Black Canyon, Dayton Canyon, Bell Canyon, Simi Valley, Hidden Hills, Santa Susana Knolls, Woodland Hills, Canoga Park and Chatsworth..

4. Long-term (>30 years) residential exposure to hydrazine and its derivatives via inhalation of emissions from SSFL in West Hills, Black Canyon, Dayton Canyon, Bell Canyon, Simi Valley, Hidden Hills, Woodland Hills and Canoga Park.

5. Residential exposure of children to lead (source unknown) via incidental soil ingestion / inhalation, or from chronic area-grown crop ingestion in Bell Canyon and areas east of the facility; as well as extended use of private water wells or habitual home-grown crop ingestion in areas east of the facility.

6. Potential residential exposure to perchlorate (source suspected to be SSFL) via chronic ingestion of groundwater or area-grown crops in areas east of SSFL (Dayton Canyon, West Hills, Woolsey Canyon).

Figure 6-4. Potential Soil and Water Contamination Exposure Points

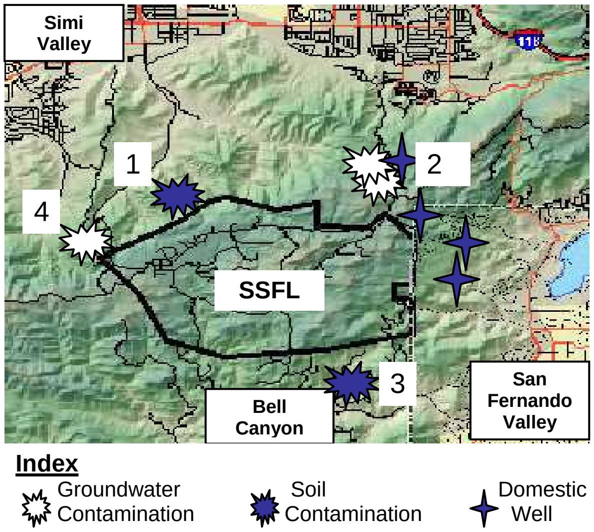
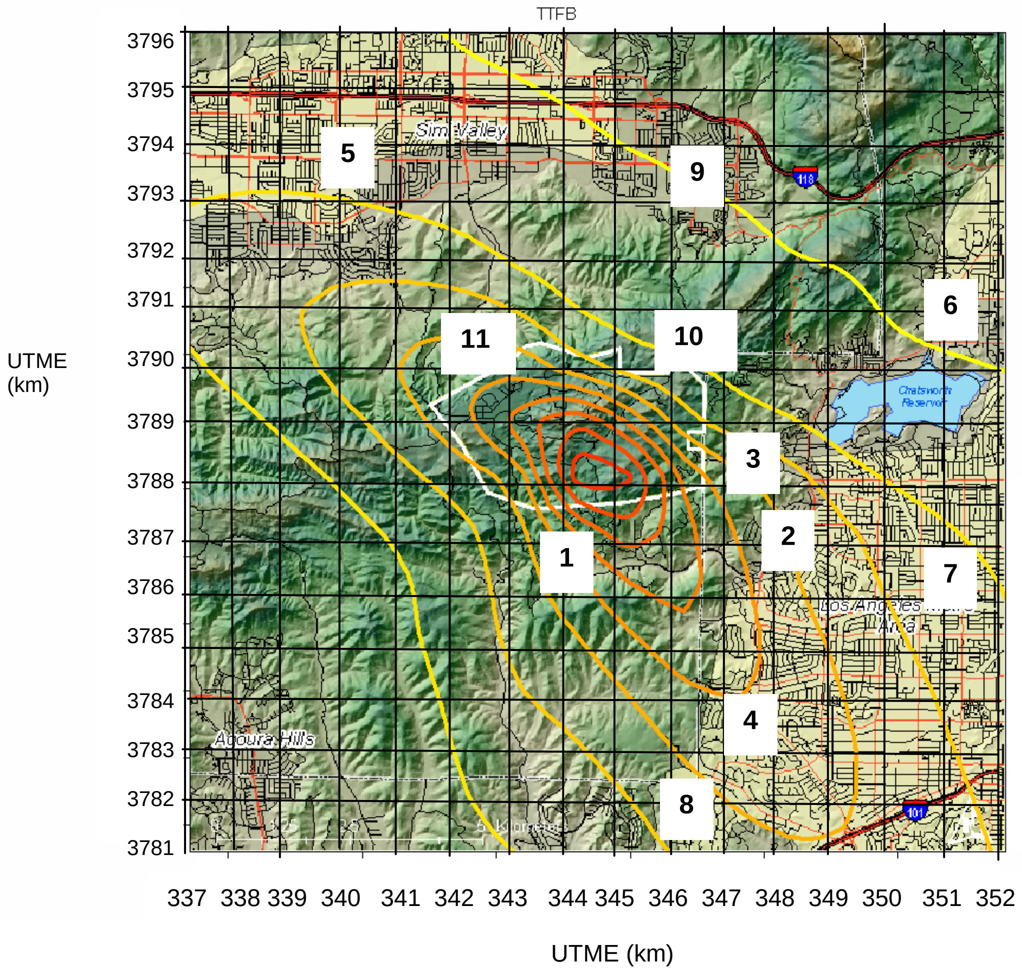


Figure 6-5. Coordinates of Receptor Communities Surrounding SSFL Used in Inhalation Dose Analysis



1. Bell Canyon
2. West Hills
3. Dayton Canyon
4. Woodland Hills
5. Simi Valley
6. Chatsworth
7. Canoga Park
8. Hidden Hills
9. Santa Susana Knolls
10. Sage Ranch / Black Canyon
11. Brandeis-Bardin

Note: The SSFL area is bounded by the white border.

Ranking of receptor sites based on the available monitoring data, modeling of available emission data, and the estimated Dose Ratio values (DRs), identified two areas of potential exposure concern (Tablel 6-5): (1) drinking water wells north and east of the facility and (2) soil in neighborhoods south (Bell Canyon), north, and east of the facility. With respect to wells north and east of the facility, note that previous SSFL studies (ATSDR, 2000; EE, 1989; ERC, 1990b; GRC, 1988a, 1988b) have assumed that there are no functioning wells in this location, but no recent well surveys in these areas have been conducted. Therefore, there is merit to conducting a comprehensive water well survey to enable quantitative exposure and risk assessments for these populations. It is important to recognize that due to the lack of monitoring data for areas east of SSFL, there is much uncertainty about exposure analysis for those areas. For a better assessment of exposure to the east of SSFL, there is a need for contaminant monitoring in the outfalls, streams, and soil.

The DRs determined for the air contaminants TCE and hydrazine were derived from a conservative analysis based on estimated emissions and dispersion modeling (Appendices S and I). Table 6-6 presents the range of potential long-term inhalation DRs (30-50 years of exposure) to contaminants from single sources to multiple sources (i.e. lowest DR for hydrazine exposure from rocket engine testing (RET) alone; highest DR for hydrazine exposure from RET and open pit burning (TTF) combined). Clearly, there is uncertainty in the analysis since the concentrations are derived from estimates based on available data. However, it is important to recognize that DR values are for *long-term* exposure of residents in the communities surrounding SSFL (Table 6-6). Such high DR values suggest that there is merit in more detailed investigation of the health impact of emissions of TCE and hydrazine and its derivatives. Ranking of the various receptor sites based on modeled emission estimates, and the estimated Dose Ratios (DRs), identified as areas of potential exposure concern those with DR values above unity (Table 6-6). For TCE exposure these areas include the Brandeis Bardin Institute, West Hills, Black Canyon, Dayton Canyon, Bell Canyon, Simi Valley, Sage Ranch, Hidden Hills, Woodland Hills, Canoga Park, and Chatsworth. The DR ratios for hydrazine were significantly lower compared to TCE. However, DR ratios above unity were encountered for the same areas as for TCE with the exception of Santa Susana Knolls and Chatsworth for which the DR values were consistently below unity. Additional information regarding receptor locations and contaminants of concern is provided in Chapters 8 and 9.

Table 6-5. Exposures of Concern Due to SSFL Activities (Dose Ratios[a] >1) Based on Offsite Monitored Soil, Groundwater and Vegetation Concentrations

Contaminant	Exposure Location with Respect to SSFL	Medium	Pathway	Scenario		
				Recreational	Occupational	Residential
TCE	Northeast (0.01–0.9 mg/L)	Groundwater	Ingestion	0–14	12–1,100	48–4,200
			Inhalation	—	—	230–21,000
			Dermal	—	—	12–1,000
			Veg. ing.	—	—	44–4,000
Vinyl chloride	Northeast (0.064 mg/L)	Groundwater	Ingestion	3	270	1,100
			Inhalation	—	—	120
			Dermal	—	—	29
			Veg. ing.	—	—	2400
1,1-DCE (vinylidene chloride)	North (0.019 mg/L)	Groundwater	Ingestion	—	23	89
			Inhalation	—	—	200
			Dermal	—	—	5
			Veg. ing.	—	—	20
Perchlorate	East (32-57 mg/kg)	Vegetation[b.]	Veg. Ing.	—	—	13-24

[a] Dose ratio is the ratio of daily lifetime average daily dose (LADD) to acceptable lifetime daily dose (ALADD =1x10^{-6} / Cancer Potentcy Factor (CPF) for 1 × 10^{-6} risk of cancer or ALADD= chronic Reference Dose (RfD) for non-carcinogens). [b.] Vegetation sampled here was not edible. This exposure scenario assumes similar levels could exist in areas along Dayton Creek; residents who grow and chronically eat vegetables in this area may be at risk.

Table 6-6. Lifetime Inhalation Exposures of Concern Due to SSFL Activities Based on Single- and Multiple-Source Inhalation Dose Ratios[a] (DRs) Derived from Air Dispersion Modeling and Air Emission Estimates

Location	TCE	Location	Hydrazine Derivatives[b]
Brandeis Bardin Institute[c]	17-503	Bell Canyon	3–35
West Hills	47-314	West Hills	2-14
Black Canyon	8-304	Dayton Canyon	2-11
Dayton Canyon	36-265	Woodland Hills	0–8
Bell Canyon	40-241	Canoga Park	0–7
Simi Valley	30-229	Black Canyon	1-5
Sage Ranch[c]	2-87	Simi Valley	0–4
Hidden Hills	30-86	Brandeis Bardin Institute[c]	1-3
Santa Susana Knolls	10-75	Hidden Hills	0–3
Woodland Hills	7-74	Sage Ranch[c]	0-2
Canoga Park	10-72	Chatsworth	≤1
Chatsworth	8-72	Santa Susana Knolls	<0

(a) Dose ratio (DR) = lifetime average daily dose/acceptable lifetime daily dose (ALADD). The ALADD is determined based on 1 × 10^{-6} risk of cancer as determined by EPA's Cancer Slope Factor. DRs were estimated based on maximum reported (or estimated) annual source emissions from 1953–2004 (Appendix S) and are representative of maximum receptor-specific modeled concentrations estimated from air dispersion analysis (Appendix I). Inhalation DR calculations are presented in Appendix T. The reported range of dR values includes both DRs from single and multiple source emissions. Dose ratios from multiple emission sources were obtained by adding the doses due to exposure from these multiple sources.

(b) Hydrazine derivatives include hydrazine, and UDMH (asymetrical dimethyl hydrazine).

(c) DRs presented in Appendix T for Brandeis Bardin Institute were multiplied by 0.25 to reflect summer only residency. DRs presented in Appendix T for Sage Ranch were multiplied by 2/7 to reflect weekend use only.

7. TCE CONTAMINATION

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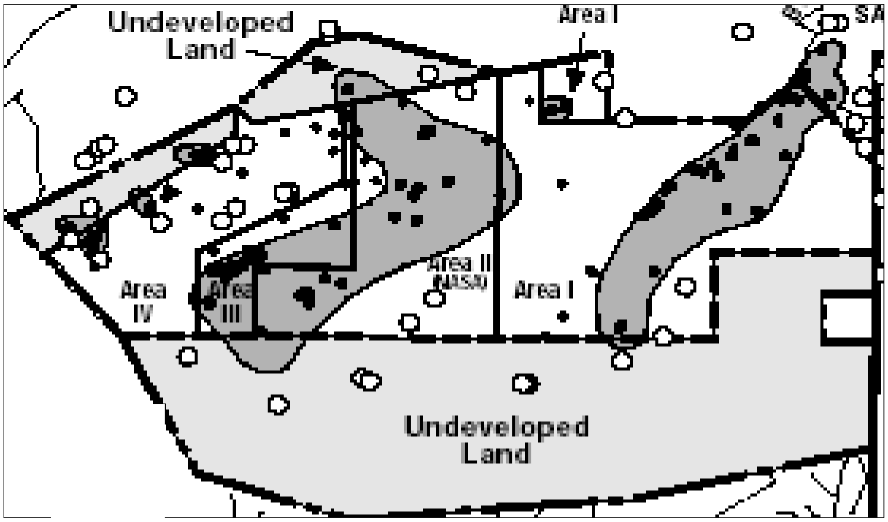
7.0 TCE CONTAMINATION

7.1 Overview

Significant groundwater contamination by TCE has been detected at SSFL as early as March 1984 (Rocketdyne, 1988). A TCE plume was found to underlie much of the site's 2,700 acres in Areas I, II, and III (Rocketdyne, 1988; Figure 7-1). The major source of TCE contamination was associated with cleaning of rocket engines in the rocket testing areas (Sections 3.2.2 and 5.3). TCE was detected in groundwater wells at the facility in concentrations of up to 5,200 µg/L (RD-4 near Bravo test area, Area II; see GRC, 1987). The presumed source for most of the groundwater TCE contamination was downward flow from a series of surface water impoundments that drained the rocket engine test areas (GRC, 1987).[7.1] Offsite groundwater contamination by TCE and its degradation products, trans-1,1-DCE and 1,2-DCE, has also been reported (see Appendix H).

Figure 7-1. TCE Plumes On Site



Source: ATSDR, 1999.
Note: Black dots represent groundwater detections; white dots represent groundwater non-detections.

The total amount of TCE that infiltrated groundwater has been estimated at 313,000 gallons (3,660,000 pounds) by CH2M Hill (1993). It is also possible to estimate the total amount of TCE that infiltrated the subsurface using a study by Hurley et al. (2003) and estimates of the superficial areas of different plumes at SSFL. Hurley et al. estimated the amount of TCE per unit area in the contaminated subsurface, based on measurements in seven boreholes drilled on SSFL at locations where TCE infiltration was suspected. The average amount of TCE per unit of area in these seven boreholes is 617 g/m^2 and the surface area of the TCE plumes is on the order of 1,160,000 m^2 (see Section 5.1.4). Therefore, the total amount of TCE in the contaminated zone (i.e., the product of the TCE surface density and the contaminated area) is estimated at about 716

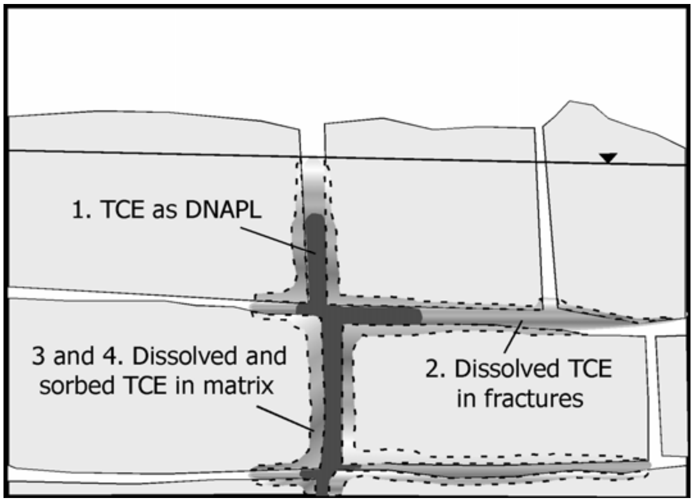
[7.1] Historically, TCE was used to wash the rocket engines between tests (CH2M Hill, 1993). Other chemicals were carried along with the TCE wash and also infiltrated the subsurface soil.

metric tons (1,600,000 pounds). This estimate differs with the estimate by CH2M Hill (1993) by about a factor of 2. The two estimates are, however, within the same order of magnitude (1,600 and 3,660 thousand pounds, respectively). Both indicate that a significant amount of TCE has contaminated the subsurface zone. Sections 7.2 and 7.3 discuss the distribution and extent of TCE contamination of groundwater below SSFL and the potential migration of TCE.

7.2 A Simplified Conceptual Model of TCE Distribution in SSFL Groundwater

Groundwater contamination by TCE is extensive relative to contamination by other organic compounds identified at SSFL, and has been the subject of intense investigation (Montgomery Watson, 2000a, b). The past, current, and future status of subsurface TCE in SSFL can be summarized with a conceptual model of the site, depicted in Figure 7-2.

Figure 7-2. Conceptual Model of TCE Distribution in a Fractured Sandstone Groundwater Environment



Note: The horizontal line with pointer represents the water table in this conceptual model. Adapted from information presented in Montgomery Watson, 2000 a,b.

TCE is categorized as a denser-than-water organic solvent, or a dense nonaqueous-phase liquid (DNAPL). This means that the infiltrating TCE penetrated to depths below the water table and continued to sink until the resistances posed by friction against the fracture walls and buoyancy forces halted its progress. The time period encompassing the release of TCE and its infiltration into the subsurface soil is relatively short (hours to days or weeks after each release episode). While residing in the fractures, the TCE DNAPL (TCE fraction 1) dissolves into slowly passing groundwater (TCE fraction 2). Due to its low aqueous solubility (about 1.1 g/L), TCE can be present as a saturated (pure) DNAPL phase that is extremely persistent in groundwater. Dissolved TCE also diffuses from the DNAPL and from regions of high dissolved TCE concentrations into stagnant water of the fracture network and within the relatively tight porosity of the sandstone matrix (TCE fraction 3). Because TCE is hydrophobic, a significant portion of the aqueous-phase chemical can partition (or sorb) to the sandstone solids (TCE fraction 4). These latter three processes occur over years—a much larger timescale than infiltration.

TCE fraction 1: DNAPL entrapped in fractures. Dissolved TCE has been found in groundwater associated with alluvial sediments as well as in the Chatsworth Formation groundwater. TCE concentrations ranging from a few parts per billion (ppb) to 10–15 parts per million (ppm) have been reported (Montgomery Watson, 2000a; Hurley et al., 2003). Concentrations at the high end of this range may be indicative of the presence of DNAPL TCE in the vicinity of the measurements. The exact location of the DNAPL is difficult to estimate, particularly in a fractured flow system like the one at SSFL, and is related to such issues as the amount and timing of TCE release, the depth to groundwater, and the geometry of the fractures. The depth and distribution of the DNAPL can fluctuate with changing groundwater conditions, such as those caused by pumping, wet periods, or dry periods.

The total amount of subsurface DNAPL is difficult to quantify, as the released amounts and volatilization fractions are highly uncertain. At SSFL, where fractured flow dominates, DNAPL dissolution is expected to be slow and most of the DNAPL that reaches groundwater may still be harbored in the fractures. This issue is pursued further below, in the sections on the aqueous and sorbed TCE mass in the SSFL sandstone.

TCE fraction 2: aqueous TCE in fractures. It is this dissolved- (or aqueous-) phase TCE that is detected in monitoring wells throughout SSFL and, in a few cases, just off site. Plume maps, drawn to integrate the observation well data, are presented by Montgomery Watson (2000). Montgomery Watson prepared these maps by interpolating between observations, a generally accepted procedure for alluvial groundwater systems. This approach creates an approximation for fractured flow systems, in which the dissolved contaminant patterns are more closely linked to the fractures. When using such a map for SSFL's fractured flow system, one must realize that the subsurface plume depictions are representations of the contaminated fracture planes and do not necessarily reflect the actual sandstone matrix contamination within the same areas. The extent to which these maps do reflect the overall subsurface contaminant levels depends on the rate of transport of TCE from the fractures into the matrix (TCE fraction 3). Thus, if the rate of transport into the matrix is slow, these plumes may represent a relatively small amount of the TCE that initially infiltrated the fracture network.

TCE fractions 3 and 4: aqueous and sorbed TCE in the sandstone matrix. The rate and extent of penetration of TCE into the SSFL sandstone matrix depends on the geometry or "tightness" of the matrix porosity, the strength of the TCE sorption to the sand material making up the matrix, and the contact time between the TCE and the matrix. The penetration process is diffusion-driven: that is, the dissolved TCE is driven from a region of high concentration (the fracture) into a region of low concentration (the sandstone matrix). The diffusion process is hindered by the tortuous path that the TCE molecules must follow through the matrix. TCE progress is further retarded when TCE sorbs onto the sandstone matrix while passing through the matrix pores.

7.2.1 A Conceptual Model of TCE in SSFL Groundwater

A conceptual model posed for TCE (Montgomery Watson, 2000a), and later for perchlorate (Montgomery Watson Harza, 2003a, 2003b, 2003c), proposes that the contaminant sources are stationary and that contamination is transported away from the source by groundwater moving through the fractures and by diffusion into the porous, but stagnant, sandstone matrix. Model simulations were used to demonstrate the slowness of the propagation of contaminants through the fractured sandstone due to the retarding effect of the diffusion process. The models (hereafter collectively termed the Montgomery Watson or MW model) suggest that the TCE and perchlorate have accumulated in the sandstone matrix.

The simulations were two-dimensional and carried out using the numerical model Fractran, developed at the University of Waterloo (Sudicky and McLaren, 1992). Fractran is well-documented, commercially available code (Waterloo Hydrogeologic Software). The two-dimensional model domain employed was a vertical cross-section of fractured media 500 meters long and 100 meters deep. Physical parameters for the model were taken from SSFL site characterization data. The sandstone matrix hydraulic conductivity value and porosity values used were 1×10^{-6} centimeters per second and 0.12, respectively. A fracture network was generated randomly using statistics from the field data on horizontal and vertical fracture lengths, and assigning fracture densities of 0.05 and 0.075 fractures/m^2 in the vertical and horizontal directions, respectively. Horizontal and vertical fracture lengths ranged from 10 to 20 meters and 5 to 10 meters, respectively. Fracture aperture thicknesses were also randomly generated and spatially distributed in the model using a statistical data from SSFL fractures and ranged from 20 to 1000 microns.

The first step of the model simulation was to generate a steady state-flow regime through the fractured sandstone. The modelers accomplished this by specifying a hydraulic head along all four sides of the model domain so as to create 0.5 percent (horizontal) and 0.2 percent (vertical downward) hydraulic gradients, which are estimated from site conditions. The average linear groundwater velocities for these gradients and the matrix and fracture properties outlined above were reported to be 925 meters per year, or m/yr (horizontal) and 105 m/yr (vertical). The model-calculated velocity distribution values used to determine these averages ranged from -2,850 m/yr to 11,500 m/yr (horizontal) and -12,300 m/yr to 9160 m/yr. The negative horizontal velocity is in the direction opposite to the assigned hydraulic gradient, and the negative vertical velocity is downward. A comparison of these model-calculated groundwater velocities with those observed in the field or estimated more directly from field observations was not found in these reports.

Perchlorate and TCE solute transport was then modeled in the context of the steady-state flow regime. A 25-meter-long vertical source of TCE was attributed to the upper edge of the up gradient end of the simulation domain and left constant for 20 years. This was intended to simulate a DNAPL source area that had penetrated vertically into the subsurface via surface fissures. In contrast, perchlorate was admitted to the flow system as a 50-meter-long horizontal source along the top boundary of the up gradient end of the simulation domain and left constant for 10 years. This configuration was intended to simulate a release of solid phase perchlorate at the ground surface followed by infiltration into the subsurface as a solute via recharge water. Site characterization data support the TCE DNAPL source configuration in a general sense; however, the specific geometry and dissolution characteristics of the TCE source zones at SSFL remain largely unknown. The perchlorate source configuration appears to be more speculative in nature due to limited plume data at SSFL.

Simulations of diffusive transport of dissolved TCE and perchlorate were undertaken to determine the potential impact of matrix diffusion on the transport process. These simulations are based on Fick's Second Law of diffusion (Crank, 1975), modified to account for the presence of a porous medium:

$$\frac{\partial C}{\partial t} = \frac{D/\tau}{R}\frac{\partial^2 C}{\partial x^2} \tag{7.1}$$

where C is the solute concentration in the soil matrix, t is time, x is the coordinate perpendicular to the matrix face (cm), D is the aqueous diffusion coefficient of the solute (cm^2/s), τ is the dimensionless matrix tortuosity factor (≥ 1.0), and R is the dimensionless retardation factor.[7.2] It is noted that the chemical concentration in soil air phase, C_a, is related to matrix concentration as $C_a = C/\phi$, where ϕ is the soil porosity. Equation 7.1 signifies that the rate of diffusion of a solute is related to the concentration gradient (the steeper the gradient, the faster the diffusion rate) and the diffusion properties of the system—specifically the diffusion coefficient, porosity, tortuosity factor, and retardation factor. For porous systems with sorption, the net effect of these parameters is a retarded diffusion process.

The selection of diffusion and sorption model parameters is critical to assessing the relevance of the MW conceptual model. For TCE, the values applied for D, τ, and R were 1×10^{-5} cm^2/s, 10, and 2.0, respectively, resulting in an apparent diffusion coefficient value ($D_a = D/(\tau R)$) of 5×10^{-7} cm^2/s. For perchlorate, the values applied for D, τ, and R were 1.8×10^{-5} cm^2/s, 10, and 1.0, respectively, resulting in an apparent diffusion coefficient value of 1.8×10^{-6} cm^2/s. For a non-diffusing solute, the values applied for D, ϕ, τ, and R were adjusted so that the resulting apparent diffusion coefficient was more than six orders of magnitude lower (i.e., negligible) than in the preceding cases. It is worthwhile to note that the tortuosity factor can be applied mathematically in two ways. In Montgomery Watson (2002), it is used as a fractional multiplier to lower the net diffusion rate. In equation 7.1, it is used in the denominator, in which case it must be greater than 1 to show the desired tortuosity effect.

In the MW simulations, the simulated TCE and perchlorate plumes remain within the simulation domain (100 meters vertical distance, 500 meters horizontal distance) even after 100 years, whereas the non-diffusing plume encounters the down gradient boundary in only 3.5 years. Additional two-dimensional simulations were undertaken that examined the sensitivity of this result to the randomly generated fracture network and associated groundwater velocities generated by the model. No sensitivity analysis associated with the diffusion parameters was presented.

The simulations performed in support of the MW conceptual model were useful for illustrative purposes. The general dynamics of the SSFL system are likely to be similar to what the simulations describe. However, specific conclusions as to the current state of TCE and

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[7.2] $R = 1 + \rho_b K_d/\phi$,, where ρ_b is the bulk density of the sandstone and K_d is the sorption distribution coefficient: (mg chemical/g sorbent)/(mg chemical/mL water).

perchlorate, and their containment in the subsurface at SSFL, cannot be drawn from these simulations. There are several reasons for this.

First, the source configurations selected for the simulations are highly idealized and not necessarily characteristic of those at SSFL. While the general locations of the sources (DNAPL) at SSFL are known from site characterization efforts to date (Montgomery Watson, 2002); Hurley et al., 2003), the sources' specific locations and configurations have not been clearly delineated. Actual sources at SSFL are distributed in space; often, more than one source contributes to plume migration. This is evidenced by the existing TCE plumes, which have clearly propagated to lengths exceeding 500 meters in less than 100 years (Montgomery Watson, 2000a).

A second issue has to do with flow parameters used in the model. The flow model has not been calibrated to actual site conditions, and thus is more appropriate as a conceptualization of the general characteristics of the SSFL site. Actual groundwater flow at SSFL is driven by a range of vertical and horizontal hydraulic gradients that fluctuate with recharge and pumping conditions on site. Creating a more realistic, calibrated version of the flow model at SSFL would constitute a major effort, but may be necessary for portions of the site where contaminant plume containment is critical.

A third issue pertains to the estimated diffusion rates into the sandstone, which are defined too narrowly in the simulations. In particular, the retardation and tortuosity effects employed could be greater than the simulations depict. An independent estimate of the TCE diffusion rate in a sample of SSFL sandstone were made for comparison with the abovementioned rate (see Appendix U for method details). The TCE sorption capacity of the sandstone was measured, producing a retardation factor value of about 20. Diffusion estimates for the same sandstone yielded a tortuosity estimate of about 48. This value points to the feasibility of an apparent diffusion coefficient value that is roughly 50 times lower than the values employed in the MW model for TCE. If this is the case, the majority of the mass may not be harbored in the SSFL sandstone matrix and hydraulic containment of the mobile (fracture-driven) groundwater is a key issue in preventing further offsite migration and surface manifestations of contaminant plumes (e.g., at springs).

7.3 Extent of Existing TCE in SSFL Groundwater

Extensive past site characterization and monitoring efforts have been reviewed in various previous reports on SSFL. The most recent characterization efforts for groundwater have focused on TCE and perchlorate (Montgomery Watson, 2000a, b, 2002; Montgomery Watson Harza, 2003a, 2003b, 2003c). A large number of contaminants, including other chlorinated solvents and their transformation products, have been identified in SSFL groundwater and remain chemicals of concern. However, the discussion here focuses primarily on the more recent TCE characterization efforts, which provide the most definitive data on potential exposure pathways.

Horizontal extent of chlorinated solvent plumes. A network of shallow and deep monitoring wells has identified chlorinated solvent plumes (primarily TCE, along with other solvents and their transformation products) in SSFL groundwater. The plume sources are generally located at the centers of solvent handling and disposal activities, such as the rocket test areas and former sodium disposal facility. An assessment of SSFL periphery monitoring well data over time (GRC, 1999, 2000 was undertaken to confirm Montgomery Watson's (2000a, b) rendering of the extent of these plumes. The assessment determined that the general configuration of the published plume configurations and boundaries is reasonable. Historical TCE monitoring well data throughout SSFL (GRC, 1999–2002) were examined as time series in order to determine whether the plumes continued to grow longitudinally. Continued plume growth would suggest that the plumes were not being contained by natural attenuation processes and/or groundwater extraction operations at SSFL. This could also mean that the plumes pose a significant risk to water resources and humans using those resources down gradient from the existing plume boundaries.

The time series data were found to be complicated by large variations in groundwater levels over time, caused by onsite pumping and normal seasonal variation at SSFL. Examination of individual wells within plumes at SSFL suggested that most of the plumes had achieved approximately steady-state conditions. This does not mean that contaminants are no longer being dispersed off site. Instead, stationary plumes are receiving mass from their sources as quickly as they lose mass at the plume front (via transport and mixing in water or transformation of the contaminants). The plume size appears to be constant, in part, because of the detection limits of the methods used to measure the concentrations. Note that the stationary state of a plume depends on the existence of a steady hydraulic regime; changes in this regime, such as may be caused by changes in pumping activity or recharge, can change the plume geometry.

Based on historical monitoring data for wells situated at or near approximate plume boundaries, areas of concern were defined qualitatively at the locations of wells where elevated concentrations appeared to persist or where concentrations appeared to be increasing (i.e., where the plumes were not at steady state). One area of concern was in the northeast portion of SSFL, where concentrations at wells RD-38A and OS-24 appeared to increase from 1998 through 2001 (GRC, 1998, 1999, 2000). It is known that TCE is dispersing via the groundwater pathway over SSFL site boundaries in this part of Area I, and substantial additional characterization efforts have focused on this area (Mongomery Watson Harza, 2003a). A second area of concern is located along the northern SSFL boundary, where elevated TCE concentrations in well RD-56A have been observed (GRC, 1998, 1999, 2000). This is the same region where significant levels of transformation products, such as vinyl chloride, have been observed. Note that wells along the western and southwestern boundaries do not indicate current contaminant levels comparable to those in the abovementioned wells. However, these areas are also of some concern due to past detection of chlorinated solvents at RD-59 and OS-5, as well as RD-59's proximity to the former radioactive waste handling facilities and OS-5's proximity to the sodium disposal pond. Note also that TCE was detected on site in a number of Area IV wells at elevated concentrations (see Appendix H, Table H-3) and that this area drains to the southwest via the outfalls.

Vertical extent of chlorinated solvent plumes and source zones. Recently a substantial core hole sampling and analysis effort was undertaken to characterize the subsurface source zones for chlorinated solvents (DNAPL) at SSFL (Hurley et al., 2003). The extensive data set described in Hurley et al.'s report delineates the vertical distribution of chlorinated solvents in core holes C-1 through C-7. In core hole C-1, several TCE concentrations as high as 0.5 mg/L were observed at depths greater than 400 feet, while more concentrations above 1 mg/L occur at depths greater than 300 feet and a still greater frequency of concentrations above 1 to 10 mg/L appears at depths ranging from about 70 to 200 feet. While the connectivity between the source and this aqueous distribution is complex in a fractured flow system, the aqueous distribution here likely corresponds to the vertical DNAPL distribution. This would imply that (in the vicinity of C-1) a large portion of the DNAPL is harbored in the subsurface between 70 and 200 feet, a smaller (but still significant) portion resides between 200 and 300 feet, and a lesser portion resides around 300 to 400 feet. Overall, the plots of chlorinated solvent pore water concentration as a function of depth provide conclusive evidence of DNAPL penetration to a depth of 400 or 450 feet in some instances.

Hurley et al. (2003) employed the core hole data to reach the conclusion that “all or nearly all of the DNAPL has been converted to dissolved and sorbed mass existing in the rock matrix.” This conclusion is suspect for three reasons. First, there is an abundance of elevated TCE concentrations (in the ppm range) persisting near the source zones. Concentrations of this magnitude are difficult to conceive in the absence of nearby DNAPL material. Second, although the core hole investigations represent an appreciable effort, the horizontal extent of the source zones is not delineated by these core holes; many more core holes of this type would be needed to fully delineate the zones’ horizontal extent. Third, mass transfer rates associated with DNAPL dissolution in fractured media are not well understood. These three points suggest that, given the current state of knowledge, there is no basis for dismissing the possibility that there may be appreciable DNAPL mass remaining in the vicinity of the core holes, and that this DNAPL is responsible for the elevated concentrations observed in the core holes.

Crude estimates of the total dissolved and sorbed TCE mass (i.e., the non-DNAPL mass) were made using the Montgomery Watson (2000a) plume maps of the entire SSFL site and the sorption capacity measured for a sample of SSFL sandstone (see Section 7.3.2). These estimates suggest that roughly 3,000 to 56,000 gallons of TCE (depending on the specific diffusion penetration depth and fracture spacing assumed) now reside in an aqueous or dissolved state throughout the SSFL site. The difference between what was released into the ground (and not volatilized) and this aqueous/sorbed portion is the remaining DNAPL phase. Thus, these results suggest that if large volumes ($\gtrsim$ 100,000 gallons) of DNAPL entered the subsurface, then a substantial portion continues to reside as DNAPL in the SSFL subsurface.

Samples from core holes C-1 through C-7 also revealed vertical distributions of DCE isomers (cis-DCE, trans-DCE, and 1,1-DCE) and perchloroethene. The latter is another well-known solvent that was used at SSFL, though to a lesser extent than TCE. As Hurley et al. (2003) discuss, the cis- and trans-DCE levels are consistent with generally observed TCE biotransformation pathways. The 1,1-DCE levels are more difficult to explain: some of the levels are quite elevated (i.e., in the mg/L range), suggesting that this DCE isomer was also used as a solvent at SSFL or was present as an impurity at relatively high levels in the TCE. Vinyl chloride, a well-known transformation product, did not appear in many of the field samples; if transformation of TCE is occurring at the site—as it appears to be in some areas—then vinyl chloride would be expected to be present. Vinyl chloride is a gas at ambient temperatures, and it is therefore difficult to measure accurately in groundwater samples. Investigations into anaerobic oxidation pathways of TCE degradation at the SSFL may help clarify this issue.

7.3.1 Interaction Between Sandstone Matrix and Dissolved TCE

The study team used experiments to measure TCE diffusion rates, and thus estimate the rate at which dissolved and sorbed TCE could penetrate into the SSFL sandstone. (It is known that the characteristics of the sandstone vary significantly at SSFL; the study team's measurements were intended to be more representative of site behavior than literature values, but they did not account for spatial variability in the sandstone.) The experiments were carried out on one of two core samples (1 foot long, 3 inches wide) provided by Boeing at the team's request. Both these samples were collected during the drilling of hole C-5. Core 1, the one used for the sorption and diffusion measurements, was a sandstone sample taken roughly 215 feet below ground level. Core 2 was a shale sample taken from 97 to 100 feet below ground surface.

The study team pulverized a portion of Core 1 and split it into sample vials for the sorption study, following accepted methods for sorption measurements (Harmon and Roberts, 1994; see Appendix U for details). Triplicate vials containing the solids were filled with clean water, spiked with varying amounts of TCE, and analyzed after reaching equilibrium. The sandstone-TCE sorption coefficient was measured as roughly 1.1 mL/g, which is not uncharacteristic of sand with low organic carbon content. Using the above value for K_d, a bulk density value of 2.3 g/cm^3, and a porosity value of 0.13 (Montgomery Watson Harza, 2003a, b, c), the team obtained a retardation factor ($R = 1 + \rho_b K_d/\phi$) of about 20. This means that the TCE will appear to diffuse roughly 20 times more slowly than it would in the absence of sorption.

The diffusion of TCE into the sandstone was assessed experimentally using a diaphragm-cell (a single unit containing two compartments separated by a porous barrier). Measurements using tritiated water were undertaken because small changes in concentration were more easily measured with this radioactive species. The experimentally derived pore diffusion coefficient value was about 1.05×10^{-6} cm^2/s (see Appendix U for details). Given that the self-diffusion coefficient for water is about 2.2×10^{-5} cm^2/s, this implies that the sandstone tortuosity reduces the tritiated water's effective diffusivity by a factor of about 18 for this core sample. Scaling this up to account for the relatively large TCE molecule (see Schwarzenbach et al., 1993) results in a TCE tortuosity factor 2.7 times larger than that for tritiated water—a value of about 48. Also, TCE will be retarded relative to tritiated water (by a factor of roughly 20, as estimated above). Therefore, based on the estimated free aqueous diffusion coefficient for TCE of 8.6×10^{-6} cm^2/s (Hayduk and Laudie, 1974), the value of the apparent TCE diffusion coefficient in the sandstone sample tested is about $(MW_{water}/MW_{TCE}) \times (8.6 \times 10^{-6})(20 \times 48) = 1.15 \times 10^{-9}$ cm^2/s. This low diffusion coefficient suggests that TCE propagates into the SSFL sandstone extremely slowly. Note that computer simulations by Montgomery Watson (2003) addressing the matrix diffusion issue assume that TCE's free aqueous diffusion coefficient value is 1×10^{-5} cm^2/s, the tortuosity factor is 0.1 (or a factor of 10 reduction of diffusivity), and the retardation factor is 2; this produces an apparent diffusion coefficient value (6.5×10^{-8} cm^2/s) about 56 times greater than the one estimated in the study team's analysis. Thus, the MW model's estimates for diffusive penetration into sandstone are much higher than would be suggested by the team's estimate of the diffusion coefficient of TCE.

7.3.2 Estimates of Current TCE Mass in SSFL Groundwater and Sandstone Matrix

The study team used the information on sorption and diffusion described in the previous sections, together with TCE plume maps (Figure 7-3), to estimate the total mass of sorbed and dissolved TCE presently in the SSFL subsurface. This estimate was made under the assumption that the plume maps for the site actually represent flat or "pancake"-type plumes that exist in the fracture network and propagate to some extent into the adjacent sandstone.

The conceptual model used to estimate the amount of dissolved TCE in the fractured sandstone formation is depicted in Figure 7-4. It suggests structured fractures separated by a given fracture spacing. From the edges of these fractures, dissolved TCE diffuses into the sandstone matrix. The penetration depth of the invaded matrix increases as a result of the diffusion progress. Of course, the number of fractures per unit depth (or fracture spacing) and the degree to which the plumes diffuse into the sandstone will greatly affect the estimates generated by this conceptual model. To obtain a rough estimate of the amount of TCE in the subsurface, the study team made a series of assumptions about key parameters. First, the overall plume thickness was assumed to be 50 or 100 meters, based roughly on the core hole data (Hurley et al., 2003). Next, the fracture spacing was assumed to be 2, 5, or 10 meters, based roughly on the fracture density cited in the MW model simulations (Montgomery Watson Harza, 2003a). The matrix porosity was assumed to be 0.1 and the penetration depth of TCE was approximated to be in the range of 50 centimeters to 100 centimeters, based on transient diffusion calculations. The aqueous mass in the fracture as well as in the matrix was then calculated for each plume thickness, with varying penetration depth and fracture spacing. Similarly, the team calculated the sorbed mass in the matrix for each penetration depth, with varying fracture spacing and a value of 1.1 mL/g for the sorption distribution coefficient K_d.

The TCE plumes at the SSFL site occupy large areas and were estimated using the map reproduced here as Figure 7-3 (Montgomery Watson, 2000a). These areas are specified according to the concentration ranges given in Table 7-1. Using the assumptions listed in the previous paragraph, the team summed the estimated aqueous and adsorbed mass in the plume "layers" with the results plotted in Figure 7-5 (see Appendix U for additional details). This graph depicts the equivalent volume of spilled TCE that is dissolved or adsorbed to the sandstone matrix. These calculations do *not* account for non-dissolved (DNAPL) TCE remaining in the subsurface: an estimated DNAPL volume remaining in the subsurface would be the difference between the estimated net amount that infiltrated the soil (and did not volatilize) and the volumes plotted in Figure 7-5.

Table 7-1. Size of TCE-Contaminated Areas

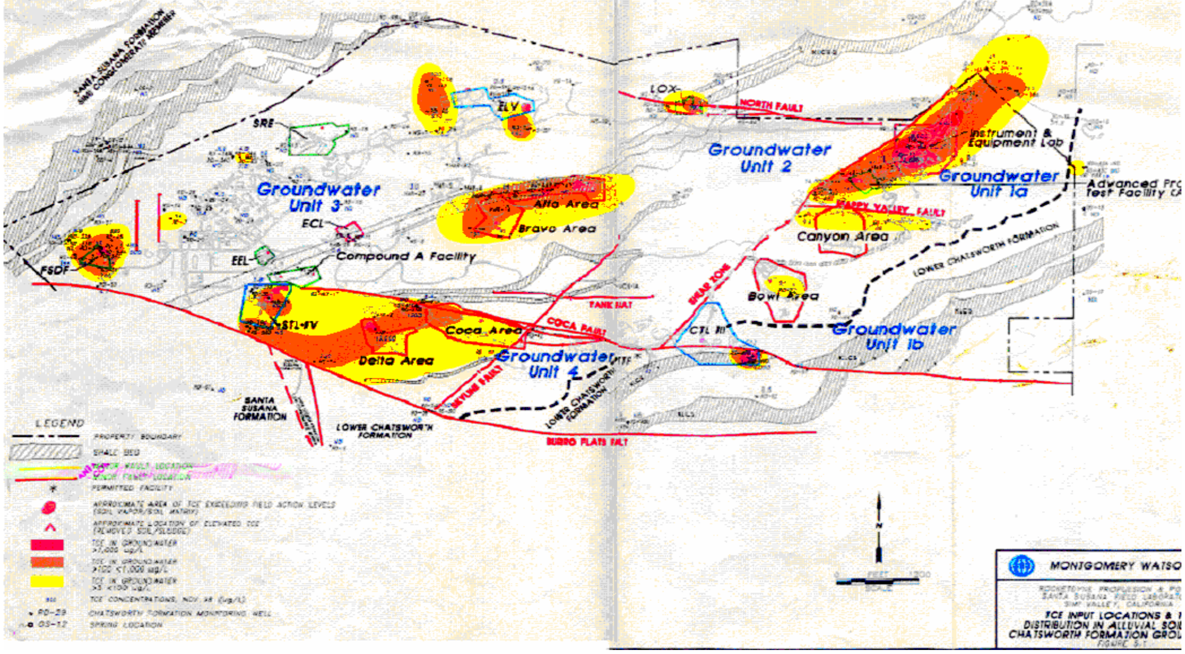
TCE Concentration Range (ppb)	Contaminated Area (m^2)
5–100	695,000
100–1,000	399,000
1,000–10,000	66,000

The results in Figure 7-5 demonstrate that the estimates of total sorbed and dissolved TCE are strongly related to the fracture spacing and diffusive penetration depth into the sandstone matrix. Given an overall plume thickness estimate of 100 meters, the curves suggest an upper limit of the dissolved and sorbed TCE equivalent to about 56,000 gallons of TCE when all the sandstone is invaded by dissolved TCE (for instance, when the fracture spacing is 2 meters and the penetration depth is 1 meter). These calculations suggest that roughly 3,000 to 56,000 gallons of TCE (depending on the diffusion penetration depth and fracture spacing assumed) now reside in an aqueous or dissolved state, and the remainder is DNAPL.

The above calculations suggest that a relatively large fraction of the TCE that originally infiltrated the SSFL subsurface remains, as DNAPL. However, the study team would need data demonstrating (a) direct evidence of the DNAPL volume remaining in the fractures and (b) penetration depth due to TCE diffusion to conclusively estimate the distribution of TCE in the sandstone groundwater environment. The presence of dissolved TCE (aqueous) concentrations in excess of 10 mg/L in the vicinity of the core holes (Hurley et al., 2003) lends support to the hypothesis that significant DNAPL may indeed persist in the SSFL sandstone.

Removal of the large amount of TCE that is estimated to reside in the soil subsurface and groundwater at SSFL is beyond the capabilities of current remediation technologies. Therefore, there is potential for long-term exposure to TCE if contaminated groundwater will come into contact with human and ecological receptors. There is also potential for continuing volatilization of TCE from the soil subsurface. The above concerns are consistent with the conclusions of the 1990 U.S. Army Corps of Engineers–sponsored baseline public health risk assessment for the SSFL property. That assessment concluded that there may be a public health risk associated with residential use of the property. It was stated that “Exposure of site residents to TCE via multiple pathways could lead to cancer risks exceeding the 1 × 10^{-6} level” (Techlaw, 1990).

Figure 7-3. TCE Plume Map for SSFL



Source: Montgomery Watson, 2000a, b.

Figure 7-4. Schematic Representation of TCE Distribution in Fractured Sandstone

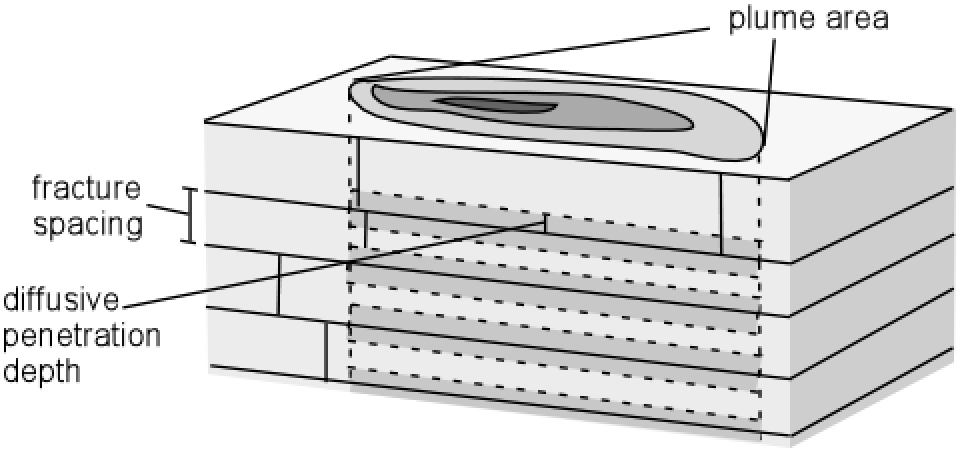
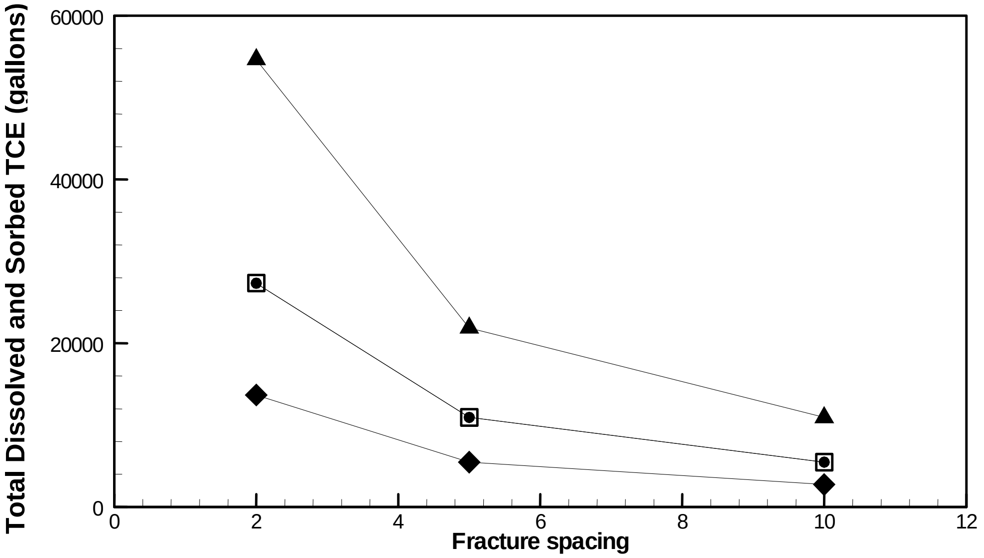


Figure 7-5. Estimated Total Dissolved and Sorbed TCE in SSFL Groundwater (Using the Simplified Conceptual Model)



Calculated total dissolved and sorbed TCE volume (in gallons) as a function of sandstone matrix fracture spacing for:

▲ 100-meter plume thickness and 1-meter diffusive penetration depth.
□ 100-meter thickness and 0.5-meter penetration depth.
• 50-meter thickness and 1-meter penetration depth.
◆ 50-meter thickness and 0.5-meter penetration depth.

8.0 IMPLICATIONS OF DATA QUALITY, MONITORING, AND CONTINUING CLEANUP FOR PUBLIC HEALTH ASSESSMENT AND FUTURE LAND USE

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8.0 IMPLICATIONS OF DATA QUALITY, MONITORING, AND CONTINUING CLEANUP FOR PUBLIC HEALTH ASSESSMENT AND FUTURE LAND USE

8.1 Overview

The presence of contaminants does not necessarily imply that exposure levels will be a human health concern. Health risk depends on numerous factors, including the transport of contaminants from the source to the exposure locations, level of contamination in the various media (e.g., air, water, soil, vegetation) at the exposure locations, exposure frequency, exposure duration, characteristics of the target human receptor (e.g., age distribution, activity patterns), and resulting contaminant uptake rate via various routes of exposure (e.g., inhalation, ingestion, dermal contact). Although this study does not focus on quantitative risk assessment—as discussed in Chapter 6—in order to evaluate the relevant present and future public health hazards, one must consider the quality of the data, monitoring, and continuing cleanup efforts associated with SSFL. Accordingly, the next section of this chapter summarizes the main issues of concern: inadequacies in sampling and monitoring protocols, limitations of modeling results, and gaps in data. The following sections outline the public health implications of the present study and make recommendations about future land use.

8.2 Data Quality

In 1990 and again in 1997, EPA's Las Vegas office identified problems with SSFL sampling and sample processing techniques (EPA, 1989a). Specific problems involved survey instrument calibration procedures; use of spacing grids that were too large and un-comprehensive; filtering of water samples, which was suspected of removing potential mobile metals and radioactivity; drying of soil samples at excessively high temperatures, which may have led to volatilization of radionuclides of interest; and washing of vegetation samples, which would have led to removal of a certain fraction of adsorbed contaminant (Dempsey, 1990, 1997). These deficiencies in sampling and analytical protocols could have resulted in an under-reporting of contamination.

The removal of mobile metals by filtration was an issue identified and assessed by the EPA as early as 1989 (EPA, 1989b). The results of the Area IV Phase III Investigation and the background study indicated that filtration of groundwater samples had a significant impact on the analysis of turbid samples with high sediment content (GRC, 1990b). Unfiltered samples collected from wells constructed in shallow alluvial deposits at the facility consistently had higher radioactivity than filtered samples from the same well (for both gross alpha and gross beta; see GRC, 1990b). Curiously, the consistent protocol, followed in the bimonthly reporting, was to filter water samples to remove sediment particles (GRC, 1990b). The soil was sieved through a coors crucible to obtain uniform particle size (specifically, a size at which approximately 10 percent of the soil would not pass through). Because of absorption of the alpha and beta radionuclides within the soil, the procedure of filtering water samples had highly variable results (EPA, 1989a). It was also noted that attempts to correct for this variability were inadequate (EPA, 1989a). Spiked samples (samples with known radioactivity) were not run to verify the accuracy and precision of this method (EPA, 1989a). Thus, even though gross alpha and beta radiation were detected, it is reasonable to surmise that these detections were underestimations, and not a true representation of conditions at the site. This sampling protocol is of concern because these techniques were used regularly at SSFL over more than 10 years.

Similar problems were observed with other sample processing protocols (EPA, 1989a). For example, vegetation samples collected until 1986 were washed with warm tap water to remove external foreign matter. If past operations had produced airborne contamination that settled on the surface of the vegetation, then washing would have removed a significant fraction of the surface-accumulated contaminants that would have been volatilized during the ashing at 500 degrees. SSFL stopped collecting vegetation in 1986 (EPA, 1989a), and meat was not monitored for radioactivity. Although there are deer and squirrels in the vicinity of SSFL, they have not been tested. Also of concern to EPA was the fact that the contract laboratory conducting the radioanalysis of strontium-89/90 was not audited for its performance (EPA, 1989a). As stated by EPA (1989a), “The Strontium-89/90 analysis is extremely difficult and tedious and it will be necessary to verify lab performance before samples are generated so worthless data is not generated.” EPA concluded that the radiological lab needed updating “very badly” (EPA, 1989a). EPA inspectors went on to say:

> *SSFL sampling, placement of sample locations, and analysis cannot guarantee that past actions have not caused offsite impacts. If the environmental program stays uncorrected, SSFL cannot guarantee that unforeseen or undetected problems onsite will not impact offsite environments in the future. It is clear to us that Rocketdyne does not have a good handle on where radiation has been inadvertently dumped onsite. Most of the evidence for onsite spills is incompletely documented or anecdotal*. (EPA, 1989a).

EPA’s opinion that “Rocketdyne does not have a good handle on where radiation has been inadvertently dumped onsite” is consistent with the fact that, despite repeated statements that 99.99 percent of all radioactivity has been removed from the site (Lafflam, S., 1993, 2004), recent findings have revealed tritium levels as high as 83,000 pCi/L in new wells on site (Area IV, DOE Community Meeting, Simi Valley, 6/3/2004).

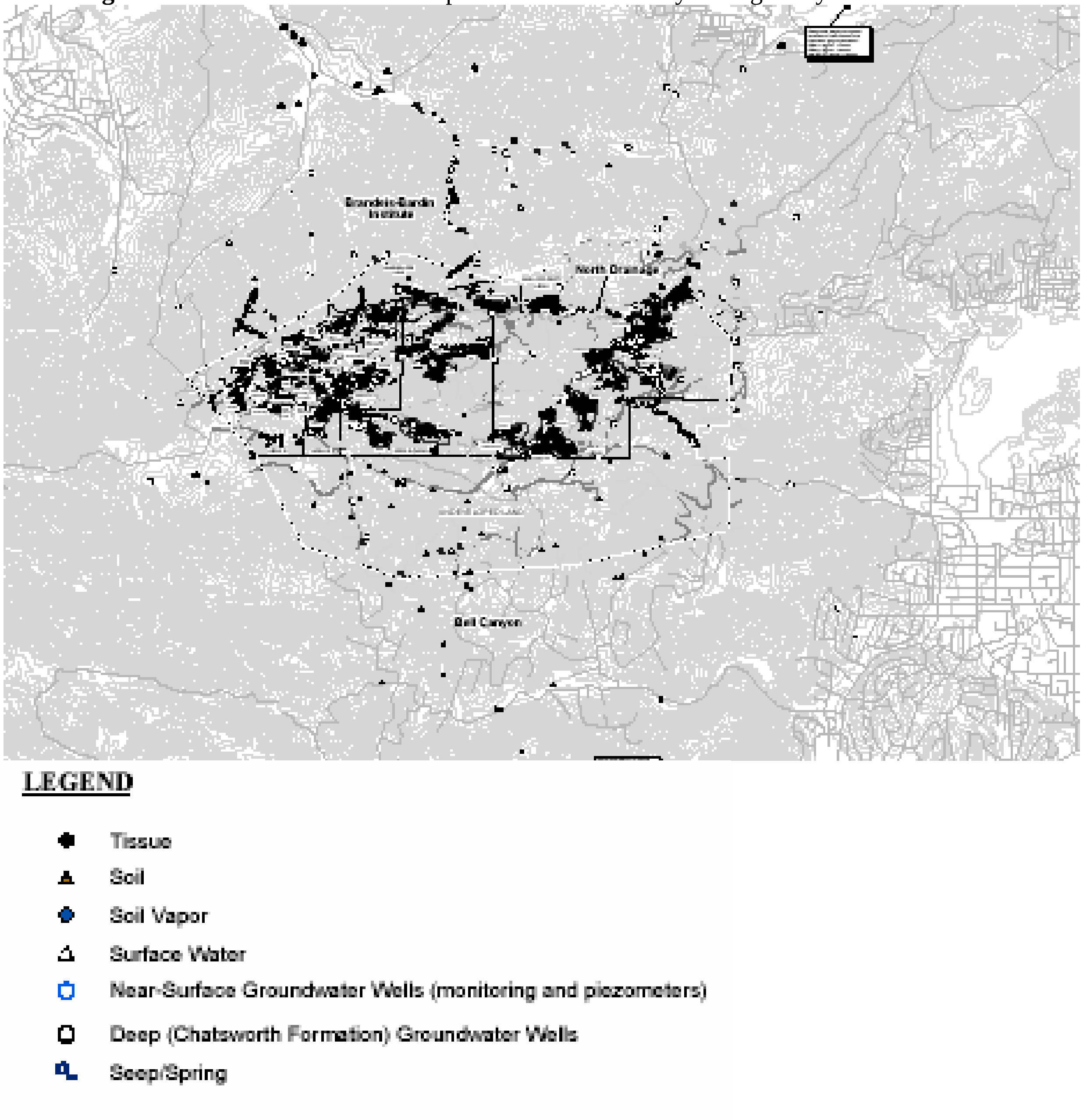
8.3 Monitoring Needs

Despite extensive monitoring at and around the SSFL facility, there is public concern that the extent of contamination off site is uncertain. These concerns arise, in part, from limited monitoring in some offsite areas, concentration that were detected for some contaminants above levels of regulatory concern, and the inability to clearly identify the sources of contaminants detected in some offsite areas. This section summarizes the major concerns that illustrate the need for more extensive monitoring data.

Storm water from SSFL flows north, south and east from SSFL. While the areas north and south have been monitored (McLaren Hart, 1993–1995; Ogden, 1998a; Appendix H), the areas to the east of SSFL lack monitoring data. Onsite and offsite sample locations were surveyed by Montgomery-Watson Harza (MWH, 2004) for work conducted up to December 2003 (Boeing, 2004). This survey (Fig. 8-1) illustrates that there are regions at and around SSFL that have either not been monitored or only sparsely monitored.

Storm water can flow northeast and east from SSFL. Eastern offsite areas are approximately 500 feet lower in elevation than operational areas within the northeast portions of SSFL's Area I, thus drainage to this area is highly probable (MWG, 2004). Therefore, there is merit for additional monitoring in the above areas to accurately map the extent of groundwater and surface water contamination and the likely transport to offsite areas.

Figure 8-1. Onsite and Offsite Sample Locations Taken by Montgomery-Watson Garza

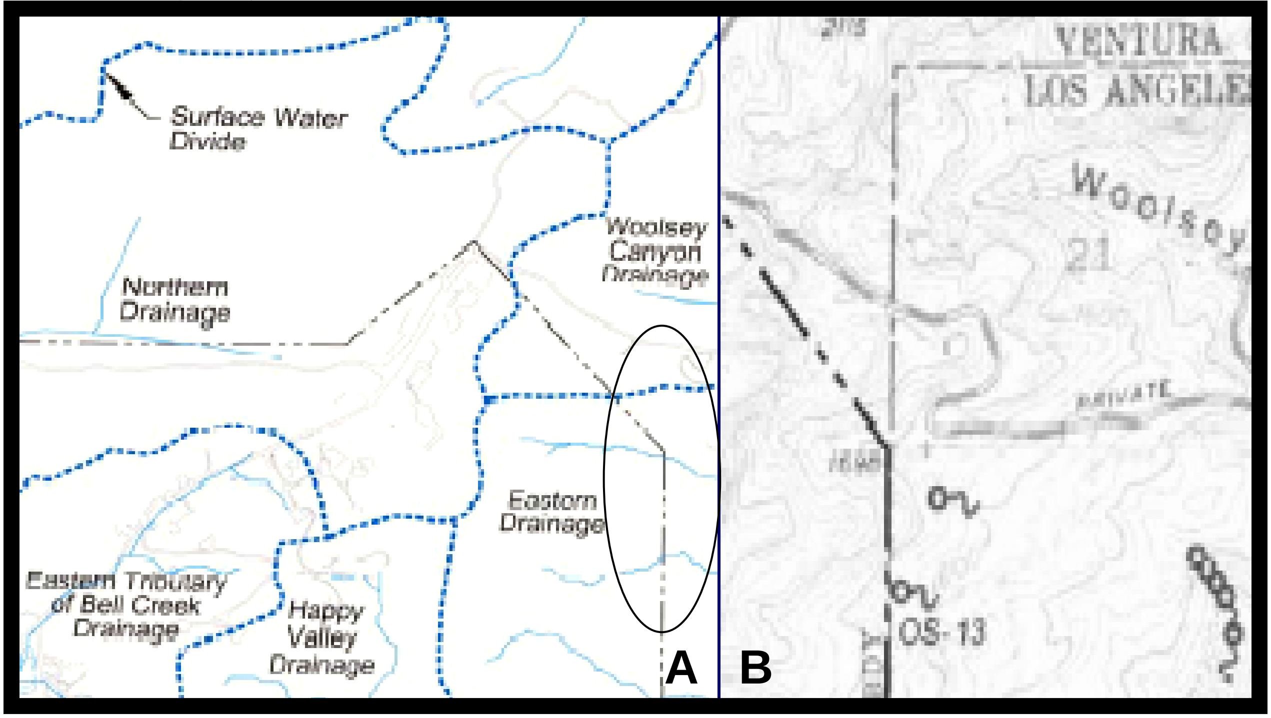


Monitoring of perchlorate in Area I (Happy Valley) was first reported in 2000 (Boeing, 2002). Since then perchlorate has been detected in drainages to the east of SSFL (Outfall 008 and Dayton Canyon; CA Regional Water Quality Control Board (RWQCB), 2006; Allwest

Remediation, 2005; (Table H-1, Appendix H). These detections are not surprising as regulated storm water flows east from Area I Happy Valley through Outfall 008 into Dayton Creek. Past monitoring of areas east of SSFL (Dayton Creek and Outfall 008) was limited considering the potential for offsite contaminant transport to these areas by surface and groundwater, and the potential for population exposure to population residing in the hills to the east of SSFL[8-1]. It is noted that monitoring of Outfalls 008 and Dayton Creek was recently initiated by the RWQCB and the Dept. of Toxic Substances Control (DTSC).

The northeast area of SSFL is a source of surface and groundwater to five different drainage systems (Figure 8-2a). All drainages are ephemeral when flowing. The northern drainage flows toward Simi Valley via Meier, Runckle and Black Creeks; the remaining four drainages flow into San Fernando Valley via Woolsey, Dayton and Bell Creeks. Recently, field reconnaissance was performed to identify groundwater drainages east of SSFL (MWG, 2004). The recent drainage survey identified six previously unidentified springs east of SSFL (Figure 8-2b). One other spring was identified in earlier studies. Work is presently underway to characterize the nature of the water discharging to and from these locations (MWG, 2004).

Figure 8-2. SSFL's Northeast Area Drainage System and Newly Identified Springs.
(Source: Montgomery Watson Harza, 2004).



A. The northeastern drainage at SSFL. ***B.*** The area circled in A was blown up (B) to present the newly identified springs located east of SSFL. Springs are identified by the empty circles and squiggly lines.

Woolsey and Black Canyons are of particular concern as storm water collects runoff from the SSFL's former NASA LOX plant (Areas 1 and 2 landfills) and exits at Outfall 009 which drains into these canyons (RWQCB, 2006). The drainage flows through these areas, through Sage Ranch– an area of past agricultural operations and where a shooting range is located, and into the Chatsworth Reservoir and the Arroyo Simi. This location (northeast area including Sage Ranch

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[8-1] For example, Dayton Creek flows east to West Hills and into Orcutt Ranch, a community garden.

and Woolsey Canyon) has only been sampled once in the past[8-2]. Various contaminants were detected in wells at Sage Ranch, as well as at the Chatsworth Reservoir[8-3] (Appendix H). Additional monitoring data would provide information regarding the potential for transport of SSFL-related contaminants to areas east and northeast of SSFL.

8.4 Continuing Cleanup and Associated Future Monitoring

Continued groundwater remediation via pump and treat should decrease the dispersion of contaminants emanating from the SSFL subsurface. Therefore, exposure estimates based on the current level of contamination are likely to overestimate the risk. Clearly, future retardation of contaminant migration from the SSFL site will depend on effective continual remediation of the site. Continued monitoring will assist efforts to assess the success of remedial actions taken and the natural attenuation of contaminants. Monitoring, however, should be conducted in relation to knowledge of existing transport pathways. For example, soil should be sampled more than once a year, during appropriate seasons and at various depths and locations. Areas of water contamination should be monitored before and after rainfall events, and air should be monitored in locations near SSFL where wind dispersion is likely to have the greatest impact (see Chapters 3 and 6). Precautions should be taken with respect to sample preparation and preservation, and analytical protocols should be carefully evaluated to ensure that contaminant loss from the samples is minimized. The reliability, accuracy, and precision of the analytical data should be assessed with blind controls sent to multiple laboratories, prior to sample analysis. A thorough monitoring program should also include sampling and analysis of offsite vegetation and animals for chemicals that have the potential to bioaccumulate. It is recognized that realistic assessment of residents' exposure to contaminants of concern would probably be best achieved by personal monitoring of residents in locations of concern. Such an endeavor would require significant resources, but would likely provide more information on actual exposure levels than possible even by the most comprehensive exposure assessment models.

[8-2] In 1987, Rockwell conducted a study of the quality of non-regulated storm water drainage from the facility (Ecology and Environment, 1991). Health-based standards were exceeded for arsenic, lead, chromium and beryllium in offsite samples taken east of SSFL (including Woolsey Canyon, Sage Ranch and Chatsworth Reservoir; see Tables 4-1 and H-5 in Appendix H). The source of arsenic, lead and chromium at the above locations has not been established; beryllium is likely to have come from SSFL as rocket fuel used at SSFL contained beryllium. It is reported that Rocketdyne removed beryllium-contaminated soils after the use of beryllium-containing fuels was discontinued (Ecology and Environment, 1991). Monitoring results for surrounding soils, however, do not rule out that beryllium persists at concentrations of concern in offsite areas (Ecology and Environment, 1991). Additional monitoring would be needed to establish the extent and level of contamination, especially relative to background levels and levels at SSFL.

[8-3] The origin of contamination detected at the Chatsworth Reservoir is unclear. It is known that from 1966 to 1976 Rocketdyne occupied the Hughes Aircraft Company site (8433 Fallbrook Avenue, Canoga Park, south of Chatsworth Reservoir; the "Canoga Facility") with Hughes and Bunker Ramo. Soil and groundwater at the northwest and southwest portions of the site (now the DeVries Institute) are contaminated with VOCs (TCE, 1,1-DCE, 1,2-DCE, benzene, toluene, xylene, 1,1,1-TCA, 1,1-DCA, and PCE). Soil and groundwater at the east and southeast portion of the site are contaminated with TCE, 1,1-DCE, 1,1,1-TCA, freon-11, and alpha radioactivity (McLaren/Hart, 1990). Groundwater from the northeastern portion of SSFL is contaminated with VOCs (TCE, 1,1-DCE, cis-1,2-DCE, and benzene). Given the available data, it is not possible to establish if the contamination levels are due to past operations at the former Hughes Aircraft Company site or due to migration via surface water or groundwater pathways from SSFL.

8.5 Justification of Future Restricted Land Use for SSFL Based on Proposed DOE Cleanup Levels

Remediation activities at SSFL are currently ongoing, so the level of future residual contamination can only be assessed through continued monitoring in the post-cleanup period. Possible future uses of the site have been considered by various stakeholders. The potential residential use of the site has been a topic of great interest and concern.

EPA has assessed DOE's cleanup levels for the ETEC site in Area IV (EPA, 2003b). DOE, the primary responsible party for radiologic cleanup at SSFL, proposed to remediate the site to its own approved standards (DOE, 2004). These standards are not consistent with EPA's CERCLA standards or those of the California Department of Health Services, Radiologic Health Branch (EPA, 2003b). The DOE proposal calls for site radionuclide decontamination such that a future site resident would not be exposed to more than an additional 15 millirems annually above background—that is, would not experience an additional lifetime cancer risk above 3×10^{-4}. (EPA, 2003b). It appears that EPA's assessment did not agree with DOE's justification of the proposed cleanup levels and that the proposed DOE cleanup levels would not meet the relaxed (3×10^{-4}) standard of lifetime cancer risk (EPA, 2003b).

In an unpublished letter (EPA, 2003b), EPA expressed concern over earlier decommissioning which, at the allowed residual radionuclide levels, could "result in cancer risks exceeding the CERCLA risk range of 10^{-6} to 10^{-4}." EPA further stated that the current DOE "cleanup goal of 15 mrem/yr corresponds to a residual cancer risk of approximately 3×10^{-4}," and that the risk at this dose limit "may vary by an order of magnitude or more depending upon the radionuclide present and the selected land use." EPA concluded that the proposed cleanup level will not satisfy standards for unrestricted land use. EPA also expressed concerns regarding inadequate subsurface and groundwater characterization—stating, for example, that sampling (in terms of number of samples and location) is insufficient to justify an unrestricted land use decision. In addition, EPA expressed concern about the use of insensitive and non-specific radiological survey methods.

These EPA opinions on the inadequacy of DOE's cleanup goals, monitoring deficiencies, and the recent detection of tritium at levels as high as 83,000 pCi/L in new wells onsite (Area IV, DOE Community Meeting, Simi Valley, 6/3/2004) cast doubt on the suggestion that the SSFL site can be declared suitable for unrestricted use. Even if DOE met EPA's radiologic cleanup goals, it can be argued, the SSFL site may not be suitable for residential land use due to the massive and likely long-lasting TCE plume beneath the site. This conclusion is consistent with the summary conclusions of a 1990 U.S. Army Corps of Engineers–sponsored baseline public health risk assessment for the SSFL property (Techlaw, 1990). This latter assessment concluded that there may be a concern for potential public health risk associated with onsite *personnel* and *residential* use of the property. It was concluded that exposure of site residents to TCE via multiple pathways could lead to cancer risks exceeding the 1×10^{-6} level (Techlaw, 1990).

8.6 Health Implications

The exposure analysis presented in this study provides upper limit estimates of contaminant dose relative to acceptable dose measures in order to rank the various chemicals and exposure locations of concern. The estimated dose ratios, along with detailed analysis of the various exposure pathways, estimates of emissions, and critical assessment of available monitoring studies, should provide the public and decision makers with a reasonable indication of the potential for exposure to SSFL-associated contaminants and help in evaluating future site management with respect to remedial action, monitoring, and future land use.

Assessing health impacts in a quantitative manner is beyond the scope of the present study. A study of SSFL's impact on community health would have to directly assess community health through detailed epidemiological studies and comparison of community health relative to other regions of similar character. In 1992, the California Department of Health Services (DHS) released a preliminary statistical report that indicated that a higher-than-usual number of lung cancers had been diagnosed from 1983 to 1987 in Ventura County residents near SSFL, as well as a higher-than-average rate of bladder cancer among Los Angeles County residents near SSFL (DHS, 1992). In 1999, an occupational study by UCLA School of Public Health researchers reported positive associations between measures of hydrazine exposure and the rates of terminal cancers of the lung, kidney, and bladder (Morgenstern, 1999). The 1999 UCLA study and the earlier DHS study could not rule out confounding impacts by other chemical carcinogens, such as TCE, to which many subjects were likely exposed.

TCE, 1,1-DCE, and vinyl chloride, which were identified as contaminants of concern (Chapter 2), are carcinogens that can target the liver, lung, bladder, kidney, biliary tract, and skin. Systemic diseases associated with these contaminants include non-Hodgkin's lymphoma; liver, kidney, and nervous system toxicity; peripheral neuropathy; anemia; and skin diseases. Epidemiological studies on cancer incidence in workers exposed to TCE demonstrated a measurable association between TCE exposure and non-Hodgkin's lymphoma, esophageal cancer, kidney cancer, bladder cancer, and prostate cancer.[8.4] Exposure to 1, 1-DCE has been linked to liver and kidney toxicity (ATSDR, 1990). Vinyl chloride is a known Class A human carcinogen by the oral and inhalation routes (ASTDR, 1990). Studies of occupational exposure have identified the liver and the central nervous system as the two primary target organs of vinyl chloride toxicity (ASTDR, 1990). Other health effects include fatigue, damage to the lungs, poor circulation, and angiosarcoma, rare malignant cancer of the blood vessels (ASTDR, 1990).

This study suggests that the major contaminant of concern is TCE, and that exposure could be of concern for lifelong residents of West Hills, Bell Canyon, Dayton Canyon, Simi Valley, Canoga Park, Santa Susana Knolls, Chatsworth, Woodland Hills, and Hidden Hills. Exposure of residents to 1,1-DCE could have occurred in the northeast quadrant offsite of SSFL through use of private groundwater wells. In order to arrive at more definitive answers, it may be worthwhile to revisit and expand on the 1992 DHS epidemiology study. However, one would have to carefully consider the mobility of the population in the region and the intermittent nature of exposure to contaminants associated with SSFL.

[8-4] Non-Hodgkin's lymphoma: SIR = 3.5, n = 8; esophageal cancer: SIR = 4.2, n = 6; Hansen et al., 2001.
Kidney cancer: RR = 1.89, 95% CI = 0.85–4.23; bladder cancer: RR = 1.41, 95% CI = 0.52–3.81;
prostate cancer: RR = 1.47, 95% CI = 0.85–2.55; Morgan et al., 1998.

9.0 CONCLUSIONS AND RECOMMENDATIONS

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9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

9.1.1 Data Limitations:

1) Data limitations include, but are not limited to:
    a) Inadequate assessment of vertical and horizontal hydraulic gradients.
    b) Insufficient delineation of the extent of groundwater contamination in areas east of SSFL.
    c) Insufficient identification and monitoring of ephemeral springs.
    d) Lack of current well use surveys in areas east, northeast, and south of the facility.
    e) Lack of long-term (>4 years) historical onsite meteorological data.
    f) Lack of air monitoring data (historical and current) for chemicals and radionuclides.
    g) Potential for non-detection of significant concentrations in past monitoring programs due to the detection limits of monitoring devices (1948–1980s).
    h) Inadequate monitoring data for offsite areas with particular deficiencies east and northeast of SSFL.

2) It was not possible to conduct a quantitative dose reconstruction and health risk assessment due to:
    a) Lack of historical chemical/radionuclide activity reports and release data.
    b) Unreliable radionuclide monitors during accidental leaks.
    c) Lack of air quality monitoring data
    d) Unreliable sediment analytical monitoring procedures.
    e) Insufficient monitoring to accurately delineate the extent of offsite contamination.

9.1.2 Contaminant Migration Pathways

3) Migration pathways from SSFL to offsite areas include (but cannot be limited to):
    a) Surface water runoff (controlled and natural) to the north, south and east.
    b) Groundwater migration to the northeast and northwest.
    c) Air dispersion and deposition.
    d) In general, the contribution of soil to offsite exposure was found to be low compared to that of other pathways.

9.1.3 Past and Present Exposures

4) Past community exposures of concern include (but cannot be limited to):
    a) Potential chronic exposures to TCE and hydrazine resulting from emissions associated with rocket engine testing and open-pit burning between 1953 and early 1980s. Potential residential receptor locations of inhalation exposure include West Hills, Bell Canyon, Dayton Canyon, Simi Valley, Canoga Park, Chatsworth, Woodland Hills, and Hidden Hills.
    b) Chronic exposure to TCE and associated degradation products in groundwater from 1953 to the late 1970s via use of private wells east and north of SSFL. Potential receptors include residents using private wells and residents who habitually ingested area-grown crops or livestock.

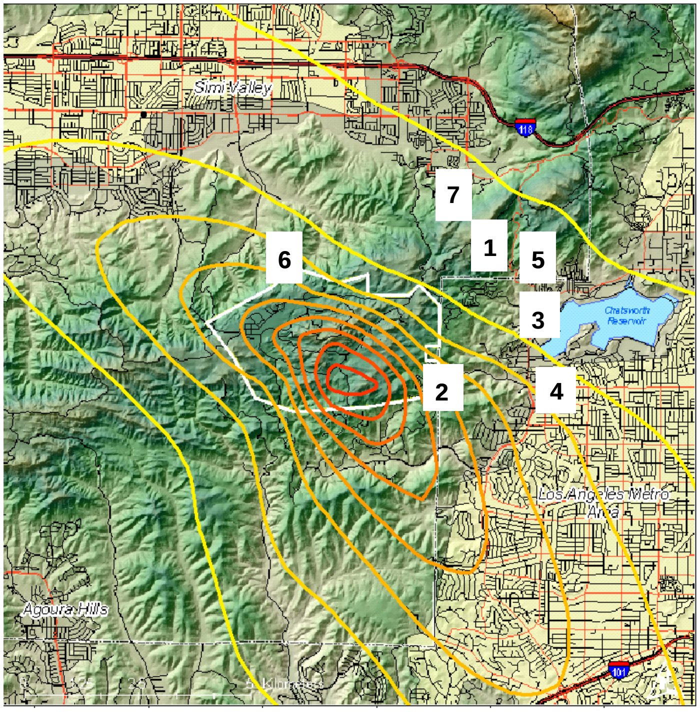
5) There is potential for chronic exposures, in areas within ~1-2 miles of SSFL, which include, but are not limited to :
    a) TCE, vinyl chloride, and 1,1-DCE in the northeast quadrant off site of SSFL through use of private groundwater wells or from habitual home-grown crop ingestion.
    b) Arsenic (source unknown) via habitual home-grown crop ingestion in Bell Canyon, Brandeis-Bardin, and potentially all areas north and east of SSFL, including Simi Valley, Dayton Canyon, and West Hills.
    c) Lead (source unknown) via incidental soil ingestion/inhalation or from habitual home-grown crop ingestion in Bell Canyon and potentially areas east of the facility; as well as extended use of private water wells or habitual home-grown crop ingestion.

6) Removal of the large amount of TCE that is estimated to reside in the soil subsurface and groundwater at SSFL is beyond the capabilities of current remediation technologies. Therefore, there is potential for long-term exposure to TCE if contaminated groundwater if it comes in contact with human and ecological receptors and also due to volatilization from the soil subsurface.
    a) The above concern is consistent with the conclusions of the 1990 U.S. Army Corps of Engineers–sponsored baseline public health risk assessment for the SSFL property. That assessment concluded that there may be a public health risk associated with onsite personnel and residential use of the property: “Exposure of site residents to TCE via multiple pathways could lead to cancer risks exceeding the 1×10^{-6} level” (Techlaw, 1990).
    b) It has also been stated by the U.S. EPA(EPA, 2003b) that:
        i) “Future Land Use” DOE cleanup levels for the ETEC site in Area IV could “result in cancer risks exceeding the CERCLA risk range of 10^{-6} to 3×10^{-4}”; risk from this dose limit “may vary by an order of magnitude or more depending upon the radionuclide present and the selected land use.”
        ii) DOE-selected cleanup levels do not satisfy standards for unrestricted land use.

7) Areas of exposure concern (AEC) where: (i) contaminant levels exceed health-based standards; (ii) there is potential for exposure; (iii) exposure could result an adverse health effects at the levels detected, include (Figure 9-1):
    a) The upper northeast (offsite) quadrant and Bell Canyon. These are areas of exposure concern due to:
        i) the potential for the use of domestic wells in the northeast quadrant area, and existence of mobile home communities that have used wells in the past, and
        ii) lead and arsenic levels in Bell Canyon soils and the potential for exposure of children in this area.

8) Potential areas of exposure concern where: (i) monitoring is inadequate; (ii) onsite to offsite transport pathways exist; and (iii) exposure is possible include (Figure 9-1): West Hills, and Dayton, Woolsey, Meier, Runckle, and Black Canyons.

Figure 9-1. Areas of Potential Exposure Concern



Areas of Exposure Concern (AEC)

Area where:
i. contaminant levels exceed health-based standards;
ii. exposure is possible;
iii. exposure could result in an adverse health effect at the levels detected.

Identified AEC

1. Northeast Quadrant
2. Bell Canyon

Potential AEC

3. Dayton Canyon
4. West Hills
5. Woolsey Canyon
6. Meier and Runckle Canyons
7. Black Canyon

9.2 Recommendations

9.2.1 Data Needs

1) Extent of groundwater contamination and conductivity:
    a) There is need for accurate determination of the DNAPL volume remaining in the subsurface fractures.
    b) Accurate estimation of subsurface TCE distribution.
    c) Mapping of soil gas emissions throughout the site.
    d) Continued monitoring of subsurface TCE and its degradation products

2) Extent of private well use and potential contamination within three miles of SSFL:
    a) There is a need for a comprehensive canvas of private wells north and east of SSFL (including Santa Susana Knolls).
    b) Quantitative exposure analysis will require information on population distribution and activity patterns.
    c) Mapping of the location and extent of contamination of ephemeral springs arising from the hills and canyons during heavy rainfall.

3) If onsite land is to be used for residential or recreational activities, the following activities/analyses are suggested:
    a) Continuous monitoring of onsite groundwater, soil, and subsurface for contaminants that are of primary concern.
    b) Assessment of aggregate exposure to single chemicals from multiple sources and pathways, as well as cumulative exposures to multiple chemicals. Areas where mixtures of hazardous wastes were disposed of—Areas I, III, and IV—are of particular concern.

4) Considering the ongoing extensive development at and in the vicinity of SSFL, there should be an enforcement of sampling/monitoring of soil/sediment, groundwater, and resuspended dust for all construction sites.

5) Due to extensive onsite contamination, information on potential security gaps is needed for (1) SSFL[9-1] and (2) Chatsworth Reservoir[9-2]. Precautionary defensive measures around these areas should be taken to prevent access to children.

9.2.2 Future Monitoring

6) The following chemicals should be considered for continuing offsite monitoring (see Appendix L for full list of COCs): PCBs, PCDDs/PCDFs, perchlorate, beryllium, asbestos, arsenic, chromium, mercury, lead, N-nitroso-dimethylamine, TCE and DCE.

7) Areas that warrant continuing future monitoring include: *Meier and Runckle Canyons*, *Bell Canyon campground, playground and Bell Creek, Dayton Canyon and Creek, Orcutt Ranch, Woolsey Canyon and Creek, Santa Monica Mountains Conservancy / Sage Ranch (ephemeral streams), Black Canyon, West Hills, Brandeis-Bardin Institute campground and garden.*

8) A comprehensive offsite monitoring of radionuclides is warranted given the recent detection of tritium at levels as high as 83,000 pCi/L in new groundwater wells (Area IV, DOE Community Meeting, Simi Valley, 6/3/2004). Some radionuclides to monitor include: tritium, cesium-137, strontium-90, radium-226/228, plutonium-238, thorium-230, and uranium-235 (see Appendix L for full list of COCs).

9) Offsite monitoring plans should consider and/or include:
    a) Adequate survey instrument calibration procedures.

[9-1] Access to SSFL was reported during informal interviews (Appendix G), and gaps in SSFL boundary fences were observed within one block of Bell Canyon neighborhoods during site visits (Chapter 6, Figure 6-2).

[9-2] Review of Chatsworth Reservoir was not directly within the purview of this report as contamination of this area (see Appendix R, Table R-7 and Appendix H, Table H-5) resulted from activities at the former Hughes Aircraft Company site (8433 Fallbrook Ave., Canoga Park, south of Chatsworth Reservoir; the “Canoga Facility”). However, from 1966 to 1976, Rocketdyne occupied the site with Hughes and Bunker Ramo. There are three areas of concern at Hughes: the northwest, the southwest and the southeast corners. The northwest and southwest portions of the site (now DeVries Institute) is contaminated (soil and groundwater) with VOCs (including halogenated compounds) and the southeast portion of the site is contaminated (soil and groundwater) with Freon-11 and radioactivity (Ecology and Environment, 1991). Areas of contamination are confined within fences, however informal community interviews revealed that children access the area via subterranean canals, thus it was deemed appropriate and significant for mention.

b) Use of spacing grids.
c) Filtered and unfiltered water samples.
d) Monitoring of local edible vegetation in agricultural and residential areas.
e) Soil samples from various depths and soil types.
f) Unfiltered samples from groundwater wells in shallow alluvial deposits for radionuclides.
g) Precautions for sample preparation and preservation.
h) Assessment of reliability, accuracy, and precision.
i) Blind-processed controls to multiple labs.

10) Municipal water supply companies using groundwater wells in Ventura and Los Angeles counties (within 3 miles of SSFL) should regularly monitor for perchlorate, NDMA, 1,4-dioxane, and chromium and assess the ability of their water treatment systems to remove these chemicals.

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Appendix A. List of Acronyms

AI	Atomics International
AL	Action level
APTF	Advanced Propulsion Test Facilities
ARARs	Applicable and Relevant or Appropriate Requirements
ATSDR	Agency for Toxic Substances and Disease Registry
BAF	Bioaccumulation factor
BBI	Brandeis-Bardin Institute
BCF	Bioconcentration factor
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COC	Chemical of concern
COPC	Chemical of potential concern
CPF	Cancer potency factor
CSF	Cancer slope factor
DCA	Dichloroethane
DCE	Dichloroethene
D&D	Decontamination and decommissioning
DHS	Department of Health Services (State of California)
DOE	Department of Energy (U.S.)
DTSC	Department of Toxic Substances Control
ECL	Engineering Chemistry Labs
EPA	Environmental Protection Agency (U.S.)
ETEC	Energy Technology Engineering Center
GRC	Groundwater Resources Consultants
HI	Hazard index
HRS	Hazardous Ranking System
HWMF	Hazardous Waste Management Facility
LARWQB	Los Angeles Regional Water Quality Control Board
LETF	Laser Engineering Test Facilities
MCL	Maximum contaminant level
MMH	Monomethyl hydrazine
MWD	Municipal Water District
NAAQS	National Ambient Air Quality Standards
NAKA	North American Kindleberger Atwood Laboratory
NASA	National Aeronautics and Space Administration
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission (U.S.)
NTO	Nitrogen tetroxide
PAH	Polyaromatic hydrocarbon
PCB	Polychlorinated biphenyl
RAIS	Risk Assessment Information System
RCRA	Resource Conservation and Recovery Act
RfC	Reference concentration
RfD	Reference dose
RMDF	Radioactive Material Disposal Facility
RME	Reasonable Maximum Exposure
RMHF	Radioactive Materials Handling Facility
RSSL	Residential Soil Screening Level
SCRAM	Scoring Chemicals and Ranking Assessment Model
SCWC	Southern California Water Company
SDF	Sodium Disposal Facility
SMMC	Santa Monica Mountain Conservancy
SNAP	Space Nuclear Auxiliary Power
SRE	Sodium Reactor Experiment complex
SSFL	Santa Susana Field Laboratory
STL	Systems Test Area Laboratories
TCA	Trichloroethane
TCDD-TEQs	2,3,7,8-tetrachlorodibenzo-p-dioxin toxic equivalents
TCE	Trichloroethene
TTF	Thermal Treatment Facility
UDMH	Unsymmetrical dimethyl hydrazine
USEPA	Environmental Protection Agency (U.S.)
USGS	United States Geological Survey
VCAPCD	Ventura County Air Pollution Control Department
VOC	Volatile organic compound

Appendix B. Glossary

Acute exposure
Contact with a substance that occurs for a limited or short duration.

Additive response effect
A biologic response to exposure to multiple substances that equals the sum of responses of all the individual substances added together.

Ambient
Surrounding (for example, *ambient* air).

Analyte
A chemical for which a sample (such as water, air, or blood) is tested in a laboratory. For example, if the *analyte* is mercury, the laboratory test will determine the amount of mercury in the sample.

Antagonistic effect
A biologic response to exposure to multiple substances that is less than would be expected if the known effects of the individual substances were added together.

Background level
The typical naturally occurring or prevailing concentration of a chemical or radioactive material in a specific environment.

Berm
A sloped wall or embankment (typically constructed of earth, hay bales, or timber framing) used to prevent surface overflow or inflow.

Biodegradation
Decomposition or breakdown of a substance through the action of microorganisms.

Biologic monitoring
Monitoring of hazardous substances in biologic materials (such as blood, hair, urine, or breath) to determine whether exposure has occurred. A blood test for lead is an example of biologic monitoring.

Biota
Plants and animals in an environment.

Cancer
Any one of a group of diseases that occur when cells in the body become abnormal and grow or multiply out of control.

Cancer risk
A theoretical risk of getting cancer if exposed to a substance every day for 70 years (a lifetime exposure). The true risk might be lower.

Carcinogen
A substance that causes cancer.

Case-control study of exposure
A study that compares exposures of people who have a disease or condition (cases) with people who do not have the disease or condition (controls).

CAS registry number
A unique number assigned to a substance or mixture by the American Chemical Society Abstracts Service.

Central nervous system
The part of the nervous system that consists of the brain and the spinal cord.

Chronic
Occurring over a long time period; the opposite of acute.

Chronic exposure
Contact with a substance that occurs over a long time period.

Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)
CERCLA, also known as Superfund, is the federal law that concerns the removal or cleanup of hazardous substances in the environment and at hazardous waste sites.

Concentration
The amount of a substance present in a certain environmental (e.g., air, water, and soil) or biologic medium (e.g., leaf, blood, and fat tissue).

Contaminant
A substance that is regarded as being foreign to the location where it is found.

Decommissioning
The process of removing from service a facility that is no longer needed for its original purpose. *Decommissioning* may involve environmental cleanup of contaminated facilities.

Dermal
Referring to the skin. For example, *dermal* absorption means absorption through the skin.

Dermal contact
Contact with (touching) the skin.

Detection limit
The lowest concentration of a chemical that can reliably be analyzed and distinguished from a zero concentration.

Disease prevention
Measures taken to prevent a disease or reduce its severity.

Disease registry
A system of ongoing registration of cases of a particular disease or health condition in a defined population or region.

DOD
The United States Department of Defense.

DOE
The United States Department of Energy.

Dose (for chemicals)
The amount of a chemical agent that is taken or absorbed by the body. *Dose* is often expressed as milligrams (amount) of the chemical agent per kilogram (a measure of body weight) per day of contaminated water, food, or soil. An absorbed *dose* is the amount of a substance that actually penetrates the receptor’s body.

Dose (for radioactive chemicals)
The radiation *dose* is the amount of energy from radiation that is actually absorbed by the body.

Dose-response relationship
The relationship between dose of a given substance or radiation and the changes in body function or health (response).

Environmental feasibility study
A study to determine the best way to clean up environmental contamination and associated environmental and health impacts.

Environmental media
Soil, water, air, biota (plants and animals), or any other parts of the environment.

Environmental transport
The mode or mechanism that leads to the movement of chemicals through an environmental medium or across environmental phase boundaries.

EPA
The United States Environmental Protection Agency.

Epidemiology
The study of the distribution and determinants of disease or health status in a population; the study of the occurrence and causes of health effects in humans.

Exposure
Contact with a contaminant or radiation. *Exposure* can be short-term (acute), of intermediate duration, or long-term (chronic).

Exposure assessment
The process of determining how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and the concentration of the substance at the contact boundaries.

Exposure pathway
The route a substance takes from its source (where it began) to the point of exposure at the receptor’s location.

Groundwater
Water in the soil subsurface.

Half-life ($t_{½}$)
The time to reach half the original amount or concentration of a substance or radiation.

Hazard
A source of potential harm from past, current, or future exposures.

Incidence
The number of new cases of disease in a defined population over a specific time period.

Ingestion
The process of taking food, medicine, or another substance through the mouth and into the gut, where it can be digested. A hazardous substance can enter the body via *ingestion.*

Inhalation
The act of breathing. A hazardous substance can enter the body via *inhalation.*

Intermediate-duration exposure
Contact with a substance that occurs for a period greater than 14 days and less than a year.

In vitro
In an artificial environment outside a living organism or body.

In vivo
Within a living organism or body.

Lowest-observed-adverse-effect level (LOAEL)
The lowest tested dose of a substance that has been reported to cause harmful (adverse) health effects in people or animals.

Metabolism
The conversion or breakdown of a substance from one form to another by a living organism.

Metabolite
A product of metabolism.

mg/cm^2
Milligrams per square centimeter (of a surface).

mg/kg
Milligrams per kilogram.

mg/m^3
Milligrams per cubic meter.

Migration
Moving from one location to another.

Minimal risk level (MRL)
An ATSDR estimate of daily human exposure to a hazardous substance at or below which that substance is unlikely to pose a measurable risk of harmful (adverse), noncancerous effects. *MRLs* are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic). They are not to be used as predictors of harmful (adverse) health effects.

Morbidity
The state of being ill or diseased. *Morbidity* is the occurrence of a disease or condition that alters health and quality of life.

Mortality
Death.

Mutagen
A substance that causes mutations (genetic damage).

Mutation
A change (damage) to the DNA, genes, or chromosomes of living organisms.

National Priorities List for Uncontrolled Hazardous Waste Sites
(National Priorities List or **NPL)**
EPA’s list of the most serious uncontrolled or abandoned hazardous waste sites in the United States. The NPL is updated on a regular basis.

National Toxicology Program (NTP)
A program of the Department of Health and Human Services. The *NTP* develops and carries out tests to predict whether a chemical will cause harm to humans.

No-observed-adverse-effect level (NOAEL)
The highest tested dose of a substance that has been reported to have no harmful (adverse) health effects to people or animals.

Physiologically based pharmacokinetic model (PBPK model)
An analytical or numerical model that describes the distribution of chemical in the body. A *PBPK model* describes how the chemical enters the body, its movement throughout the body, its metabolism, and how it leaves the body.

Pica
A craving to eat nonfood items, such as dirt, paint chips, and clay. Some children exhibit *pica*-related behavior.

Plume
A volume of a substance flowing or diffusing from its source to places farther away from the source. *Plumes* can be described by the volume of air or water they occupy and the direction they move. For example, a *plume* can be a column of smoke from a chimney or the boundary of a contaminated groundwater volume that is migrating along with groundwater.

Point of exposure
The location of contact of a receptor with a contaminant.

Population
A group or number of people living within a specified area or sharing similar characteristics.

ppb
Parts per billion.

ppm
Parts per million.

Prevalence
The number of existing disease cases in a defined population during a specific time period. (Contrast with incidence.)

Prevalence survey
The measure of the current level of disease(s) or symptoms and exposures through a questionnaire that collects self-reported information from a defined population.

Radioisotope
An unstable or radioactive isotope (form) of an element that decays spontaneously into a more stable form as it emits radiation.

Radionuclide
Any radioactive isotope (form) of any element.

RCRA Facility Assessment (RFA)
An assessment required by the Resource Conservation and Recovery Act to identify potential and actual releases of hazardous chemicals.

Receptor population
People who could come into contact with specified hazardous substances.

Reference dose (RfD)
An EPA estimate, with uncertainty or safety factors built in, of the daily lifetime dose of a substance that is unlikely to cause harm in humans.

Registry
A systematic collection of information on persons exposed to a specific substance or having specific diseases.

Rem (Roentgen equivalent in man)
The unit of a dose equivalent from ionizing radiation to the human body that is used to measure the amount of radiation to which a person has been exposed.

Resource Conservation and Recovery Act (1976, 1984) (RCRA)
This Act regulates management and disposal of hazardous wastes currently generated, treated, stored, disposed of, or distributed.

Risk
The probability that an adverse effect will occur.

Route of exposure
The pathway that leads to contact of a receptor with a hazardous substance. For example, the three major *routes of exposure* are breathing (inhalation), eating or drinking (ingestion), and contact with the skin (dermal contact).

Safety factor
See uncertainty factor.

Sample
A portion or piece of a whole. For example, environmental soil, water, or air *samples* are collected to measure contamination in the environment at a specific locations.

Solvent
A liquid capable of dissolving or dispersing another substance.

Source of contamination
The place of origin of a contaminant.

Special susceptible populations
People who might be more sensitive or susceptible to adverse health effects resulting from exposure to hazardous substances. Children, pregnant women, and older people are often considered special populations.

Superfund
See Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and Superfund Amendments and Reauthorization Act (SARA).

Superfund Amendments and Reauthorization Act (SARA)
In 1986, SARA amended the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) and expanded the health-related responsibilities of ATSDR.

Surface water
Water on the surface of the earth, such as in lakes, rivers, streams, ponds, and springs.

Synergistic effect
A biologic response to multiple substances in which one substance worsens the effect of exposure to another substance. The effect of the substances acting together is greater than the sum of the effects of the substances acting by themselves.

Teratogen
A substance that causes defects in development between conception and birth—that is, structural or functional birth defects.

Toxic agent
Chemical or physical (for example, radiation, heat, cold, microwaves) agents that, under certain circumstances of exposure, can harm living organisms.

Tumor
An abnormal mass of tissue that results from excessive cell division that is uncontrolled and progressive. *Tumors* perform no useful body function; they can be either benign (not cancerous) or malignant (cancerous).

Uncertainty factor
A mathematical adjustment made for safety reasons when knowledge is incomplete. For example, *uncertainty factors* are used to account for variations in people's sensitivity, for differences between animals and humans, and for differences between LOAELs and NOAELs.

Volatile
According to DTSC Office of Scientific Affairs, a compound with a Henry's Law Constant of 1×10^{-5} or higher and a vapor pressure of 0.001 mm Hg or higher is considered *volatile.*

Volatile organic compounds (VOCs)
Organic compounds that evaporate (or volatilize from a solution mixture) readily into the air.

Appendix C. List of Chemicals of Potential Concern

Acenaphthalene
Acetaldehyde
Acetone
Acrolein
Acrylonitrile
Alachlor
Aldehyde
Aldrin
Alpha BHC
Alpha endosulfan
Alpha particles
Aluminum
Ammonia
Ammonium perchlorate
Anthrocene
Antimony
Argon
Aroclor 1242
Aroclor 1254
Arsenic
Asbestos
Atrazine
Barium
Benzidene
Benz(a)anthracene
Benzene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
1,2-Benzoperyline
Beryllium
Beta BHC
Beta endosulfan
Beta particles
Biphenyl
Bis(2-chloroethoxy)methane
Bis(2-chloroethyl)ether
Bis(2-chloroisopropyl)ether
Bis(2-ethylhexyl)phthalate (DEHP)
Boron
Brominepentafluoride
Bromodichloromethane
Bromoform
4-Bromophenylther
1,3-Butadiene
Butylbenzylphthalate
Cadmium
Carbaryl
Carbofuran
Carbon monoxide
Carbon tetrachloride
Cesium-137
CFC113
Chlorate
Chlordane
Chloride
Chlorine pentafluoride
Chlorine trifluoride
Chlorobenzene
2-Chloroethylvinylether
Chloroform
Chloromethane
2-Chloronaphthalene
2-Chlorophenolchloroethane
4-Chlorophenylether
Chromium (total)
Chromium VI
Chrysene
Cobalt-60
Copper
Cyanide
1,1-DCA
1,2-DCA
1,1-DCE
Cis-1,2-DCE
Trans-1,2-DCE
4,4-DDD
4,4-DDE
4,4-DDT
Delta BHC
Dibenz(a,h)anthracene
1,2,5,6-Dibenzoanthracene
Dibenzofuran
Diborane
Dibromochloromethane
Dibromochloropropane
1,2-Dichlorobenzene
1,3-Dichlorobenzene
1,4-Dichlorobenzene
3,3-Dichlorobenzidene
Dichlorodifluoromethane
1,2-Dichloroethane
Dichloromethane
2,4-Dichlorophenol
1,2-Dichloropropane
1,3-Dichloropropene
Dieldrin
Di(2-ethylhexyl)phthalate
Diethylphthalate
1,2-Dimethylhydrazine
2,4-Dimethylphenol
Dimethylphthalate
Dimethylsulfoxide
Di-n-butylphthalate
4,6-Dinitro-o-cresol
2,4-Dinitrophenol
2,4-Dinitrotoluene
2,6-Dinitrotoluene
Di-n-octylphthalate
1,4-Dioxane
1,2-Diphenylhydrazine
Endosulfan sulfate
Endrin
Endrin aldehyde
Ethion
Ethylbenzene
Ethylene dibromide
Ethylene glycol
Ethylene oxide
Europeum-152
Fluoranthene
Fluorene
Flouride
Formaldehyde
Gamma BHC
Gamma radiation
HCHά
HCHβ
HCHγ (Lindane)
HCH (technical)
Heptachlor
Heptachlor epoxide
N-Heptane
Hexachlorobenzene
Hexachlorobutadiene
Hexachlorocyclopentadiene
Hexachloroethane
HMX
Hydrazine
Hydrochloric acid
Hydrogen fluoride
Hydrogen peroxide
Hydrogen sulfide
Isophrone
Indeno(1,2,3-cd)pyrene
Iodine-129
Iodine-131
Iron-55
Isopropyl alcohol
Isopropylbenzene
Kerosene
Lead
Lithium
Manganese
Mercury
Methane
Methoxychlor
Methylene chloride
1-Methylhydrazine (MMH)
Methylnaphthalene
4-Methylphenol
Molinate
Monochlorobenzene
Methyl bromide
Methyl chloride
Naphthalene
Nickel
Nitrate
Nitric acid
Nitrobenzene
Nitrocellulose
Nitrogen dioxide
Nitrogen tetroxide
Nitrogen trifluoride
Nitroglycerin
N-Nitrosodimethylamine (NDMA)
4-Nitrosodiphenylamine (NDPA)
NMA nitrosomethylamine
Nitrous oxide
4-Nitrophenol
2-Nitrophenol
N-nitrosodi-n-propylamine
N-propylbenzene
Oxygen difluoride
Ozone
Parathion
PCBs (1016,1221,1232,1242,1248,1254,1260)
P-chloro-m-cresol
Pentaborane
Pentachlorophenol
Perchlorate
Perchloroethylene
Phenanthrene
Phenol
Plutonium-238, -239, -259, -240
$PM_{2.5}$
PM_{10}
Polychlorinated dibenzodioxin (PCDD)
Polychlorinated dibenzofuran (PCDF)
Polychlorinated terphenyls (PCTs)
Polycyclic aromatic hydrocarbons (PAHs)
Potasium-40
Propane
Pyrene
Radium-226, -228 (combined)
RDX
Selenium
Silver
Silvex (2,4,5-TP)

SO_2
Sodium azide
Sodium pentaborane
Strontium-90
Styrene
Sulfates
TCDD-TEQ (total)
2,3,7,8-TCDD
Terphenyls
Tertbutyl alcohol
1,1,1,1-Tetrachloroethane
1,1,2,2-Tetrachloroethane
Tetrachloroethylene (PCE)
Tetraethyl aluminum
Tetraethyl boron
Tetraethyl lead
Tetrafluorohydrazine
1,1,1-Trichloroethane (TCA)
1,1,2-Trichloroethane
Trichloroethene (TCE)
Thallium
Thorium-228, -230, -232
Toluene
Toxaphene
1,2,4-Trichlorobenzene
Trichlorofluoromethane
1,2,3-Trichloropropane
2,4,6-Trichlorophenol
Trichlorotrifluoroethane (freon-113)
1,1,2-Trichloro-1,2,2-trifluoromethane
Trihalomethanes (total)
Tritium (H-3)
1,1-UDMH(unsymmetrical dimethylhydrazine)
Uranium-235, -233, -234, -238
Vanadium
Vinyl chloride
Vinylidene chloride
Volatile organic compounds (VOCs)
Xylene
Zinc
Zinc-65, -69
Zirconium-95, -97
Zirconium hydride

Appendix D. Site Facilities and Waste Management Facilities

D-1. Area I

North American Kindelberger Atwood Laboratories (NAKA)
and Thermal Treatment Facility (TTF)

The Area I TTF is on the south site of the SSFL site; NAKA is less than a mile away. NAKA was used for research on solid rocket propellant and gun propellant (Rockwell Int., 1992). About 1 to 30 pounds of explosive wastes, including pyrotechnics and solid propellants, were generated at NAKA and Happy Valley per week. Waste generated at NAKA included HMX, RDX, nitrocellulose, nitroglycerin, and ammonium perchlorate. This waste, approximately 30 pounds of waste per month, was sent to the Area I TTF from 1958 to as late as 1992 (24.72 pounds of NAKA propellants, 1.92 pounds of triethylaluminum-triethylborane, (Rockwell International, 1992a). From 1982 to 1990, the TTF handled 1.28 pounds of gas cylinders). Other wastes sent to Area I TTF were "strong oxidizers" and hypergolic propellants—i.e., chlorine pentafluoride, tetrafluorohydrazine, and "limited quantities" of solvents and kerosene (Rockwell International, 1992a). Surface water from the Area I TTF can run off into the Perimeter Pond, which is part of SSFL's reclaimed water system. During normal operation and rainfall events, the Perimeter Pond overflows into NPDES Outfalls 001 and 002 to the south of the facility; these release the water into Bell Canyon Creek (Rockwell International, 1992a).

Laser Engineering Test Facility (LETF) and Engineering Chemistry Labs (ECL)

The LETF in Area I and the ECL pond in Area III were reported to be the only surface impoundments that stored and treated hazardous wastes on a routine basis for Areas I, II, or III (Hargis and Associates, 1985). The LETF pond held corrosive liquids, such as sodium hydroxide and sodium fluoride, before their removal to a Class I disposal facility.

Rocket Engine Testing Sites

Eight major rocket engine test facilities began operation in the late 1950s and early 1960s: the Bowl, the Canyon, and the Advanced Propulsion Test Facility (APTF), located in Happy Valley in Area I, and Alfa, Bravo, Coca, Delta, and the Systems Test Laboratory (STL) in Area II (Techlaw, 1990). These areas were in operation simultaneously in the late 1950s and early 1960s. The Bowl, Canyon, and Delta test areas were phased out of operation in the late 1960s and 1970s. The Coca test area was shut down in May 1988.

Engine testing at these areas primarily used petroleum-based compounds as the "fuel" and liquid oxygen as the "oxidizer." Solvents—primarily trichloroethene (TCE)—were used to clean engine components. The primary propellants used at SSFL were (a) hydrazine-based fuels (including hydrazine, monomethyl hydrazine, and unsymmetrical dimethyl hydrazine) and nitrogen tetroxide (oxidizer), (b) kerosene-based fuels (RP-1 and JP-4) and liquid oxygen (oxidizer), and (c) liquid hydrogen fuel and liquid oxygen (oxidizer). At present, hydrazine- and kerosene-based fuels are being used at SSFL (CH2M Hill, 1993; Rocketdyne, 1999b). Oxidizers are reactive and have very short half-lives in air or soil. Therefore, they are expected to disappear rapidly from soil and sediment following an accidental spill or release.

D-2. Area II

Alpha, Bravo, Coca, Delta, and Systems Test Laboratory (STL) Engine Test Areas

The Alfa and Bravo test areas are currently the only rocket engine test areas in operation. The Alpha-Bravo pond traps and retains raw fuel, lubricant oil, and other hydrocarbons from the test firings and/or spills in the Alpha-Bravo test area (DHS, 1999). STL is a NASA-associated test stand and laboratory.

D-3. Area III

Engineering Chemistry Laboratory (ECL)

The ECL pond received a wide variety of wastes. Records show that these wastes included sodium hydroxide, methylene chloride, dimethyl sulfoxide, and sodium azide. This pond was excavated in 1984 and the excavated materials were transported to an offsite Class I disposal facility (Hargis and Associates, 1985).

D-4. Area IV

Hazardous Waste Management Facility (HWMF)

The HWMF included two buildings in Area IV: T133 and T029, both owned by DOE. T133 operated as a sodium treatment facility from 1978 to 1987, and was used to react Na and Na / K to form NaOH and KOH; it is no longer active. Building T029 operated as a storage facility for containerized alkali metal waste; it too was used beginning in 1978 and is no longer active. Wastes generated at T029 (Building 29) were PCBs, mercury, and contaminated soil from underground storage tank removals (DHS, 1988a). Metal boxes and drums containing waste were stored on pallets along Building 29’s perimeter (DHS, 1999). The building did not have enough impervious paved areas and diking to properly contain wastes in the event of drum leakage (Ecology and Environment, 1989). Mercury and PCBs were detected in the soil under the building (DHS, 1988a). At this time, Building 29 was storing PCB-containing transformers that had been undergoing phase-out.

Energy Technology Engineering Center (ETEC)

The current primary purpose of operations at ETEC is the environmental restoration of SSFL areas and facilities that have been impacted by DOE operations. A longer-term objective is to provide turn the DOE facilities into a commercially available test facility.

Systems for Nuclear Auxiliary Power (SNAP), Building T059

Building T059 (Building 59) is a former reactor test facility; decontamination and decommissioning of the building involved removal of activated steel and concrete, which may have generated radioactive effluents. Only filtered atmospheric effluents were reported to be released from the building to uncontrolled areas during operations. Activation products consist of iron-55, europium-152, and cobalt-60, as well as minimal amounts of tritium (DOE, 1989). Groundwater and sand beneath Building 59 was found to be contaminated with radioactive Cobalt-60. Building 59 formerly housed the SNAP prototype reactor. A program of controlled groundwater pumping has lowered the groundwater level beneath the building to depress the water level, preventing the migration of contaminated water from the building. Monitoring around the area is insufficient to determine if this program has been successful (DOE, 1989). Drums of reactive metal were also stored at the site for treatment at the Sodium Burn Facility or for removal. These drums contained sodium, potassium, sodium-potassium, zirconium hydride, and lithium.

Hot Lab

Operations at Building T020 (the Hot Lab) that may have generated radioactive effluents in the past consisted of hot cell examination and decladding of irridated nuclear fuels, as well as examination of reactor components. T020 was shut down in 1988. While it was active, the following radionuclides were handled in unencapsulated form there: uranium and plutonium (constituents of the various fuel materials), cesium-137 and strontium-90 as mixed fission products, and cobalt-60. The Nuclear Regulatory Committee license for the Hot Lab was terminated on September 27, 1996 and the facility was transferred to DOE for decontamination and decommissioning.

Sodium Reactor Experiment Complex (SRE)

The SRE was a graphite-moderated, liquid-sodium-cooled 20-megawatt nuclear reactor. In the summer of 1959, a coolant channel became clogged, which resulted in localized melting of 30 percent of the fuel elements. Some fuel elements dislodged and fell to the bottom of the primary sodium containment vessel, and the reactor was shut down. Most of the radioactive fission products were trapped in the sodium coolant or attached to metal components.

Former Sodium Disposal Facility (SDF; Building T886) and Associated Disposal Ponds

The SDF was a waste disposal facility. It is located on the western boundary of Area IV. The “Old Sodium Burn Pit,” as it was otherwise known, was the site of regular combustion of hazardous wastes. Studies there were carried out between 1962 and the 1970s in support of DOE and predecessor agencies. No records were kept about the types and amounts of materials discharged here but CERCLA-mandated DOE investigations found enough contamination at the site to indicate that the quantity was significant (Rockwell International, 1987). Soils in the SDF impoundment were slightly radiologically contaminated (ETEC, 1987). Cesium-137 was the primary gamma-emitting constituent; some metal components containing enriched uranium were also detected. EPA detected radioactive contamination in the soil here during inspections on July 12 and 13, 1989. According to the information reviewed, chemicals from the SDF migrated to offsite areas. An area of approximately 50,000 square feet was found to be contaminated with VOCs, metals, oil and grease, PCBs, polychlorinated terphenyls (PCTs), terphenyls, and biphenyls. Asbestos was found in a runoff sample taken behind the SDF (Ecology and Environment, 1989). In addition, radioactive cesium-137 was found in soil samples in this area (Rockwell International, 1987).

The SDF was located near unlined earth-bermed impoundments, the Upper, Lower, and Western Ponds. These ponds were used for the disposal of materials from reactor heat transfer experiments. There are three surface water bodies within 1 mile of the Lower Pond: R2A, R2B, and Silvernale. The Lower Pond drainage system drains to the north toward Simi Valley, whereas R2A, R2B, and Silvernale flow toward the San Fernando Valley through Bell Creek (DHS, 1989a). There are no natural springs within 1 mile of the SDF, but there are several artesian wells flowing at land surface about 2,000 feet north. During periods of rainfall, surface water from the SDF flows mainly north via two channels that ultimately discharge at NPDES-permitted outfalls at the northwest property boundary. In 1995, contractors for SSFL collected soil and sediment samples along these surface drainages. Sampling data indicate that PCBs, TCDD, asbestos, and mercury had migrated in these drainages from the SDF to offsite areas. Maximum concentrations were found in offsite samples collected a short distance downstream of the upper and lower ponds; concentrations decreased with increasing distance from the ponds. Approximately 12,000 cubic yards of soil have been removed from this area to an offsite landfill. In the lower pond, all soils have been removed down to bedrock (ITC, 1999).

Radioactive Materials Disposal Facility (RMDF)

The handling of radioactive wastes, including treatment and storage, took place at the RMDF in Area IV. Operations at the RMDF's Buildings T021 and T022 that may have generated radioactive effluents consisted of processing, packaging, and temporary storage of liquid and dry radioactive waste material for disposal. Waste treatment consisted of the solidification and evaporation of radioactive wastes. These wastes were then placed in 55-gallon drums for shipment to an offsite radioactive waste disposal facility. Contamination from nuclear fuel and decontamination operations contained uranium and plutonium plus cesium-137 and strontium-90 as mixed fission products, and cobalt-60 and europium-152 activation products.

In the 1970s, there was an accidental spill of radioactive-contaminated water from a tank in the RMDF. While investigating the results of this spill, radiation was found beneath the RMDF leachfield. It is believed that in the early 1960s, water containing strontium-90 and yttrium-90 was accidentally released to the sanitary sewer leachfield for the RMDF. After this contamination was found, the soil in the area was excavated and the joints and fractures in the Chatsworth Formation were sealed with asphalt. Given that about 15 years elapsed between the accidental spill and its discovery, migration of the associated contaminant to the aquifer below this area may have been likely. This potential release has not been fully investigated (DOE, 1989). Radionuclides have washed down from the RMDF at SSFL onto what was part of the Brandeis-Bardin property, located north of Area IV (McLaren/Hart, 1993, 1995). This area was purchased by Rocketdyne and is now part of the SSFL buffer zone. Strontium-90 and tritium were detected at concentrations slightly above background levels there.

Old Conservation Yard

Eighty-nine drums containing such materials as oils, alcohols, sodium and sodium reaction products, grease, phosphoric acid, and asbestos were removed in the early 1980s from an unregulated temporary drum storage area referred to as “the Old Landfill” (or “Old Conservation Yard”) in Area IV (Rockwell International, 1987. This site borders SSFL’s undeveloped northern border area (the former Brandeis-Bardin Institute). Hydrocarbon and cesium contamination was detected in the soils at the Old Conservation Yard (Ecology and Environment, 1989). Aerial photographs show that hundreds of drums were stored there in the 1960s and 1970s with no containment structures.

D-6. NPDES Outfalls

Discharges from SSFL waste systems have been regularly monitored through the National Pollutant Discharge Elimination System (NPDES) outfalls at seven locations, five in Meier Canyon (NPDES 003–007, in the northwestern portion of the site) and two in Bell Canyon (NPDES 001 and 002, in the southwest). Another, in Woolsey Canyon, was monitored only once due to infrequent surface water flow and the lack of source areas. NPDES outfalls 001 (Perimeter Pond) and 002 (R2A) are located near the undeveloped area south of SSFL and upstream (north) of the residential area of Bell Canyon (and Bell Creek). These two onsite drainage channels join to form the headwaters of Bell Creek in the southern buffer zone of SSFL. According to Rocketdyne (1999a):

> *Approximately 90% of the surface water flows from SSFL into Bell Creek through the Bell Canyon residential community located directly south of SSFL property. The remaining surface flow from SSFL (10%) discharges via drainage channels flowing in a northerly direction from Area IV to Meier and Runckle Canyon in Simi Valley.*

Rain flow also emanates from Happy Valley, where propellant and munitions testing were conducted. The water falls down through Woolsey Canyon into Chatsworth and from Dayton Canyon into West Hills, but little testing has been done in these areas.

D-7. De Soto Site

The De Soto site is offsite of SSFL. Operations that could have generated radioactive effluents there consisted of research studies in applied physics and physical chemistry using activated materials. Analysis of activated test samples in the mass spectrometer laboratory was terminated in May 1995. The laboratory was relocated to a DOE facility at Batelle-Pacific Northwest National Laboratories in early 1996.

D-8. Other Contracted Sites

Hughes Missile Systems Group, an aerospace research and development company, was previously located at 8444 Fallbrook Avenue in Canoga Park. The site is south of the former

Chatsworth Reservoir, which was drained in 1971 due to structural damage caused by faulting. To the north, west, and southwest of the site lie the Simi Hills, which form the drainage divide between the San Fernando Valley and the Simi Valley to the west. From 1966 to 1976, Hughes shared this site with Rocketdyne and Bunker Ramo, an electrical component design and testing company. Presently the site is occupied by the De Vries Institute and an administrative complex where Rocketdyne has office space. VOCs and radioactivity were discovered in the soils and groundwater beneath the site, exceeding regulatory levels (Hughes, 1989). The area occupies approximately 80 acres between the Chatsworth Creek drainage to the west and a low area beneath the Chatsworth Reservoir dam to the east. Elevation ranges from 879 feet above mean sea level in the central irrigated courtyard to 840 feet above mean sea level along Fallbrook Avenue, Roscoe Boulevard, and Chatsworth Creek. The vast majority of chemical products used by Hughes were used in minute quantities either under laboratory conditions or in prototype manufacturing and testing “clean” rooms employing sophisticated environmental controls (Hughes, 1989).

Summary Tables: Site Facilities and Waste Management Facilities

Table D1. Area I

Facility	Use	Waste
APTF Ponds #1, #2[1]	Cooling water catchment and emergency spill containment and treatment	Kerosene-based fuels (skimmed off), nitric acid (neutralized), monomethylhydrazine (treated with hydrogen peroxide, if spilled)
LETF Pond[1]	Waste treatment and storage	Corrosive liquids (NaOH, NaF) held for disposal in Class I landfill
Burn Pit Area	Waste treatment and storage	Solid propellants and explosives (burned and disposed of in Class I or regular landfill depending on constituents)
Potassium Loop[2]	Inactive testing facility	Metallic potassium meal
Perimeter Discharge Pond	Waste containment and storage	Kerosene-based fuels, nitric acid, monomethylhydrazine, trichloroethene, 1,1,1-trichloroethane, freon, corrosive liquids
R-1 Reservoir	Waste storage	Kerosene-based fuels, nitric acid, monomethylhydrazine, trichloroethene, 1,1,1-trichloroethane, freon, corrosive liquids
Bowl Skim Pond[3]	Catchment for Bowl test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon
Bowl Retention Pond[3]	Catchment for Bowl test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon
Canyon Retention Pond[3]	Catchment for Bowl test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon
Canyon Skim Pond[3]	Catchment for Bowl test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon

Notes:

1. Not used since November 1985; closed under RCRA.
2. Closed under RCRA.
3. Inactive.

Table D2. Area II

Facility	Use	Waste
SPA Ponds #1 and #2[1]	Container rinsate and emergency spill containment and treatment	1,2-dimethylhydrazine, monomethylhydrazine, nitrogen tetroxide, hydrogen peroxide (hydrazines treated with hydrogen peroxide in event of spill)
MMH Pond (or PLF Impoundment) [1]	Spill containment and treatment	Monomethylhydrazine, nitrogen tetroxide (hydrogen peroxide used if spilled)
Delta Impoundment[1]	Rinsate and spill containment	Inhibited red fuming nitric acid (oxidizer), cryogenic fluorine and hydrogen, kerosene-based fuels, hydrazines, chlorinated and fluorinated solvents
ABSP Pond	Cooling water catchment and spill containment	Kerosene-based fuels (skimmed off), chlorinated solvents, hydraulic oil
Alpha Tank[3]	Storage tank	Spent TCE, stored until removed for reclamation
PCB Storage	Drum storage	PCBs and hazardous wastes
Hazardous Waste Storage	Drum storage	Solvents, alcohol, kerosene, oil, paint thinner, turco descalent, and lab packs
Bravo Skim Pond	Catchment for Bravo test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon
Alpha Skim Pond	Catchment for Alpha test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon
Alpha Retention Pond	Catchment for Alpha test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon
Coca Skim Pond[2]	Catchment for Coca test area emergency spill containment	Kerosene-based fuels, trichloroethene, 1,1,1-trichloroethane, freon
R-2A Discharge Pond	Water containment and storage	Kerosene-based fuels, isopropyl alcohol, trichloroethene, 1,1,1-trichloroethane, freon, hydrogen peroxide, monomethylhydrazine
R-2B Discharge Pond	Water containment and storage	Kerosene-based fuels, isopropyl alcohol, trichloroethene, 1,1,1-trichloroethane, freon, hydrogen peroxide, monomethylhydrazine
CTL II Retention Pond	—	—
Flowmeter Catch Pond	—	—

Notes:

1. Not used since 1985; closed under RCRA.
2. Inactive.
3. Generator only.

Table D3. Area III

Facility	**Use**	**Waste**
ECL Pond[1]	Treatment and storage	Sodium hydroxide, methylene chloride, dimethyl sulfoxide, sodium azide, and other chemicals depending on current contract
STL-IV Ponds #1, #2[2]	Cooling water catchment and spill containment	Monomethylhydrazine, nitrogen tetroxide, chlorinated and fluorinated solvents
Compound A	Wastewater catchment	Hydrofluoric acid
Silvernale Reservoir	Water storage	Kerosene-based fuels, nitric acid, trichloroethene, 1,1,1-trichloroethane, freon, hydrogen peroxide, monomethylhydrazine

Notes:
1. Closed under RCRA.
2. Not used since 1985; closed under RCRA.

Table D4. Area IV

Facility	**Use**	**Waste**
Sodium Burn Pit	Treatment and disposal	Metallic sodium, NaK, kerosene, organic solvents, diesel fuel, oil, grease, PCBs, PCTs, terphenyls and biphenyls, cesium-137, zirconium hydride, lithium, metals, VOCs, asbestos
SRE Watershed	Runoff from SRE building	Asbestos
SNAP Reactor Building (T059)	Groundwater contamination from building T059	Cobalt-60, iron-55, europium-152, tritium, chlorinated solvents
Old Landfill	Drum storage or disposal	Oil, grease, alcohols, sodium and sodium reaction products, phosphoric acid, and asbestos
RMDF Leachfield	Accidental release of contaminated wastewater	Strontium-90, yttrium-90, uranium, plutonium, cesium-137, cobalt-60, europium-152, tritium
Old Conservation Yard	Drum and equipment storage	Unknown hydrocarbons, asbestos, cesium-137
ESADA Chemical Storage Yard	Drum storage	Alcohols and unknown others
Building 100 Trench	Burning and disposal	Construction debris and possible hazardous wastes
SE Drum Storage Yard	Drum storage	Unknown
New Conservation Yard	Drum and equipment storage	Unknown
Sodium Burn Facility (T133)	Equipment storage	Metallic sodium, high-pH soils, asbestos

Appendix E. Partial List of Violations Cited, Hazards Observed by Site Inspectors, and Accidents

Table E-1. A Partial List of Violations Cited and Hazards Observed by Site Inspectors

Year of Citation	Ref	Site	Cited by	Violations	Comments
1983	1	Areas I and III	DHS	Inadequate groundwater monitoring program for uppermost aquifer	
1983	1	TTF (Area I)	DHS	Inadequate waste storage of PCBs	
1984	6			Failure to design, construct, maintain, and/or operate the sodium burn facility to minimize the hazardous waste at the facility	Title 22, California Code of Regulations, Section 67120(a)
1985	6	Sodium Storage Area (T029)	DHS	Failure to submit a written report to DHS and EPA within 15 days after determination of release of radioactive materials	40 CFR, Part 264.56(j)
1988	6	Area II	DHS	Failure to obtain permit for air stripping tower Delta (in operation)	Title 22, California Code of Regulations, Section 66371(a)
1989	6	Sodium Burn Facility		False statement made in permit application submitted on Dec. 21, 1988, where RD stated that there was no hazardous waste contamination at the Sodium Burn Facility	Health and Safety Code, Section 25189.2
1989	6	Outside Building 59 (Area IV)	DHS	Failure to obtain permit to operate groundwater treatment unit	California Code of Regulations, Section 67120(a)
1989	5	Building T133	DHS	"Soil samples were not collected to determine if migration of the waste occurred"	Violation for April 1984 to February 1989
1989	2	Burn pit in Area I	EPA	Failure to notify EPA of the TTF unit	Violation for January 1985 to November 1989
1989	2	Alpha/Canyon (Area I) and Delta (Area II)	DHS	Failure to obtain a permit for two air stripping towers	
1989	2		DHS	Failure to prepare waste analysis plans	
1989	2	Areas I and II	DHS	Failure to document inspections of generator tanks before June 19, 1989	
1989	2	Sodium Storage Area (T029)	EPA	Failure to notify EPA within 15 days of a "release of radioactive materials"	EPA detected radioactive contaminants in soil at the Sodium Burn Pit facility during the July 12–13, 1989, inspection
1991	3	Burn pit in Area I	DHS	Burning flammable liquid in batches exceeding 5 pounds	
1990	3		DHS	"Radioactivity was detected in a leak in the sodium Na/K pipe"	
1994	7	TTF	EPA	Illegal burning of triaminoguanidine nitrate at the TTF	Two scientists were killed
February 14, 2000	4	Energy Technology and Engineering Center	DTSC	1. Failure to conduct weekly inspections 2. Accepting wastes from an offsite source without authorization 3. Conducting stabilization (treatment) without authorization	The final settlement amount was $12,000

Notes: TTF = Thermal Treatment Facility; DHS = Department of Health Services; EPA = Environmental Protection Agency; DTSC = Department of Toxic Substances Control

References: ***1.*** Letter, Sept. 15, 1983, DHS (John A. Hinton) to Rocketdyne, CA D093365435. ***2.*** Letter, Aug. 11, 1989, DHS (Scott Simpson) to Rocketdyne (Steve Lafflam), Re. Nov. 1989 Addendum Report RD Corp SSFL, Area IV, EPA ID #CAD000629972 and CA389009000. ***3.*** Comments on the Draft Closure Plan for Haz. Waste Site Management Facility, Area IV, DHS Report, Dec. 6, 1991. ***4.*** ETEC, 1987. ***5.*** Letter, Sept. 14, 1989, DHS to Rocketdyne, "Information regarding potential releases from solid waste management units" in reference to seven separate spills that occurred at Building 133 from April 1984 to Feb. 1989. ***6.*** DTSC, Toxic Substances Control Division (Region 3) Addendum Report for Violations of Rockwell Int., SSFL, by Vajie Motiaford. #000685. Nov. 1989. ***7.*** Multinational Monitor, May 1996, Vol. 17 No. 5.

Table E-2. Chronological List of Radiological Incidents in Area IV of SSFL

Date	Description of Incident	Environmental Releases	References
March 25, 1959	AE-6 power doubling excursion[1]	Improper operating procedures allowed it to reach double its maximum allowable power. Caused "rather heavy air contamination in the reactor room" and contamination of several members of the operating staff. Count rate measurements indicated short-life fission products.	Release of Fission Gas from the AE-6 Reactor,[1] NAA-SR Memo 3757[5]
June 4, 1959	SRE wash cell rxplosion[2]	Unknown; max recorded 700,000 mrem/100 square centimeters (in building). Air vented to atmosphere.	SRE Fuel Element Damage Report, NAA-SR-4488[2]
July 13, 1959	SRE power excursion	Unknown; potential radioactive "leaks." Reactor's power increased uncontrollably; it was restarted two hours later negligently.[6]	Analysis of SRE Power Excursion, NAA-SR-5989
July 26, 1959	SRE fuel damage "meltdown"	Same reactor from the SRE power excursion had a partial meltdown. Absolute amount released unknown due to multiple monitor problems. 13 of 43 fuel elements melted. 10,000 Ci released to coolant. Xenon and krypton gases "captured" and emitted over time (1 year) at "safe levels."	Distribution of Fission Product Contamination in the SRE, NAA-SR-6890; Fuel Damage Element, NAA-SR-4488
March 19, 1960	SRE steam cleaning pad contamination	Unknown. Radioactive pipe taken outdoors to be decontaminated; pipe exploded.	ATSDR Draft Preliminary Site Evaluation of the Santa Susana Field Laboratory (SSFL)[4]
1964	SNAP 8 (S8ER) fuel element failures[3]	Unknown; "substantial release of fission products."[4] Meltdown of 80% of fuel rods.	Atomics International memo 12790
1969	SNAP 8 (S8DR) fuel element failures[3]	Unknown.	ATSDR Draft Preliminary Site Evaluation of the Santa Susana Field Laboratory (SSFL)[4]
May 19, 1971	Hot Lab NaK fire in the Hot Lab decontamination room	Unknown.	ATSDR Draft Preliminary Site Evaluation of the Santa Susana Field Laboratory (SSFL)[4]
November 3, 1976	Radioactive Material Disposal Facility leachfield contamination	Unknown; "high amount of strontium-90." Undiscovered for 14 years. (Upon discovery, radioactive soil was dug up and shipped to Beatty, Nevada.)	ATSDR Draft Preliminary Site Evaluation of the Santa Susana Field Laboratory (SSFL)[4]

Notes: ***1.*** AE-6 was a 2-kilowatt, low-power research reactor, used as a neutron source, with a solution of uranyl sulfate in a spherical tank. ***2.*** The SRE (Sodium Reactor Experiment) was part of a program with the Atomic Energy Commission to demonstrate the feasibility of a high-temperature, sodium-cooled power reactor for civilian application. ***3.*** SNAP 8 was a small sodium-cooled reactor for space applications. ***4.*** Adapted from ATSDR Draft Preliminary Site Evaluation of the Santa Susana Field Laboratory (SSFL), Ventura County, California, CERCLIS No. CAD074103771, December 3, 1999. ***5.*** Blackshaw, 1959. ***6.*** Atomics International/Energy Commission Report (NAA-SR-5989) concluded: "It is quite clear that the reactor should have been shut down and the problems solved properly. Continuing to run it in the face of a known tetralin leak, repeated scrams, equipment failures, rising radioactive releases, and unexplained transient effects is difficult to justify. Such emphasis on continued operation can and often does have serious effects on safety and can create an atmosphere leading to serious accidents."
Source: Adapted from ATSDR, 1999.

Appendix F. Contaminants of Concern (COCs) and Sources of Toxicological Information and Health Based Standards

Aliphatic and Cyclic Hydrocarbons
Trichloroethene (TCE)
Carbon Tetrachloride
1,2- and 1,1-Dichloroethane
Trans- and Cis-1,2-Dichloroethene
1,1-Dichloroethene (Vinylidene chloride)
Methylene Chloride (Dichloromethane)
Chloromethane (Methyl Chloride)
Methyl Chloroform (1,1,1-TCA)
Tetrachloroethene (Perchloroethene)
Vinyl Chloride (VC)

Aromatic Compounds
Xylene
Toulene
Benzene
Polychlorinated Biphenyls (PCBs)
Bis(2-ethylhexyl)phthlate (DEHP)
Polycyclic Aromatic Hydrocarbons (PAHs)
Benzo(a)pyrene

Nitrogen-Containing Organic Compounds
Hydrazines (MMH, UDMH, and NDMA)

Oxygenated Organic Compounds
Polychlorinated Dibenzo-p-dioxins (PCDDs)
Dibenzofurans (PCDFs)
Perchlorate

Inorganic Compounds
Arsenic
Mercury
Lead
Beryllium
Chromium
Manganese
Nickel
Cadmium
Selenium

Radioactivity
Tritium
Cesium-137
Strontium-90
Plutonium-238
Radium-226, -228
Potassium-40
Thorium-228, -232

The following sources of toxicity information were considered in the evaluation of contaminants of concern:

1. *EPA's Integrated Risk Information System (IRIS).* IRIS contains reference doses (RfDs), reference concentrations (RfCs), cancer slope factors, drinking water unit risk values, and inhalation unit risk values. IRIS normally represents the official Agency scientific position regarding the toxicity of the chemicals based on the data available at the time of the review. IRIS toxicity assessments have undergone external peer review and thus contain consensus toxicity parameter values. IRIS can be accessed online at: http://www.epa.gov/iris/.

2. *California's Environmental Protection Agency (Cal EPA).* Cal-EPA's recommended toxicity parameter values are available online at http://www.oehha.ca.gov/risk/chemicalDB//index.asp. These are peer reviewed and address both cancer and non-cancer effects.

3. *The Agency for Toxic Substances and Disease Registry (ATSDR).* ATSDR's Minimal Risk Levels (MRLs) are estimates of the daily human exposure to a hazardous substance that are likely to be without appreciable risk of adverse non-cancer health

effects over a specified duration of exposure. The ATSDR MRLs are peer reviewed and are available at http://www.atsdr.cdc.gov/mrls.html.

4. *Health Effects Assessment Summary Tables (HEAST).* Table 4 of HEAST includes peer reviewed radionuclide slope factors which are available on the EPA Office of Radiation and Indoor Air (ORIA) website at: http://www.epa.gov/radiation/heast/download.htm. The published radionuclide slope factors have been adopted by EPA in its Preliminary Remediation Goals for Radionuclide Calculator; they are available on EPA's internet website at: http://epa-prgs.ornl.gov/radionuclides/. The Soil Screening Guidance for Radionuclide documents are available at: http://www.epa.gov/superfund/resources/radiation/radssg.

Appendix G. Interview Documentation

In the course of the study, various residents in the SSFL area have approached members of the study team and shared information that exemplified their concerns about SSFL's impact on their community. The tables below summarize examples of the kind of information provided by concerned residents. The identities of the residents are concealed to protect their privacy.

Name/Affiliation:	[redacted]
Address/City:	Erringer Road and Cochran St. (about 3 miles north of the lab).
Contact(s):	[redacted]
Phone:	[redacted]
Date:	4/30/2003
Site Name:	West Hills and Simi Valley
Comments:	Mr. X [redacted] was a resident of West Hills from 1975 through 1981, between the ages of 15 and 21. Mr. X lived in Simi Valley since 1990. He walked his dog 2-3 times per week at night, and rode his Jeep up into the hills frequently (Castle Peak at Bell Canyon). First got sick in April 2000, and in Sept. 2000 was diagnosed with Graves' Disease. Has been diagnosed with different diseases from stiff person syndrome to dystonia (muscle and nerve disease). [redacted] He went from a diagnosis of hyperthyroidism 2 years ago to hypothyroidism (slowed-down metabolism). His doctors now suspect he may have Sjogren's syndrome, an autoimmune disease that attacks the saliva glands. He was referred to the National Institute of Health (Maryland), and is awaiting those results. The study team was informed that one of his neighbors has Graves' disease; another has lung cancer (see the last table). There were no physical problems until after he moved to Simi Valley. His parents still live in West Hills (Highlander and Valley Circle) and are physically fine. He experienced breathing difficulties and voice impairment during our interview when moving into other rooms.

Name/Affiliation:	[redacted]
Address/City:	Previous Address: [redacted] Ballard St., Simi Valley, CA., 93065 (In the Santa Santa Susana Knoll Present Address: Erringer Rd. and Cochran St., Simi Valley, CA (Orangewood)
Phone:	[redacted]
Date:	April 31, 2003
Site Name:	Simi Valley
Comments:	[redacted] Ms. X and Mr. XX lived at the previous address (above) for 13 years. They have a few kids and pets. [redacted] was an avid gardener, growing pumpkins, bell peppers, tomatoes, and various other vegetables, which they consumed regularly. She was outside regularly with her children; claims her house was a "meeting place for the neighborhood kids." She remembers hearing huge blasts during the day from Rocketdyne. She also remembers a strong sulfurous smell around her house; when she called the fire department she was told it was her sewer system. In 1987, there was a spill in the area and everyone was evacuated (he believes it was due to ammonia). [redacted] She was diagnosed with thoracic outlet syndrome (a musculoskeletal disease). She was also diagnosed with Graves' disease (hyperthyroidism) early this year (2003) and Hashimoto's syndrome. (She is 38.) On Dec. 24, 2002 she was diagnosed with heart disease. [redacted]. She says her symptoms began a year ago. She started having heart palpitations, her hair fell out, and she lost 55 pounds. She says she is in constant pain and shakes all the time. Her oldest and youngest boys have asthma (not in her or her husband's family). The oldest boy has had 6-inch tumors on his jaw line (lymph nodes) and problems with reoccurring ringworm infections since he was 14 (now he's 20). (There was a big outbreak at his high school, [redacted] when he was younger.) Her 7-year old son has cystic fibrosis (also not in either family). ([redacted] has mapped sick residents in the area.) She receives calls from people who have lupus, cancer, Graves' disease, various thyroid diseases, Moersch-Woltman syndrome, etc. She has mapped 50-60 people with thyroid diseases in Simi Valley. Presently they get their water from American Water Co. (AWC). The previous house received its water from AWC.

Name/Affiliation:	[redacted]
Address/City:	[redacted]
Phone:	[redacted]
Site Name:	Simi Valley
Comments:	[redacted] Ms. X has lived in Simi Valley since 1976. She was diagnosed with Graves' disease, breast cancer, and Hodgkin's lymphoma. [redacted]. She has had two dogs die of thyroid disease.

Name/Affiliation:	[redacted]
Phone:	[redacted]
Comments:	Dr. X [redacted] has seen 12-13 cases of thyroid disease in the last three months (Jan 2003-April, 2003).

Name/Affiliation:	[redacted]
Phone:	[redacted]
Comments:	[redacted] Ms. X has been living in Simi Valley since 1964. She is an elementary school teacher [redacted]. She claims that there is a significant number of teachers that have lupus/thyroid diseases ([redacted] [Lupus]).

Name/Affiliation:	[redacted]
Comments:	[redacted] Mr. X is in his late teens [redacted] and has lived north of Simi Valley all his life. He camped at Sage Ranch frequently and even admits to breaking into Rocketdyne on occasion when younger (as other kids have been known to do). He attends a local [redacted] High School. He heard blasts and saw black plumes about 3 times a week in his early growing years. (The last plume was about two months prior to the interview). He has developed 3 tumors on his neck. Two were removed and another is growing. His doctor thinks he may have Hodgkin's lymphoma but a definitive diagnosis has not been reached.

Name/Affiliation:	[redacted]
Address/City:	Erringer Road and Cochran St. (About 3 miles north of the lab).
Date:	5/2/2003
Site Name:	Simi Valley
Comments:	[redacted] Mr. X, is a middle-aged resident [redacted] of Simi Valley. He has lived in the area for 20 years. He was diagnosed with lung cancer about 3.5 years ago [redacted] [redacted]. [redacted] He does not smoke. One of [redacted] His brother-in-law lived nearby, and died of lung cancer 10 years ago. His mother and another brother-in-law, both residents of the same neighborhood, also suffer from thyroid-related conditions.

Appendix H. Monitoring Data Compendium

The following tables present chemical (Tables H-1 to H-6) and radionuclide (H-7 to H-9) contaminant levels that were detected in soil, surface water and groundwater samples and reported in monitoring reports at levels exceeding health-based standards or background levels. The data presented here were compiled from *various* monitoring reports identified in the Reference (Ref) column of each table. Contaminant detections are reported based on data reported for the 1964-2004 period and grouped by tables according to the sampling site locations. For example, Table H-1 lists chemicals detected onsite in Area I above background or standard levels. Chemicals detected onsite are presented in Tables H-1 to H-3, (Areas I, II and IV respectively); these detections were used to evaluate SSFL as a potential source of contaminants detected offsite. Chemicals detected offsite are presented in Tables H-4 to H-6; contaminants detected offsite were considered in exposure scenarios if detections occurred near potential areas of exposure. Rows in italics in these offsite tables are addressed within the body of the report. Each row contains the identity of the chemical detected, the media phase in which it was detected (air, water or soil), the standard or background comparison value, the detected concentration level or range, the sampling date, any report-specific sample identification presented with the data, the reference report from which data were derived, and reported comments specific to the detection.

Table H-1. Onsite Area I: Thermal Treatment Facility, Happy Valley, and Bowl, Canyon, and APTF Rocket Test Areas, 1964–2003

Chemical	Phase	Standard of Comparison	Concentration or Range	Date	Location/Sample Identification	Ref	Comments
Beryllium	A	0.01 μg/m^3	0.09 μg/m^3	12/4/64	Happy Valley	2	
Beryllium	A	0.01 μg/m^3	0.14–7.9 μg/m^3	1/65	Happy Valley	2	
Beryllium	A	0.01 μg/m^3	0.1–5.4 μg/m^3	3/67	Happy Valley	2	
Beryllium	A	0.01 μg/m^3	0.3 μg/m^3	8/18/67	Happy Valley	2	
Beryllium	A	0.01 μg/m^3	0.02–0.33 μg/m^3	7/68	Happy Valley	2	
Beryllium	A	0.01 μg/m^3	0.09–5.64 μg/m^3	12/68	Happy Valley	2	
Beryllium	A	0.01 μg/m^3	0.05–2.4 μg/m^3	7/69	Happy Valley	2	
Chromium (total)	S	21 mg/kg	290 mg/kg	6/17/93	TTF: 0–0.5’ depth	3	
Chromium (total)	S	21 mg/kg	860 mg/kg	6/17/93	TTF: 0–0.5’ depth	3	
Arsenic	S	0.39 mg/kg	1.3–7.3 mg/kg	6/16–6/17/93	TTF: 0–4.5’ depth	3	64 samples in range
1,4-Dichlorobenzene	S	3.4 mg/kg	8.2 mg/kg	6/17/93	TTF: 4–4.5’ depth	3	
Tetrachloroethene	S	1.5 mg/kg	4.8 mg/kg	6/17/93	TTF: 4–4.5’ depth	3	
TCE	S	0.043 mg/kg	190 mg/kg	6/17/93	TTF: 4–4.5’ depth	3	
Pentachlorophenol	S	3 mg/kg	4,000 mg/kg	6/17/93	TTF: 0–0.05’ depth	3	
Benzidene	S	0.0021 mg/kg	<700 mg/kg	6/17/93	TTF: 0–0.05’ depth	3	IDM
Benzidene	S	0.0021 mg/kg	<7 mg/kg	6/17/93	TTF: 0–4.5’ depth	3	IDM
Benzidene	S	0.0021 mg/kg	<300 mg/kg	6/17/93	TTF: 4–4.5’ depth	3	IDM
1,2-Dichlorobenzene	S	370 mg/kg	460 mg/kg	6/17/93	TTF: 4–4.5’ depth	3	
Perchlorate	W	2 μg/L	16 μg/L	3/23/2000	Happy Valley	1	
Perchlorate	W	2 μg/L	13 μg/L	3/5/2000	Happy Valley	1	
Perchlorate	W	2 μg/L	8.2 μg/L	3/5/2000	Happy Valley	1	
Perchlorate	W	2 μg/L	9.4 μg/L	3/5/2000	Happy Valley	1	
Perchlorate	W	2 μg/L	8 μg/L	1/12/2001	Happy Valley	1	
Perchlorate	W	2 μg/L	5.5 μg/L	2/13/2001	Happy Valley	1	
Perchlorate	W	2 μg/L	4.2 μg/L	2/26/2001	Happy Valley	1	
Perchlorate	W	2 μg/L	5.3 μg/L	3/5/2001	Happy Valley	1	
Perchlorate	W	2 μg/L	4.9 μg/L	3/7/2001	Happy Valley	1	
Perchlorate	W	2 μg/L	5.2 μg/L	3/8/2001	Happy Valley	1	
Perchlorate	W	2 μg/L	4.8 μg/L	3/9/2001	Happy Valley	1	

Notes: Shallow zone wells: SH-11, RS-5, RS-11, RS-16, RS-18, RS-23-25, RS-27-28, RS-54, ES-31. Chatsworth Formation wells: RD-6-7, RD-13-25, RD-27-30, RD-34A, WS-7, WS-13, OS-16, OS-21. Offsite wells: RD-33A, RD-35A-B, RD-59A; **Phase Designations:** W=water; S=soil; A=air; **Location Designations:** TTF=Thermal Treatment Facility; **Comments:** IDM=insensitive detection method; MCL=maximum contaminant level; **References:** ***1.*** Boeing, 2002. Most of these samples were monitored with non-sensitive equipment and had recorded values of <4 μg/L, while the MCL is 2 μg/L. ***2.*** Fax transmittal from Michael Sullivan, Rocketdyne (8/25/99), “Industrial Hygiene Data from Solid Fuel Operations.” ***3.*** GRC, 1993.

Table H-2. Onsite Area II: Alpha, Bravo, Coca, and Delta Rocket Engine Test Areas, 1983–2003

Chemical	**Phase**	**Standard**	**Concentration**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
TCE	W	5 µg/L	800 µg/L	6/83–8/83	Alpha II testing area	1	IT removed cont. soil/water (spill of 285–322 gal TCE; most in air; unknown)
TCE	S	0.43 mg/kg	200 mg/kg	6/83–8/83	Alpha II testing area	1	See above
Beryllium	A	0.01 µg/m^3	5,000 µg/m^3	6/12/92	Behind engine during test	2	5x10^{5}x > AAQS

References: ***1.*** Rockwell letter dated August 17, 1983. ***2.*** ABB Environmental Services, Inc., 1992.

Table H-3. Onsite Area IV: Sodium Disposal Facility, Radioactive Material Disposal Facility, 1987–2003

Chemical	**Phase**	**Standard**	**Concentration**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
PCB (Aroclor 1254)	S	0.22 mg/kg	2.0–2.4 mg/kg	4/1/87	SDF: 0.5–1.0’	1	
PCB (Aroclor 1254)	S	0.22 mg/kg	1.0 mg/kg	4/1/87	SDF: 1.5’	1	Irregular distribution
PCB (Aroclor 1254)	S	0.22 mg/kg	2.6 mg/kg	4/1/87	SDF: 3.5–4.0’	1	
PCB (Aroclor 1254)	S	0.22 mg/kg	12 mg/kg	4/1/87	SDF: 4.5’	1	
PCB (Aroclor 1254)	S	0.22 mg/kg	1.1 mg/kg	4/1/87	SDF: 5.5–6.0’	1	55x > RSSL
Carbon tetrachloride	S	0.25 mg/kg	500 mg/kg	4/1/87	SDF: Building 886, 3.5–4.0’	1	2,000x > RSSL
1,2-DCA	S	0.28 mg/kg	430 mg/kg	4/1/87	3.5–4.0’	1	1,535x > RSSL
Ethylbenzene	S	8.9 mg/kg	44 mg/kg	4/1/87	3.5–4.0’	1	
Tetrachloroethylene	S	1.5 mg/kg	1.7 mg/kg	4/1/87	1.5’	1	
Tetrachloroethylene	S	1.5 mg/kg	1,200 mg/kg	4/1/87	3.5–4.0’	1	800x > RSSL
1,1,1-TCA	S	1,200 mg/kg	1,840 mg/kg	4/1/87	3.5–4.0’	1	
TCE	S	0.043 mg/kg	>40 mg/kg	4/1/87	3.5–4.0’	1	>930x > RSSL
TCE	S	0.043 mg/kg	34 mg/kg	4/1/87	5.5–6.0’	1	790x > RSSL
Toluene	S	520 mg/kg	800 mg/kg	4/1/87	3.5–4.0’	1	
Chromium (total)	W	50 µg/L	150 µg/L	4/1/87	BPL-8, SDF	1	
Chromium (total)	S	210 mg/kg	710 mg/kg	4/1/87	SDF, 3.5–4’ depth	1	
Chromium (total)	S	210 mg/kg	320 mg/kg	4/2/87	SDF, 0.5–1’ depth	1	
Chromium (total)	S	50 µg/L	150 µg/L	4/2/87	BPR-3, SDF	1	Sediment
Chromium (total)	W	50 µg/L	1,500 µg/L	4/2/87	BPR-3, SDF	1	
Lead	S	150 mg/kg	864 mg/kg	4/2/87	SDF, 0.5–1’ depth	1	
Vinyl chloride	S	0.79 mg/kg	<15 mg/kg	4/2/87	3.0’	1	IDM
TCE	S	0.043 mg/kg	22 mg/kg	4/2/87	3.0’	1	511x > RRSL
1,1-DCA	W	5 µg/L	24 µg/L	12/4/87	GW: RS-18	1	
1,1-DCE	W	6 µg/L	33 µg/L	12/4/87	GW: RS-18	1	

Chemical	Phase	Standard	Concentration	Date	Location/Sample Identification	Ref	Comments
TCE	W	5 µg/L	660 µg/L	12/4/87	GW: RS-18	1	132x > MCL
1,2-DCE	W	0.5 µg/L	5 µg/L	1/20/89	RD-23	4	
TCE	W	5 µg/L	208 µg/L	3/3/89	GW: RS-18	1	41x > MCL
TCE	W	5 µg/L	203 µg/L	3/3/89	GW: RS-18	1	41x > MCL
1,1-DCE	W	6 µg/L	26 µg/L	6/4/89	GW: RS-18	1	
1,1-DCE	W	6 µg/L	21 µg/L	6/4/89	GW: RS-18	1	
1,1-DCA	W	5 µg/L	22 µg/L	6/4/89	GW: RS-18	1	
1,1-DCA	W	5 µg/L	14 µg/L	6/4/89	GW: RS-18	1	
TCE	W	5 µg/L	390 µg/L	6/4/89	GW: RS-18	1	78x > MCL
TCE	W	5 µg/L	275 µg/L	6/4/89	GW: RS-18	1	55x > MCL
Chromium (total)	W	50 µg/L	280 µg/L	7/17/89	1.5–2.0’ depth	1	
Lead	W	12 µg/L	17 µg/L	7/17/89	0.0–0.5’	1	
Lead	W	12 µg/L	1,090 µg/L	7/17/89	1.5–2.0’	1	72x > MCL
Lead	W	12 µg/L	26 µg/L	7/17/89	1.0–0.5’	1	
Lead	W	12 µg/L	33 µg/L	7/17/89	2.0–2.5’	1	
Mercury	W	2 µg/L	3.5 µg/L	7/17/89	1.5–2.0’	1	
Silver	W	100 µg/L	230 µg/L	7/17/89	1.5–2.0’	1	
Barium	W	1,000 µg/L	1,200 µg/L	7/17/89	SDF, 0–2’ depth	1	
Barium	W	1,000 µg/L	1,850 µg/L	7/17/89	SDF, 2–2.5’ depth	1	
TCE	W	5 µg/L	450 µg/L	9/12/89	GW: RD-21	3	90x > MCL
Carbon tetrachloride	W	0.5 µg/L	4 µg/L	9/12/89	GW: RD-21	1	8x > MCL
Manganese	W	50 µg/L	450 µg/L	9/13/89		2	
Trans,1,2-DCE	W	10 µg/L	15 µg/L	9/13/89	GW: RD-23	1	
TCE	W	5 µg/L	180 µg/L	9/13/89	GW: RD-23	1	36x > MCL
Benzene	W	1 µg/L	2 µg/L	9/13/89	RD-23	4	
Carbon tetrachloride	W	0.5 µg/L	7 µg/L	10/20/89	GW: RD-21	1	14x > MCL
Carbon tetrachloride	W	0.5 µg/L	5 µg/L	10/20/89	GW: RD-21	1	10x > MCL
Carbon tetrachloride	W	0.5 µg/L	5 µg/L	10/20/89	GW: RD-21	1	10x > MCL
TCE	W	5 µg/L	1,200 µg/L	10/20/89	GW: RD-21	1	240x > MCL
TCE	W	5 µg/L	940 µg/L	10/20/89	GW: RD-21	1	188x > MCL
TCE	W	5 µg/L	750 µg/L	10/20/89	GW: RD-21	1	150x > MCL
TCE	W	5 µg/L	200 µg/L	10/20/89	GW: RD-23	3	40x > MCL
1,2-DCA	W	0.5 µg/L	5 µg/L	10/20/89	GW: RD-23	1	10x > MCL
TCE	W	5 µg/L	1,800 µg/L	12/11/89	GW: RD-21	1	360x > MCL
TCE	W	5 µg/L	80 µg/L	12/11/89	GW: RD-23	1	
Carbon tetrachloride	S	0.25 mg/kg	500 mg/kg	1990	Lower Pond soil by SDF	1	Sampled by RWQCB; last delivery to pond 1972

Chemical	Phase	Standard	Concentration	Date	Location/Sample Identification	Ref	Comments
Ethyl benzene	S	8.9 mg/kg	44–171 mg/kg	1990	Lower Pond soil by SDF	1	‘’
Toluene	S	520 mg/kg	5.4–3,000 mg/kg	1990	Lower Pond soil by SDF	1	‘’
1,1,1-TCA	S	1200 mg/kg	0.16–1,840 mg/kg	1990	Lower Pond soil by SDF	1	‘’
TCE	S	0.043 mg/kg	0.14–740 mg/kg	1990	Lower Pond soil by SDF	1	‘’
PCBs	S	0.22 mg/kg	1–2.6 mg/kg	1990	Lower Pond soil by SDF	1	‘’
Mercury	S	23 mg/kg	125 mg/kg	1990	Lower Pond soil by SDF	1	‘’
Arsenic	S	0.39 mg/kg	16.5 mg/kg	1/25/90	SDF, composite soil	1	
Arsenic	S	0.39 mg/kg	21.2 mg/kg	1/25/90	SDF, composite soil	1	
Arsenic	S	0.39 mg/kg	19.4 mg/kg	1/25/90	SDF, composite soil	1	
Chromium (total)	W	50 µg/L	300 µg/L	1/25/90	SDF, composite soil	1	
Chromium (total)	W	50 µg/L	200 µg/L	1/25/90	SDF, composite soil	1	
Lead	W	12 µg/L	5,700 µg/L	1/25/90	SDF, composite soil	1	
Lead	W	12 µg/L	300 µg/L	1/25/90	SDF, composite soil	1	
Lead	W	12 µg/L	500 µg/L	1/25/90	SDF, composite soil	1	
Mercury	S	23 mg/kg	125 mg/kg	1/25/90	SDF, composite soil	1	
Mercury	W	2 µg/L	5 µg/L	1/25/90	SDF, composite soil	1	
Vanadium	W	50 µg/L	400–500 µg/L	1/25/90	SDF, composite soil	1	
TCE	W	5 µg/L	38–200 µg/L	1/90–2/90	GW: RD-23	1	
TCE	W	5 µg/L	170–660 µg/L	1/90–2/90	GW: RS-18	1	
TCE	W	5 µg/L	450–1,900 µg/L	1/90–2/90	GW: RD-21	1	
1,1-DCE	W	6 µg/L	10 µg/L	3/27/90	GW: RS-18	1	
1,1-DCE	W	6 µg/L	9 µg/L	3/27/90	GW: RS-18	1	
TCE	W	5 µg/L	170 µg/L	3/27/90	GW: RS-18	1	34x > MCL
Cis-1,2-DCE	W	6 µg/L	21 µg/L	3/29/90	GW: RD-21	1	
1,2-DCA	W	0.5 µg/L	3 µg/L	4/6/90	GW: RD-23	1	
TCE	W	5 µg/L	38 µg/L	4/6/90	GW: RD-23	1	
1,2-DCE	W	0.5 µg/L	3 µg/L	4/6/90	RD-23	4	
1,1-DCA	W	5 µg/L	370–680 µg/L	5/13/97–8/18/99	RS-54	5	10 samples
1,1-DCE	W	6 µg/L	330–1,500 µg/L	5/3/97–8/18/99	RS-54	5	10 samples
1,1,1-TCA	W	200 µg/L	1,500–8,100 µg/L	5/3/97–8/18/99	RS-54	5	11 samples
TCE	W	5 µg/L	720–2,300 µg/L	5/3/97–8/18/99	RS-54	5	11 samples

Notes: Phase Designations: W = water; S = soil; A = air. **Location Designations:** SDF = Sodium Disposal Facility; GW = groundwater; RS-18 = Shallow Zone well, NW Area IV, near NW boundary of site, Building 886; RD-21 = GW from Chatsworth Formation, NW Area IV, S of Building 886; RD-23 = GW NW Area IV, W of Building 886. **Comments:** IDM = insensitive detection method; RSSL = Residential Soil Screening Level, EPA Region 9; MCL = maximum contaminant level. **References:** ***1.*** GRC, 1990a. ***2.*** Rocketdyne, NPDES Annual Reports, various years. ***3.*** Boeing, 2002. ***4.*** Rocketdyne, 1995. ***5.*** GRC, 2000.

Table H-4. Offsite South: Ahmanson Ranch, Bell Canyon, Bell Creek and ^{2}NPDES Outfalls 001 and 002, 1993–2003

Chemical	**Phase**	**Standard**	**Concentration**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
Chromium	W	50 µg/L	75 µg/L	1/28/93	NPDES Outfall 002	2	
Pentachlorophenol	W	1 µg/L	<20 µg/L	1/94	NPDES Outfall 002	2	IDM
Nitrosodimethylamine	W	0.02 µg/L	<2 µg/L	1/25/94	NPDES Outfall 002	2	IDM—hydrazine byproduct
Hexachlorobenzene	W	1 µg/L	<3 µg/L	1/94–4/94	NPDES Outfall 002	2	IDM (10 tests)
2,4,6-Trichlorophenol	W	0.34 µg/L	<10 µg/L	1/94–4/94	NPDES Outfall 002	2	IDM (6 tests)
Pentachlorophenol	W	1 µg/L	<20 µg/L	2/94–6/6/94	NPDES Outfall 002	2	IDM (5 tests)
N-Nitrosodimethylamine	W	0.01 µg/L	<2 µg/L	7/11/94–8/2/94	NPDES Outfall 002	2	IDM
Nickel	W	100 µg/L	130 µg/L	12/6/94	NPDES Outfall 002	2	
N-Nitrosodimethylamine	W	0.01 µg/L	<2 µg/L	1/3/95–12/23/95	NPDES Outfall 002	2	IDM (19 tests)
Dieldrin	W	0.01 µg/L	< 0.1 µg/L	1/3/95–4/19/95	NPDES Outfall 002	2	IDM (8 tests)
Lead	W	12 µg/L	40 µg/L	1/9/95	NPDES Outfall 001/ Perimeter Pond	2	
Heptachlor	W	0.01 µg/L	>0.01 µg/L	3/10/95 and 3/21/95	NPDES Outfall 002	2	Concentration over standard not quantified
Pentachlorophenol	W	1 µg/L	<20 µg/L	3/10/95–5/15/95	NPDES Outfall 002	2	IDM (5 tests)
Heptachlor	W	0.01 µg/L	>0.01 µg/L	3/21/95	NPDES Outfall 002	2	
Beryllium	*S*	*150 mg/kg*	*500–1,000 mg/kg*	*8/6/96*	*Bell Canyon* *0.5–1.0’ depth*	*3*	*3-6x> RSSL*
Hexachlorobenzene	W	1 µg/L	<3 µg/L	3/95–1/97	NPDES Outfall 001	2	IDM (6 tests)
Pentachlorophenol	W	1 µg/L	<3 µg/L	12/96–1/97	NPDES Outfall 001	2	IDM (10 tests)
Arsenic	*S*	*0.39 mg/kg*	*14 mg/kg*	*1998*	*Bell Canyon along surface runoff*	*4*	*Residential area*
Arsenic	*S*	*0.39 mg/kg*	*8 mg/kg*	*1998*	*Bell Canyon along Bell Creek*	*4*	*Residential area*
Arsenic	*S*	*0.39 mg/kg*	*9 mg/kg and 14 mg/kg*	*1998*	*Unidentified Bell Canyon resident yards*	*4*	*Residential area;* *2 samples*
Arsenic	S	0.39 mg/kg	1 mg/kg	10/30/98	Las Virgenes Creek @ Sheen	3	
Arsenic	*S*	*0.39 mg/kg*	*3 mg/kg*	*10/30/98*	*Las Virgenes Creek @ Bell Canyon*	*3*	
Lead	S	150 mg/kg	383 mg/kg	6/7/99	Bell Canyon	1	Residence

Notes:
Phase Designations: W = water; S = soil; A = air.
Comments: IDM = insensitive detection method; RSSL = Region 9 Residential Soil Screening Level.
References: ***1.*** CA EPA, 2000. ***2.*** Boeing, 1990–2003. ***3.*** Masry and Vititoe, 1998. ***4.*** Ogden, 1998,Figure 4. Environmental and Energy Services, 10/05/98.

Table H-5. Offsite East: Woolsey and Dayton Canyons and Chatsworth, 1994–2003

Chemical	**Phase**	**Standard**	**Concentration**	**Date**	**Location/Sample Identification**	**Reference**	**Comments**
Manganese	*W*	*50 µg/L*	*390 µg/L*	*3/94*	*RD-32*	*1*	*Northeast (Sage Ranch)*
Manganese	*W*	*50 µg/L*	*35 mg/L*	*?*	*2N/17R-21R2*	*2*	*Northeast Chatsworth Mutual Water Co. owner*
Lead	W	12 µg/L	50 µg/L	12/94	RD-43	1	East (Woolsey Canyon)
Lead	*W*	*12 µg/L*	*59–2,239 µg/L*	*3/24/04*	*B-4W; B-3W*	*3*	*Chatsworth Reservoir*
Arsenic	*W*	*50 µg/L*	*72.7–3,217 µg/L*	*3/24/04*	*B-4W; B-3W*	*3*	*Chatsworth Reservoir*
Beryllium	*W*	*4 µg/L*	*7–123 µg/L*	*3/24/04*	*B-4W; B-3W*	*3*	*Chatsworth Reservoir*
Perchlorate	*V*	*20 mg/kg*	*32–57 mg/kg*	*6/20/05*	*Dayton Canyon Creek*	*4*	*Leaves and plant debris*

Notes:

Phase Designations: W = water; S = soil; A = air; V = vegetation.

Location Designations: RD-32, 43A = Sage Ranch and Woolsey Canyon Wells, respectively.

Comments: AAQS = Ambient Air Quality Standards; IDM = insensitive detection method.

References: ***1.*** CHDS, 1999. ***2.*** Ventura County Public Works, Water Resources Dept. Well Data Files. ***3.*** DWP, 2004. ***4.*** Allwest Remediation, Inc, 2005.

Table H-6. Offsite North: BBI, SMMC, NPDES Outfalls 003–008 and Simi Valley, 1986–2003

Chemical	**Phase**	**Standard**	**Concentration**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
Chloromethane	*W*	*1.5 µg/L*	*19 µg/L*	*4/10/86*	*OS-5*	*2*	*12x > TWSL; livestock well*
Chloride	W	0.15 µg/L	7,000 µg/L	1/13/90	SBP1—NPDES	2	NPDES analysis
Chloride	W	0.15 µg/L	6,000 µg/L	1/13/90	SBP2—Outfall 006	2	
Bis(2-ethylhexyl) phthalate (DEHP)	*W*	*6 µg/L*	*66 µg/L*	*1/13/90*	*SBP1*	*2*	*Surface water*
Bis(2-ethylhexyl) phthalate (DEHP)	*W*	*6 µg/L*	*109 µg/L*	*1/13/90*	*SBP2*	*2*	*Surface water; EPA priority analysis*
Chloride	W	0.15 µg/L	8,000 µg/L	1/17/90	SBP1	2	NPDES analysis
Bis(2-ethylhexyl) phthalate (DEHP)	*W*	*6 µg/L*	*170 µg/L*	*1/17/90*	*SBP1*	*2*	*Surface water*
Fluoride	W	2,000 µg/L	4,600–5,400 µg/L	1/90–2/90	OS-2	1	Livestock Well
Chloride	W	0.15 µg/L	3,500 µg/L	2/17/90	SBP2	1	
Bis(2-ethylhexyl) phthalate (DEHP)	*W*	*6 µg/L*	*70 µg/L*	*2/17/90*	*SBP1*	*1*	*Surface water*
Bis(2-ethylhexyl) phthalate (DEHP)	*W*	*6 µg/L*	*97 µg/L*	*2/17/90*	*SBP2*	*1*	*Surface water; EPA priority analysis*

Chemical	**Phase**	**Standard**	**Concentration**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
TCE	*W*	*5 µg/L*	*10 µg/L*	*3/11/92*	*SMMC: well by gate*	*1*	
Lead	S	150 mg/kg	280 mg/kg	1992	SMMC by shooting range	1	
Arsenic	*S*	*0.39 mg/kg*	*24 mg/kg*	*1992*	*BBI*	*1*	*61.5x>SSL*
Arsenic	*S*	*0.39 mg/kg*	*8.2 mg/kg*	*1992*	*SMMC*	*1*	
Residual chlorine	W	0.1 to 0.01 mg/L	44 mg/L	2/8/93	Outfall 006	5	SBP2
Residual chlorine	W	0.1 to 0.01 mg/L	129 mg/L	2/18/93	Outfall 006	5	SBP2
Residual chlorine	W	0.1 to 0.01 mg/L	100 mg/L	2/26/93	Outfall 006	5	SBP2
Residual chlorine	W	0.1 to 0.01 mg/L	91 mg/L	3/25/93	Outfall 006	5	SBP2
PCB-1254	*W*	*0.5 µg/L*	*120 µg/L*	*2/4/94*	*Outfall 005*	*7*	*240x>MCL*
PCB-1254	*W*	*0.5 µg/L*	*92 µg/L*	*2/4/94*	*Outfall 006*	*7*	*184x>MCL*
Lead	W	12 µg/L	210 µg/L	2/17/94	Outfall 003	5	14x>MCL
Vinyl chloride	*W*	*0.5 µg/L*	*64 µg/L*	*3/94*	*RD-56A*	*6*	*128x>MCL*
TCE	*W*	*5 µg/L*	*670 µg/L*	*8/94*	*RD-38A*	*6*	*134x> MCL*
Benzene	*W*	*1 µg/L*	*3.8 µg/L*	*11/94*	*RD-38A*	*6*	
Carbon tetrachloride	*W*	*0.5 µg/L*	*4.5 µg/L*	*2/95*	*RD-59A*	*6*	*>9x MCL; northwest (west of Area IV RMDF)*
Lead	W	12 µg/L	30 µg/L	1/3/95	Outfall 006	5	
Beryllium	*W*	*4 µg/L*	*8 µg/L*	*5/15/95*	*Outfall 006*	*5*	
Chromium (total)	W	100 µg/L	240 µg/L	5/15/95	Outfall 006	5	
Lead	W	12 µg/L	45 µg/L	5/15/95	Outfall 005	5	
Benzene	*W*	*1 µg/L*	*5.6 µg/L*	*5/15/95*	*Outfall 005*	*5*	
Lead	W	12 µg/L	16 µg/L	5/15/95	Outfall 003	5	
Lead	W	12 µg/L	45 µg/L	5/15/95	Outfall 003	5	
Lead	W	12 µg/L	75 µg/L	5/15/95	Outfall 006	5	
Nickel	W	100 µg/L	170 µg/L	5/15/95	Outfall 006	5	
Beryllium	*W*	*4 µg/L*	*5 µg/L*	*1/31/96*	*Outfall 006*	*5*	
Lead	W	12 µg/L	47 µg/L	1/31/96	Outfall 006	5	
Cadmium	W	3.7 µg/L	5 µg/L	1/31/96	Outfall 006	5	
Zinc	W	110 µg/L	420 µg/L	1/31/96	Outfall 006	5	
1,1-DCE	*W*	*6 µg/L*	*19 µg/L*	*5/96*	*RD-38A*	*6*	
Trans-1,2-DCE	W	10 µg/L	38 µg/L	5/96	RD-56A	6	
1,1-DCA	W	5 µg/L	6.5 µg/L	11/96	RD-38A	6	
Cis-1,2-DCE	*W*	*6 µg/L*	*27 µg/L*	*11/96*	*RD-38A*	*6*	

Chemical	Phase	Standard	Concentration	Date	Location/Sample Identification	Ref	Comments
TCE	*W*	*5 µg/L*	*250–570 µg/L*	*8/9/95–2/2/97*	*RD-38A (NE of Area I Offsite, Sage Ranch)*	*8*	*9 samples*
Perchlorate	W	4 µg/L	5 µg/L	8/98	RD-59A	6	Northwest (west of Area IV RMDF)
Perchlorate	W	2 µg/L	4.26 µg/L	5/5/98	Outfall 006	6	
TCE	*W*	*5 µg/L*	*130–570 µg/L*	*8/7/97–8/18/99*	*RD-38A (NE of Area I Offsite, Sage Ranch)*	*8*	*6 samples*
Cis-1,2-DCE	*W*	*6 µg/L*	*75–630 µg/L*	*3/18/84–2/4/99*	*RD 56 A N of Area III*	*8*	*19 samples*
Trans-1,2-DCE	W	10 µg/L	22–82 µg/L	3/18/84–2/4/99	RD 56 A N of Area III	8	18 samples
TCE	*W*	*5 µg/L*	*330–900 µg/L*	*3/18/84–2/4/99*	*RD 56 A N of Area III*	*8*	*19 samples*
Perchlorate	*W*	*2 µg/L*	*4–19 µg/L*	*1999*	*Simi Valley*	*9*	*15/66 wells positive for perchlorate*
Perchlorate	W	2 µg/L	<500 µg/L	3/8/2000	Outfall 003	6	IDM
Perchlorate	W	2 µg/L	<500 µg/L	3/8/2000	Outfall 004	6	IDM
Perchlorate	W	2 µg/L	<500 µg/L	3/8/2000	Outfall 006	6	IDM
Perchlorate	W	2 µg/L	<500 µg/L	3/8/2000	Outfall 007	6	IDM
Perchlorate	*W*	*2 µg/L*	*34–150 µg/L*	*2/12/2003*	*Bathtub Well #1, BBI*	*4*	*Livestock well (closed)*
Perchlorate	*W*	*2 µg/L*	*50–60 µg/L*	*2003*	*Runckle Canyon Development*	*10*	*DTSC update*

Notes:

Phase Designations: W = water; S = soil; A = air.

Location Designations: SMMC = Santa Monica Mountains Conservancy; OS-2-5 = offsite wells used for livestock NW of SSFL at BBI; RD 56A, RD-38A = SSMC wells; RD-59A; BBI = Brandeis-Bardin Institute.

Comments: IDM = insensitive detection method; SSL = soil screening level; AAQS = Ambient Air Quality Standards; TWSL = Region 9 Tap Water Screening Level.

References: ***1.*** McLaren/Hart, 1993, Vol. 2. ***2.*** GRC, 1990a. ***3.*** CDHS, 1999. ***4.*** Ogden, 1995. ***5.*** Rocketdyne, NPDES Annual Reports, various years. ***6.*** Boeing, 2002. ***7.*** Rocketdyne, 1995. ***8.*** GRC, 2000. ***9.*** DTSC Fact Sheet. Update on Perchlorate Investigation in Simi Valley, 9/2003. ***10.*** DTSC Public Meeting, July 15, 2003.

Table H-7. Radiological Contaminants, Onsite (Area IV): Sodium Disposal Facility, Radioactive Material Disposal Facility and NPDES Outfalls 003–008: 1988–2003

Radionuclide	Phase	Standard or Background	Concentration	Date	Location/Sample Identification	Ref	Comments
Gross beta	S	[1]25 pCi/g*	59±6.3 to 4970±176.9	8/25/88	RMDF Leachfield	3	6 samples
Gross alpha	W	15 pCi/L	27.6 ±8.4 pCi/L	6/4/89	RS-18	3	UF
Gross beta	W	50 pCi/L	56.1 ±0.5 pCi/L	9/12/89	RS-25	3	F
Gross alpha	W	15 pCi/L	29.9±3.0 pCi/L	9/20/89	RD-29		F
Gross alpha	W	15 pCi/L	42.3 ±7.5 pCi/L	9/27/89	RS-28	3	UF
Gross beta	W	50 pCi.L	49.3 ±1.3 pCi/L	9/27/89	RS-28	3	F

Notes: Background concentration (GRC, 1990c).
Phase Designations: W = water; S = soil; A = air. **Location Designations:** RMDF = Radioactive Materials Disposal Facility
Comments: IDM = insensitive detection method; RSSL = Residential Soil Screening Level, EPA Region 9; MCL = maximum contaminant level; UF = unfiltered groundwater; F = filtered groundwater; NE = not established; RS = shallow wells; RD = deep wells. **References:** ***1.*** NPDES Annual Monitoring Reports. ***2.*** EPA, 2000. ***3.*** GRC, 1990b.

Table H-8. Radiological Contaminants, Offsite South: Ahmanson Ranch, Bell Canyon, Bell Creek, and NPDES Outfalls 001 and 002: 1993–2003

Chemical	Phase	Standard or Background*	Maximum Concentration	Date	Location/Sample Identification	Ref	Comments
Radium Combined (226/228)	W	5 pCi/L	<500 pCi/L	2/8/93	NPDES Outfall 002	3	IDM
Thorium-228	S	0.38 pCi/g*	1.8 pCi/g	1998	Bell Canyon	4	
Thorium-230	S	3.49 pCi/g	1.4 pCi/g	1998	Bell Canyon	4	
Thorium-232	S	0.37 pCi/g*	1.5 pCi/g	1998	Bell Canyon	4	
Tritium	S	0.01 pCi/g	0.36 pCi/g	1998	Bell Canyon	4	
Uranium-233/234	S	15 pCi/g	1 pCi/g	1998	Bell Canyon	4	
Uranium-235	S	0.205 pCi/g	0.07 pCi/g	1998	Bell Canyon	4	
Uranium-238	S	4.46 pCi/g	1.1 pCi/g	1998	Bell Canyon	4	
Potassium-40	S	12.9 pCi/g*	8.3–23 pCi/g	1/27/00	Ahmanson Ranch—0.5’ deep	*2*	
Cadmium-109	S	NE	1.5–2.8 pCi/g	1/27/00	Ahmanson Ranch—0.5’ deep	2	
Radium-226	S	5 pCi/g[#]	0.82–2.2 pCi/g	1/27/00	Ahmanson Ranch—0.5’ deep	2	
Thorium-228	S	0.38 pCi/g*	0.5–0.90 pCi/g	1/27/00	Ahmanson	2	

Chemical	**Phase**	**Standard or Background***	**Maximum Concentration**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
					Ranch—0.5' deep		
Thorium-232	S	0.37 pCi/g*	0.54–0.97 pCi/g	1/27/00	Ahmanson Ranch—0.5' deep	2	
Cesium-137	S	0.11 pCi/g*	ND–0.32 pCi/g	1/27/00	Ahmanson Ranch—0.5' deep	2	4 of 6 samples positive
Total Alpha	W	15 pCi/L	33.39 pCi/L	6/02–8/02	MW P3	1	
Total Alpha	W	15 pCi/L	28.03 pCi/L	6/02–8/02	MWP6	1	
Total Alpha	W	15 pCi/L	72.34 pCi/L	9/02–11/02	MW P1	1	
Total Alpha	W	15 pCi/L	28.3 pCi/L	9/02–11/02	MW P2	1	
Total Alpha	W	15 pCi/L	15.81 pCi/L	9/02–11/02	MW P3	1	
Total Alpha	W	15 pCi/L	28.54 pCi/L	9/02–11/02	MW P5	1	
Total Alpha	W	15 pCi/L	18.78 pCi/L	9/02–11/02	MW P6	1	

Notes: ND = not detected;*=Background samples; #=DHS-based health comparisons. **Phase Designations:** W = water; S = soil; A = air. **Location Designations:** MW = monitoring wells at Las Virgenes Creek and East Las Virgenes Creek in Ahmanson Ranch. **Comments:** IDM = insensitive detection method. **References:** ***1.*** PSOMAS, 2003. ***2.*** Klinefelder, 2000. ***3.*** NPDES Reports. ***4.*** Ogden Inc., 1998a.

Table H-9. Radiological Contaminants, Offsite North: Brandeis-Bardin Institute, Santa Monica Mountains Conservancy, Canoga Park and NPDES Outfalls 003–008, 1949–2003

Chemical	**Phase**	**Standard or Background***	**Concentration or Range**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
Cesium-137	S	0.11 pCi/g*	0.23 pCi/g	1992	BB-17 above Building 59 watershed at BBI	2	
Cesium-137	S	0.11 pCi/g*	0.23 pCi/g	1992	BB-19 above SRE watershed at BBI	2	
Cesium-137	S	0.11 pCi/g*	0.34 pCi/g	1992	BB-16 in RMDF watershed at BBI	2	
Cesium-137	S	0.11 pCi/g*	0.2–0.3 pCi/g	1992	BB-19 above SRE watershed at BBI	2	2 samples
Plutonium-238	S	0.02 pCi/g*	0.19 pCi/g	1992	BB-17 above Building 59 watershed at BBI	2	
Plutonium-238	S	0.02 pCi/g*	0.22 pCi/g	1992	BB-15 above RD-51 watershed at BBI	2	Currently in buffer zone
Radium (total 226 and 228)	W	5 pCi/L	15±25 pCi/L	12/29/92	Outfall 004	3	
Strontium-90	W	8 pCi/L	<500 pCi/L	12/29/92	Outfall 004	3	IDM
Strontium-90	W	8 pCi/L	9.4±3 pCi/L	1/7/93	Outfall 006	3	
Radium (total 226 and 228)	W	5 pCi/L	23±2.3 pCi/L	12/14/93	Outfall 003	3	

Chemical	**Phase**	**Standard or Background***	**Concentration or Range**	**Date**	**Location/Sample Identification**	**Ref**	**Comments**
Cesium-137	S	0.11 pCi/g*	0.60 pCi/g	1993	RMDF watershed at BBI	2	
Cesium-137	S	0.11 pCi/g*	0.22–0.39 pCi/g	1994	BB-17 above Building 59 watershed at BBI	2	8 samples
Strontium-90	W	8 pCi/L	8±11 pCi/L	1/4/95	Outfall 003	3	IDM
Strontium-90	W	8 pCi/L	5.1 ± 5.7 pCi/L	1/10/95	Outfall 003	3	IDM
Radium (total 226 and 228)	W	5 pCi/L	3.6±2.8 pCi/L	2/14/95	Outfall 004	3	
Radium (total 226 and 228)	W	5 pCi/L	3.4±3.8 pCi/L	3/21/95	Outfall 004	3	
Cesium-137	S	0.11 pCi/g*	0.016–0.27 pCi/g	6/97	Canoga Park SSFL Recreation Center (Lawn from NE build)	1	
Gross alpha	W	15 pCi/L	14±4 pCi/L	3/14/98	Outfall 005	3	

Notes: * Background samples. If water is not used for drinking purposes or soil was not in residential or agricultural areas, then health-based environmental standards for radionuclides developed by the Nuclear Regulatory Commission were used (10 CFR). These are concentrations of radioactive material released in groundwater, surface water, air, soil, plants, or animals that do not exceed an annual dose equivalent of 25 mrem whole body (75 mrem max to thyroid, and 25 mrem max to any other organ).

Phase Designations: W = water; S = soil; A = air; **Location Designations:** BBI = Brandeis-Bardin Institute.

References: ***1.*** Lawrence Livermore National Laboratory, 1997. ***2.*** McLaren/Hart, 1993 and 1995. ***3.*** NPDES Annual Monitoring Reports.

Appendix I. Air Dispersion Modeling

I-1. Modeling Approach

Given the objectives of this study and the availability of onsite meteorological data formatted for the Industrial Source Complex (ISC) model, two models were considered candidates for this study: the ISC model (EPA, 1995) and the CALPUFF model (Scire et al., 1995). ISC is a straight-line Gaussian plume model recommended in EPA's "User's Guide for the Industrial Source Complex (ISC3) Dispersion Models" Guideline on Air Quality Models" (EPA, 1995c) for use in simple terrain settings. CALPUFF is a Gaussian puff dispersion model that has been formulated to provide a more refined estimate of air quality impacts than ISC in areas of complex terrain and meteorology. CALPUFF is more accurate than the ISC model in areas of complex meteorology as over multiple hours of transport CALPUFF uses each hour of wind to develop a curved, as opposed to the ISC straight-line, transport. This hour-by-hour treatment of transport in CALPUFF results in a better estimate of where SSFL emissions are expected to have repeated high concentrations and areas with relatively insignificant concentration impacts are located.

I-2. Model Description

CALPUFF is a non-steady-state puff dispersion model that can simulate the effects of time- and space-varying meteorological conditions on pollutant transport, transformation, and removal. CALPUFF can use single-station hourly varying winds or hourly varying complex three-dimensional meteorological fields. CALPUFF accounts for vertical wind shear, over water transport, and coastal interaction effects. CALPUFF contains algorithms for near-source effects such as building downwash, transitional plume rise, partial plume penetration, and subgrid scale terrain interactions. CALPUFF contains algorithms for longer range effects such as chemical transformation and pollutant removal (wet scavenging and dry deposition).

CALPUFF uses a Gaussian dispersion treatment recommended in EPA modeling guidance for simple terrain settings. CALPUFF treats arbitrarily-varying point source and gridded area-source emissions. CALPUFF considers point sources (buoyant or otherwise), area sources, line sources, and volume sources. Locations are specified separately for each source. Pasquill-Gifford dispersion coefficients are used for rural applications, and McElroy-Pooler dispersion coefficients are applied in urban applications. Plume rise is calculated for point sources according to Briggs' formulas for buoyant or momentum-dominated sources.

In the CALPUFF model, receptors can be specified in an organized polar or rectangular grid or as discrete receptor locations. Meteorological data are input as hourly averages. Ambient concentrations are output for short-term (1-hour) periods and post-processing is performed to obtain long-term (annual or multi-annual) averages. Model input data for CALPUFF include source characteristics, meteorological data, and topographical data.

I-3. Receptors

The CALPUFF model requires input of receptor coordinates at which to predict ambient air impacts. To allow concentrations to be estimated for 50 kilometers in all directions from the

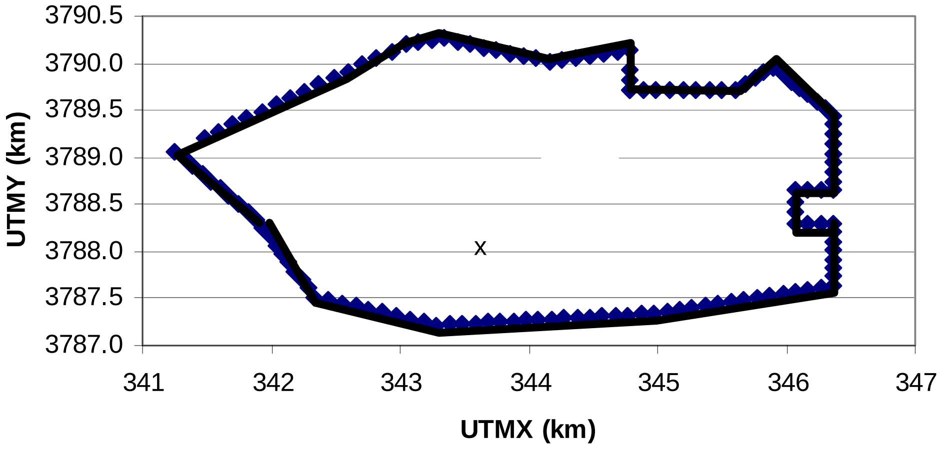
SSFL facility, receptors were specified for a grid of 101 (west to east) by 101 (south to north) points spaced at 1,000-meter intervals and centered over the SSFL facility. Figure 3-2 shows the area covered by these 10,201 receptors. The southwest corner receptor has a UTM Easting (UTM X) of 295000 m and a UTM Northing (UTM Y) of 3739000 m. These UTM coordinates are for UTM Zone 11 and for the North American Datum of 1983 (NAD83), which is an earth-centered datum based on the Geodetic Reference System of 1980.

Figure I-1a. Area Covered by the CALPUFF Receptors

Note: There are 10,201 receptors in the area, spaced at 1,000-meter intervals.

To provide better near field spatial coverage, **Figure I-1b** depicts an additional set of receptors spaced about 100-m a part that were developed and located along the SSFL property line.

Figure I-1b. Near field receptor coverage for CALPUFF modeling. The 138 near field receptors are along the SSFL property boundary and spaced about 100-m apart.



I-4. Model Options

The CALPUFF model was set to perform elevated terrain modeling; that is, receptors were assigned elevations other than the base elevation for the facility. Building downwash is a complex technical subject that has important ramifications in the field of air quality dispersion modeling. Essentially, as wind blows over building structures, a wake effect is created that can extend out to a distance of five times the minimum of the building height or perpendicular building width. This wake effect can influence the vertical extent to which stack emissions rise into the atmosphere.

I-5. Topographic Data

The National Cartographic Information Center (NCIC) distributes several types of digital elevation data sets produced by the U.S. Geographical Survey. These digital cartographic data consist of Digital Elevation Models (DEM), which are digital records of terrain elevations for ground positions at regularly spaced horizontal intervals produced as part of the National Mapping Program. Two distinct digital elevation data sets are available from the NCIC. The is the 1-degree DEM, a 1-by-1-degree block that provides the same coverage as half of a standard 1:250,000 scale map. Two 1-degree blocks are required to cover the entire area of a 1:250,000 series map. The second data set is the 7.5-minute DEM, which provides the same coverage as a 1:24,000 scale map. The 1-degree DEM data were used in this study.

The 1-degree DEM is produced by the Defense Mapping Agency and distributed by the NCIC. These data sets are available for most areas of the United States. The data format consists of elevations spaced at regular intervals of three arc-seconds and referenced by the geographic coordinate system (latitude/longitude). Three arc-seconds represent approximately 79 meters at 32 degrees latitude, the approximate latitude of the site. The 1-degree DEM data were analyzed to determine the elevation of receptors for this study.

I-6. Meteorological Data

I-6.1 Overview

Preprocessed ISC-ready meteorological data files prepared by Trinity Consultants were provided by Boeing. The meteorological data period begins January 1, 1994, and extends through December 31, 1997 (see Section 3.1.3). The files are based on surface meteorological data for 1994 through 1997, collected on-site at the SSFL in Area IV. The meteorological data include wind speed, wind direction, and temperature data. An upper-air data set was used principally to assign hourly mixing heights (rural and urban) within the ISC meteorological data files. The headers in the preprocessed files indicate that upper-air data from Miramar Naval Air Station (NKX) near San Diego were used. While the upper-air site at Los Angeles International Airport (LAX) is closer, LAX is located at the coast, while both SSFL and NKX are located on mesas inland from the coast and likely have similar mixing heights.

I-6.2 Long-Term Climatology

Climatological data from 1948 to 2003 were reviewed to determine whether the 1994–1997 meteorological data period used in this air quality analysis was representative of the longer time period during which SSFL operated. Precipitation measurements from a nearby site available from the Climate Diagnostic Center (CDC) reanalysis project were used in this analysis (http://www.cdc.noaa.gov/cdc/reanalysis).

The geopotential height at 500 mb and the temperature at 850 mb are used as indicators of stagnation. Periods with higher 500-mb height and higher 850-mb temperatures are often associated with lower wind speeds and less vertical mixing. Time series plots of monthly mean 850-mb heights and 850-mb temperatures for the years 1948 through 2003 were generated on the Climate Diagnostic Center’s reanalysis project Web site for a 4 square degree area over southern California.

The time-series of monthly mean 500-mb geopotential heights is shown in Figure I-2, and the time series of monthly mean 850-mb temperatures appears in Figure I-3. In general, the years 1994 through 1997 appear to have experienced higher 500-mb heights and 850-mb temperatures than normal for the entire 1948–2003 period. However, none of the monthly mean values are extremes for the period. While the 1994–1997 period may have been slightly more stagnant than typical for the full historical period analyzed, it is reasonably representative of what occurred meteorologically during historical operations at the SSFL.

The site with long-term annual precipitation totals nearest the SSFL station is located at Canoga Park, California, which is about 15 kilometers southeast of the SSFL. Given its proximity to SSFL, there is good reason to believe that precipitation measurements recorded in Canoga Park can be relied upon to describe the associated historical pattern of precipitation at SSFL. In Section 3’s Figure 3-8, which depicts the annual rainfall totals recorded by year at Canoga Park from 1948 to 2002, large squares identify rainfall totals for 1994 to 1997, and smaller diamonds identify rainfall totals in other years from 1949 to 2002.

The annual average rainfall from 1949 to 2002 was 16.2 inches, only 10 percent less than the annual average rainfall of 17.9 inches from 1994 to 1997. The standard deviation of the annual average rainfall from 1949 to 2002 was 9.1 inches, only 13 percent greater than the standard deviation of the annual average rainfall of 8.0 inches from 1994 to 1997. Since the Canoga Park rainfall statistics (annual average and standard deviation) for the longer-term time period of interest (1948-2002) and the 1994–1997 meteorological time period are similar, the meteorological data relied on in this air quality analysis (from 1994 to 1997) appear likely to be representative of the longer-term period of interest. It is also noted that review of climatological data suggests that the meteorological data for 1994 through 1997 are reasonably representative of the period of historical operations at the SSFL. The 500-mb height and 850-mb temperature data suggest that conditions in that period may have been more stagnant than typical. Therefore, the modeling results may be slightly conservative.

Figure I-2. Monthly Mean 500-mb Geopotential Heights for 1948–2003 over Southern California

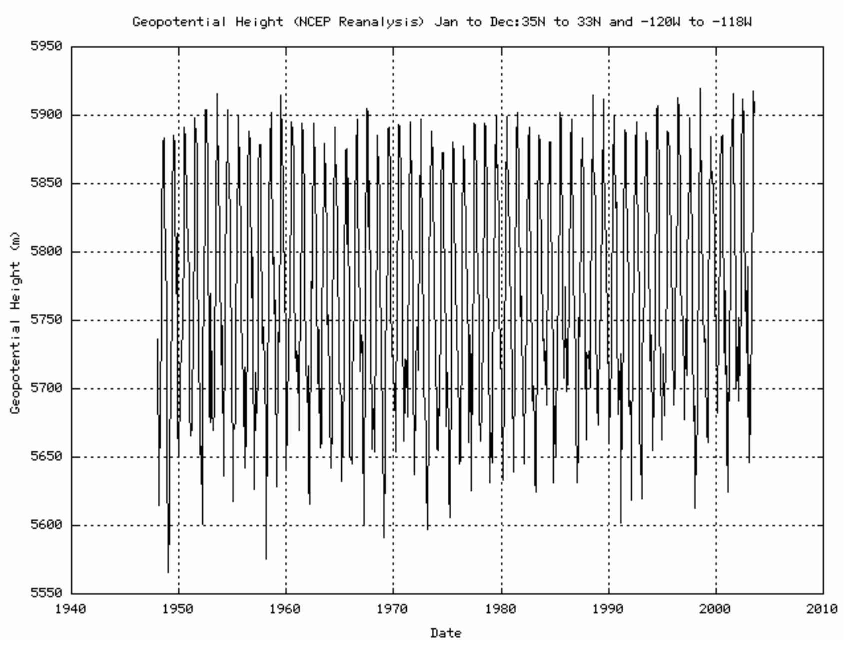
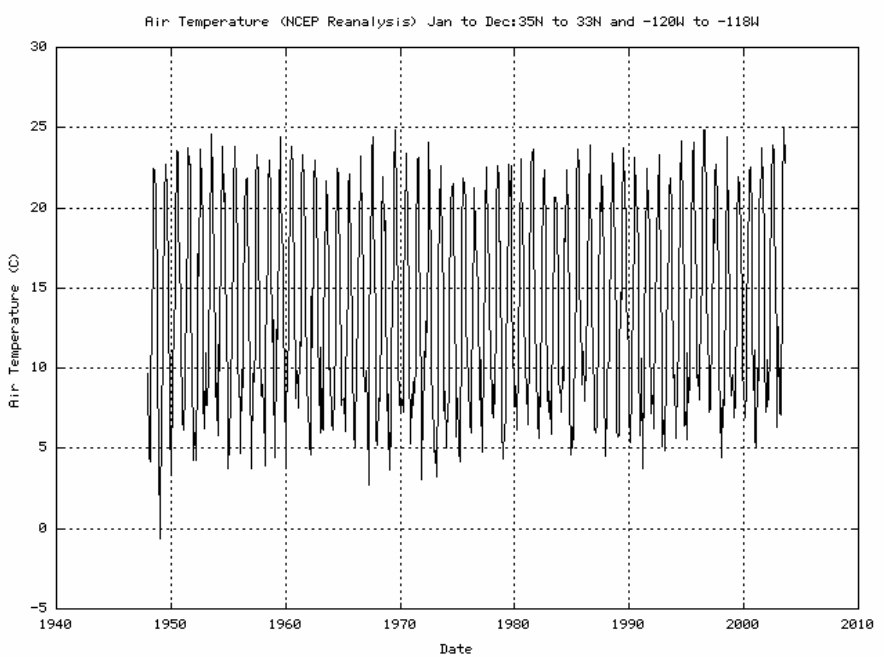


Figure I-3. Monthly Mean 850-mb Temperatures for 1948–2003 over Southern California



I-6.3 On-Site Wind Data Differences

During a number of site visits to SSFL the study team members personally observed wind directions in Areas II and III that were generally consistent with those in Area IV. In addition, winds observed during one site visit in a portion of Area I varied from those observed in Areas II, III and IV. Comparison of the available Area I and Area IV wind data revealed that the Area I site wind directions are at times rotated about 22 degrees counterclockwise from those recorded in Area IV, which is consistent with directional differences in the slope of the terrain at each location. It is believed that the terrain ridge west of Area I is a cause of this wind direction difference. This difference in Area I and Area IV wind direction is believed to have occurred during hours dominated by upslope and downslope flows. Upslope and downslope flows dominate when a weak synoptic weather pattern is present. A symptom of a weak synoptic weather pattern is surface flows with low wind speeds. Because the surface winds at SSFL were less than 2 knots 25% of the time and less than 4 knots 45% of the time, this weak synoptic weather pattern leading to different wind directions in Area I compared with Area IV could have occurred at least 25%, and possibly as frequently as 45%, of the time at this site. This complex wind flow behavior was not considered in the modeling performed in this study. For this reason, when interpreting the modeling results presented, it is important to recognize that, when the above specific complex wind patterns exist, the concentration predictions from Area I emission sources may be about 22 degrees counterclockwise from those estimated due to the use of Area IV wind data.

I-7. Emissions Data

Between 1953 and 1961, over 8,000 tests on rocket engines were completed. During the 1970s and 1980s, the site was primarily used to test engines for the NASA space shuttle program. The SSFL site is used today to build and test engines for the Atlas and Delta projects.

Emissions at the SSFL facility have occurred directly from RETs, the evaporation of solvents used to clean the rocket engines (i.e., TCE), the subsequent operation of STs to remove TCE from the groundwater, and the TTF. A review of historical emissions at the SSFL (Chapter 3) indicated that RETs were performed in dozens of locations, there were at least 10 locations with STs, and one location held the TTF. For modeling purposes these locations were consolidated into eight RET sources (modeled both as point and area sources), six ST sources, and one TTF source (see Appendix S for a complete air emission inventory). These 15 consolidated sources are summarized in Table 3-3 in Section 3.

Because the objective of this study was to model potential exposure patterns, a daily average emission rate of 1 g/s was used for each source. Using this “unit emission rate” facilitates combining predicted ambient air impacts from the individual emission source types and allows the calculation of cumulative impacts over multiple years.

Because terrain downwash is possible, RET emissions exit horizontally from the test stands, and stack information for the STs was not available, emissions from all sources were conservatively modeled for dispersion purposes with no plume rise. The source parameters used to model the release of emissions from all point and area sources are provided in Table I-1.

Table I-1. Parameters Used to Model the Release of Point and Area Source Emissions from the SSFL Facility

Point Source Parameters	Area Source Parameters
Stack height = 0 m agl	Area dimensions = 100 m x 100 m
Stack temperature = 273 degrees K	Effective height = 0 m
Stack diameter = 1 m	Base elevation = 0 m agl
Stack exit velocity = 0 m/s	Initial sigma-Z = 0 m

Documentation was not available regarding the time of day at which RETs occurred and the subsequent cleaning of rocket engines using chlorinated hydrocarbons. Based on anecdotal evidence and safety considerations, it is believed that testing occurred almost exclusively during daylight and dusk periods. It is also believed that, for safety reasons, almost all engine tests were conducted the same day the engines were prepared for testing. The implication is that the number of engine tests performed increased from morning to dusk. This is considered the "best estimate" for the diurnal profile of RET emissions for this study.

Due to the lack of documentation, the exact diurnal timing of emissions from RETs is unknown. As a sensitivity study, the ambient impact of RET emissions was also determined assuming that this activity took place uniformly throughout the day and night. Figure I-4 illustrates the effect of the "best estimate" rocket engine emissions increasing with time during the day compared to the uniform emission sensitivity study that was conducted.

TCE emissions from groundwater stripping towers were treated as occurring uniformly throughout each day, because there is no reason to believe the towers operated only during daylight hours. The timing of open burn activities is unknown, but it is assumed that they would have occurred almost exclusively during daylight hours for safety reasons. Therefore, the most representative temporal pattern would be to uniformly distribute open burning emissions during daylight hours. Table I-2 shows the three diurnal profiles used to model emissions from RET, ST, and TTF sources.

Figure I-4. Diurnal Variations in Emissions Used to Study the Impacts from RET Sources

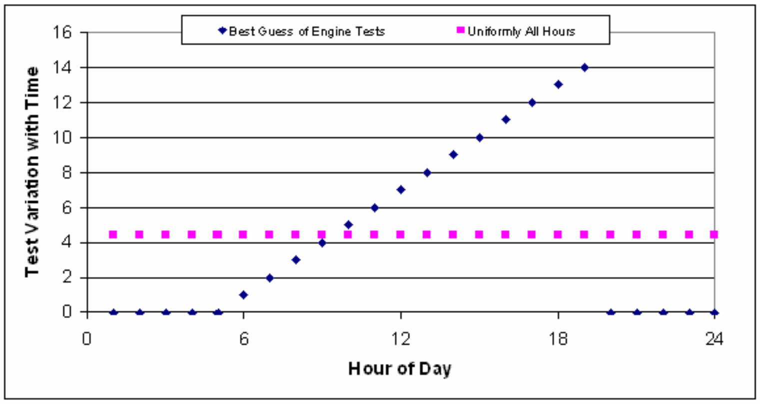


Table I-2. Diurnal Emission Profiles Used to Model and Study the Sensitivity of Ambient Impacts on the Timing of Emissions Released from the SSFL Facility.

Hour of the Day	**Diurnal Emission Profile (g/s)**		
	Daytime Increasing (Best Estimate for RET Sources)	**Uniform (Best Estimate for ST Sources; Sensitivity for RET Sources)**	**Daytime Only (Best Estimate for TTF)**
1	0	1.0	0
2	0	1.0	0
3	0	1.0	0
4	0	1.0	0
5	0	1.0	0
6	0	1.0	0
7	0.26	1.0	2.0
8	0.53	1.0	2.0
9	0.79	1.0	2.0
10	1.05	1.0	2.0
11	1.32	1.0	2.0
12	1.58	1.0	2.0
14	2.11	1.0	2.0
15	2.37	1.0	2.0
16	2.64	1.0	2.0
17	2.90	1.0	2.0
18	3.16	1.0	2.0
19	3.43	1.0	0
20	0	1.0	0
21	0	1.0	0
22	0	1.0	0
23	0	1.0	0
24	0	1.0	0

I-8. Model Application and Post-Processing

The CALPUFF model was run a total of 32 times for the RET locations. Each of the 8 RET stands was modeled as a point source and as an area using both the best-estimate diurnal profile and the uniform profile. Six simulations were carried out for the STs, one for each ST source using the uniform diurnal profile, and one for the TTF source using the daytime-only diurnal profile.

Each CALPUFF run generated four years (1987 to 1991) of hourly concentration predictions by receptor. For each receptor, these 4-years of hourly concentration predictions were averaged. The hourly averaging was done by the CALPUFF post-processor program (CALPOST). Adding together the multiplication of the emission rate by source type by the CALPUFF "unit emission rate" predicted ambient air concentration by source type and location resulted in the calculation of air toxic concentration averages over multiple years.

Because CALPUFF is a Gaussian dispersion model, it generated log-normally distributed ambient air concentrations that span roughly four orders of magnitude. Adjacent to the SSFL sources is the "hot spot" predicted by CALPUFF, where concentrations in ambient air are several orders of magnitude greater than the rest of the 101-kilometer by 101-kilometer domain. To visually reflect this predicted behavior, CALPUFF predictions are presented using log-normal contours that increase in multiples of 10 (e.g., 10^{-3} μg/m^3, 10^{-2} μg/m^3, 10^{-1} μg/m^3, 1 μg/m^3, 10 μg/m^3). The CALDESK software program was used to overlay these contours on a map of SSFL and the surrounding area. Because CALDESK does not plot logarithmic contours, the CALPUFF concentrations were first converted to the logarithmic scale using Eq. I-1.

$$LC = \log_{10} (10^3 \text{ x } C) \qquad \text{(I-1)}$$

Where LC is the logarithmic concentration, which ranged from about 0 to 4 in this study, and C is the CALPUFF-generated multi-year average concentration in μg/m^3, which varies with receptor location. In the initial analysis of the model output, it was noted that concentrations decreased by three orders of magnitude within 5 kilometers of the SSFL boundary. Therefore, contour plots of logarithmic concentrations were prepared for a much smaller domain than actually modeled (Section 3.1.3).

I-9. Sensitivity Studies

I-9.1 Overview

In the present model simulations, atmospheric chemical degradation and dry and wet deposition processes were neglected since they were deemed to have a minor role in affecting the annual averaged concentrations. In order to assess the impact of the above model simplification a detailed sensitivity study was carried out. In these sensitivity studies the hourly maximum and 24-hour concentrations of species emitted from SSFL were calculated. However, instead of using a four-year hourly average, the four-year daily concentration distribution were examined to identify the range of possible hourly average and hourly maximum concentrations.

These sensitivity tests were based on an emission rate of 1 gram per second (1 g/s) daily average pollutant emission rate. Rocket engine testing was simulated as increasing in number from 6 a.m. to 7 p.m. The predicted concentrations were expressed in units of micrograms per cubic meter (μg/m^3). Hourly average concentrations denote an average of hourly concentrations obtained based on the four year of hourly meteorological data (1994-1997). The maximum hourly concentration is the highest one-hour concentration predicted from the four-years of hourly predictions.

I-9.1 Impact of Atmospheric Degradation

In order to assess the significance of atmospheric degradation reactions on the airborne concentrations of air toxics resulting from emissions from SSFL, a series of sensitivity analysis simulations were carried out. A chemical degradation process will affect the resulting airborne air toxic concentration if the reaction time scale is of the same order or much lower than the convective residence time (i.e., its travel time due to wind dispersion). Table I-3 lists the reaction lifetimes for SSFL emitted organic species of interest. Hydrazine and 1,3-butadiene have the shortest lifetime rates of reaction ranging from 0.5 hours to 6 hours. Of the other organic species, vinyl chloride has the next shortest reaction half-life of reaction ranging from 1.6 days to 3.9 days.

Table I-3. SSFL emitted organic species reported reactivity

Organic Species	Rocket Fuel	Reactivity (lifetime)	Reference
Hydrazine/UDMH/MMH	Hydrazine	≤ 5.3 hours	CARB (1997)
Benzene	Kerosene	12 days	CARB (2004a)
1,3-Butadiene		0.5 – 6 hours; formaldehyde is a produ	CARB (2004b)
Chloroform		150 to 230 days	CARB (1990b)
Vinylidene Chloride		1.3 days	CARB (2004c)
Methylene Chloride		80 to 250 days	CARB (1989)
Toluene		several days - summer several months - winte	WHO (2000)
Trichloroethylene		4 to 15 days	CARB (1990a)
Vinyl Chloride		1.6 to 3.9 days	CARB (1990d)
Xylene (Total)		14 to 25 hours	CARB (2004d)
TCA	-	5.4 years	CARB (2004e)

Atmospheric degradation of an emitted air toxic will decrease the emitted concentration of this species. The potential importance of including chemical reactions for hydrazine which has the shortest reaction half-life (5.3 hours) I illustrated in Figs. I-5 and I-6. For the population with the maximum concentration exposure shows a 1% decrease of the hourly average concentration and a 3% decrease in the hourly maximum concentrations when atmospheric degradation of hydrazine is included in the model simulation. For the hourly average and hourly maximum concentrations are two times lower with hydrazine chemistry than without. For the population least (minimum) impacted within 30 miles of the SSFL site, the hourly average and hourly maximum concentrations, calculated with hydrazine degradation included, were found to be ten and two times lower, respectively, relative to the case in which hydrazine degradation was neglected.

Figure I-5. Hourly average concentration statistics with and without hydrazine chemistry (i.e., atmospheric degradation). Note: Emission rate= 1g/s.

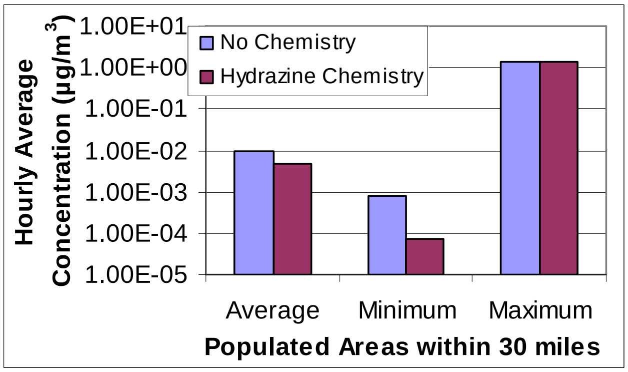
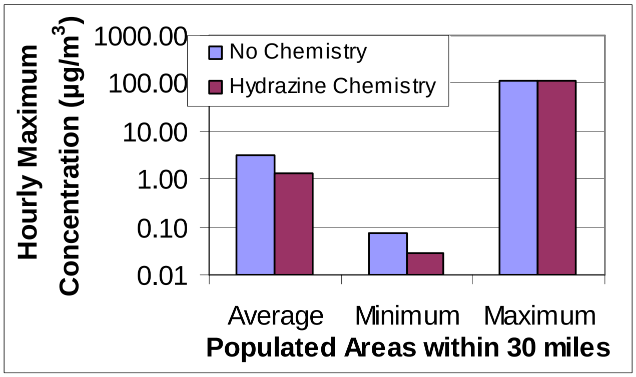


Figure I-6. Hourly maximum concentration statistics with and without hydrazine chemistry (i.e., atmospheric degradation). Note: Emission rate= 1g/s.



I-9.2 Impact of Dry Deposition

Dry deposition from the atmospheric onto the ground reduces the airborne concentration of toxic chemicals, particularly those that are in the particle-bound form. For example, heavy metals that were emitted from kerosene rocket fueled tests are likely to be present in the particulate form. Unfortunately, the PM_{10} size distribution (of most exposure concern) importance of particulate emissions from SSFL uncontrolled rocket engine tests is unknown. Therefore, the effect of dry deposition on heavy metal air concentrations was evaluated based on the U.S. Environmental Protection Agency (1998) reported PM_{10} size distribution (Table I-5) from distillate oil combustion (i.e., an uncontrolled industrial boiler.)

Table I-4. PM_{10} size distribution from uncontrolled industrial boiler burning distillate oil

Particle size (µm)	Cumulative mass less than or equal to stated size
10	100%
6	60%
2.5	24%
1.25	18%
1	16%
0.625	4%

Figures I-7 and I-8 compare predictions of air concentrations in populated areas from rocket engine test exhausts with and without dry deposition, using particle size distribution given in Table I-4. For the population with the maximum concentration exposure, there is a 0.5% to 0.8% decline in the hourly average and hourly maximum concentrations with dry deposition compared to the case without dry deposition. For the average population, the hourly average and hourly maximum concentrations are 30% and 15% lower, respectively, when dry deposition is considered. For the population least (minimum) impacted within 30 miles of the SSFL site, the hourly average and hourly maximum concentrations are 1.7 to 2.1 times lower, respectively, when dry deposition is considered relative to the case when dry deposition is neglected.

Figure I-7. Hourly average concentration statistics with and without dry deposition. Emission rate= 1 g/s.

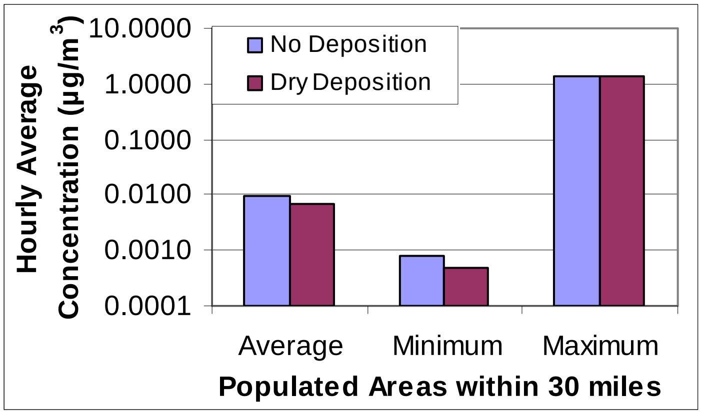


Figure I-8. Hourly maximum concentration statistics with and without dry deposition. Emission rate= 1 g/s.

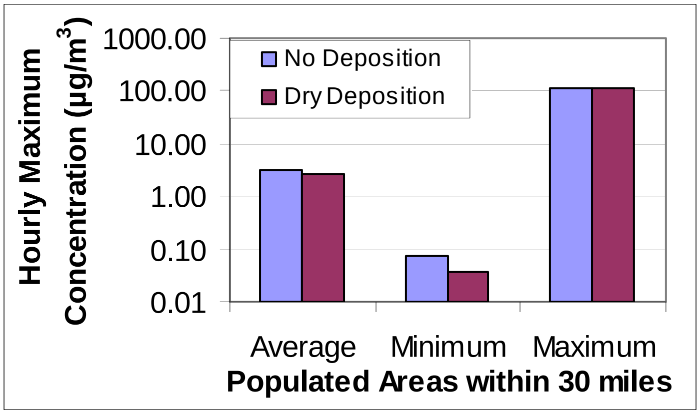
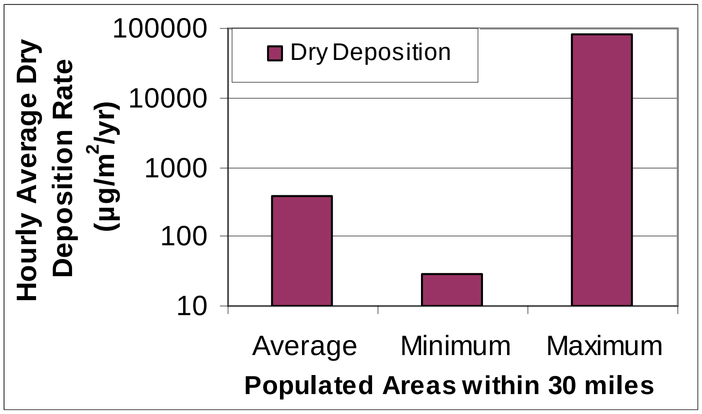


Figure I-9 summarizes predictions of dry deposition to the ground in populated areas from rocket engine test exhausts. The maximum dry deposition rate of 81,200 µg/m^2/yr is at the fenceline. The average and minimum dry deposition rates are 395 µg/m^2/yr and 29 µg/m^2/yr, respectively.

Figure I-9. Hourly average dry deposition statistics. Emission rate= 1 g/s.



I-9.3 Impact of Wet Deposition

Although precipitation statistics for SSFL are somewhat different than for Los Angeles, precipitation statistics for Los Angeles should be reflective of the general trend at the SSFL, as Los Angeles is only about 30 miles southwest of the SSFL and at nearly the same elevation. Table I-5 summarizes mean monthly and annual number of hours with measurable precipitation at Los Angeles, California[I1]. Over the period of SSFL emissions, from 1950 through 1999 precipitation events in Los Angeles (Table I-5) spanned over less than 2.1 percent of the time. precipitation.

[I1] Source: The Western Regional Climate Center: http://www.wrcc.dri.edu/htmlfiles/hrsofppt.html

Table I-5. Mean monthly and mean annual number of hours with measurable precipitation at Los Angeles, California (http://www.wrcc.dri.edu/htmlfiles/hrsofppt.html).

	YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR	% of HOURS
LOS ANGELES	1950-1999	41	35	30	15	4	1	1	1	4	5	19	26	181	2.1

There is the expectation that testing at the SSFL was conducted only during hours without precipitation. This would mean that wet deposition of chemicals emitted from SSFL would not be expected during a rocket engine test. Under even low winds, SSFL emissions would be transported 3.6 km from the test stand in an hour. Even if hours of wet deposition removed all air borne emissions released after 3.6 km, this would on average remove at most 2.1% of the chemicals released from the SSFL. The other 97.9% of emissions would remain airborne until exiting from the 30-km study (i.e., simulation) area or removed by atmospheric degradation and/or dry deposition. Given the above, it is clear that the absence of wet deposition in the present simulations would result in a conservative estimate of airborne concentrations. However, such an overestimate would not significantly affect the concentration fields calculated by the CALPUFF simulations, except for less than 2.1% of the time during short episodic rain events.

I-9.4 Exposure Concentrations at the SSFL Boundary

I-9.4.1 Frequency Distribution of Daily Average Concentrations for the Population with the Greatest Exposure

It is estimated that from 1975 to 1988, between 4 and 31 kerosene rocket fueled tests took place yearly. From 1977 to 1990, it is estimated that as little as 4 to 25 hydrazine (and derivatives) rocket fueled tests took place yearly. This means that the number of kerosene and hydrazine rocket tests in these years was or may have been less than 10% of the number of days in a year. Under such limited rocket engine testing, the calculated four-year hourly averages represent the most likely yearly concentrations in populated areas from these rocket tests. However, this best estimate does not indicate the extent of potential population exposure to significantly lower or higher concentrations in a single year with between 4 and 31 tests. The above concentration limits can be assessed by analysis of the four-year concentration frequency distribution.

The daily average concentration cumulative frequency distribution, for the population exposed to the greatest concentrations (at the SSFL property boundary), is shown in **Fig. I-10**. The arithmetic daily mean concentration of 1.36 μg/m^3 for a 1 g/s emission rate was taken as the baseline estimate. As shown in Fig. I-10, the concentration on 50% of the days are below the mean value of 1.36 μg/m^3 and 50% of the days are above. The daily minimum concentration of 0 μg/m^3 (no impact) occurred (on the average) during 19 days a year. The daily maximum concentration is 7.47 μg/m^3 and the daily concentration standard deviation is 1 μg/m^3.

The daily concentrations distribution is shown in **Fig. I-11**. A concentration of 0.25 μg/m^3 equals the mean log normal value of -1.39. The mean log normal concentration of 0.25 μg/m^3 is about 5 times less than the arithmetic mean concentration of 1.36 μg/m^3 designated as the baseline estimate. The log concentration distribution is skewed with 20% of the log concentrations below the mean and 80% greater than the mean.

Figure I-10. Daily average concentration frequency distribution for the population with the greatest exposure. Rocket engine test simulation is of increase testing from 6 a.m. to 7 p.m.

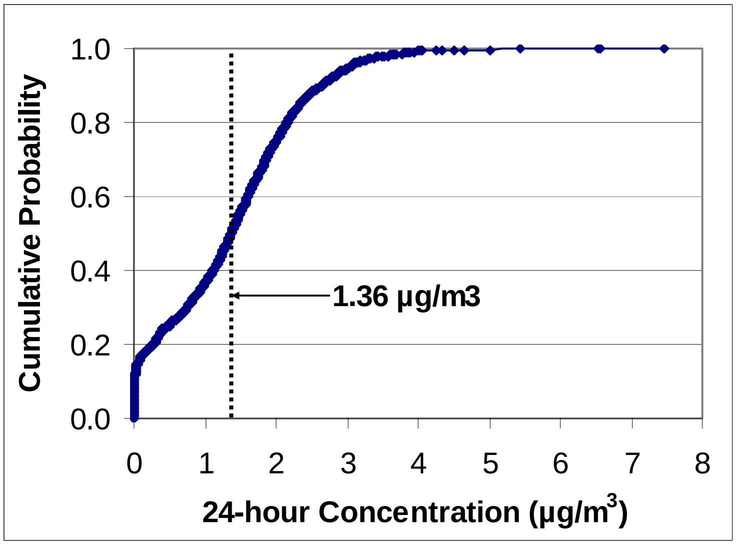
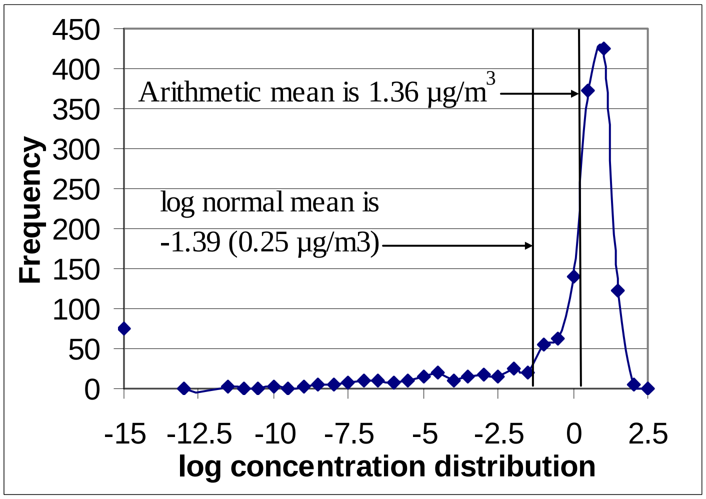


Figure I-11. Log concentration daily frequency distribution from four-years of meteorological data for the population with the greatest exposure.



Averaging of the four lowest and four highest 24-hour average concentrations from the four years simulated reveals the following. The four lowest concentrations are all zero (no impact). The average of the four highest 24-hour concentrations is 6.5 µg/m^3. These averages mean that in any single year the population exposed to the greatest hourly average concentration may have been exposed from four tests to a concentration as low as zero and as high as 6.5 µg/m^3 compared with the arithmetic mean concentration of 1.36 µg/m^3 (i.e., the baseline estimate).

I-9.4.2 Diurnal Concentration Profile for the Population with the Greatest Exposure

For the population exposed to the greatest hourly average concentration (at the SSFL property boundary), the hourly average concentration increases during the day from 6 a.m. to 7 p.m. (Fig. I-12). The hourly average peak concentration is 7.82 µg/m^3 and occurs from 6 p.m. to 7 p.m. As shown in Fig. I-13, the peak hourly maximum concentration is during 4 p.m. to 5 p.m. (i.e., late afternoon).

Figure I-12. Diurnal profile of hourly average concentration at the SSFL property boundary. Rocket engine test simulation is of increase testing from 6 a.m. to 7 p.m.

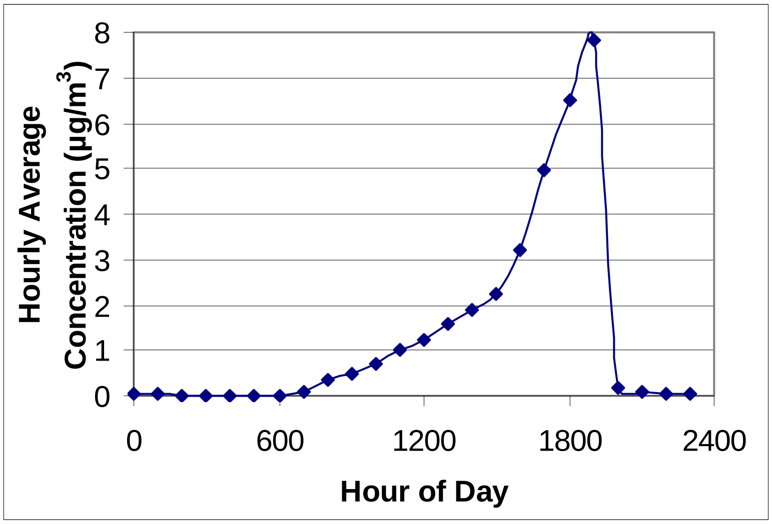
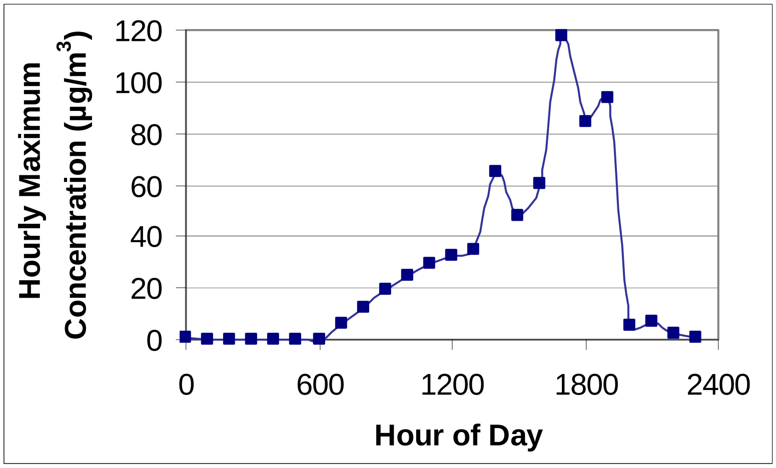


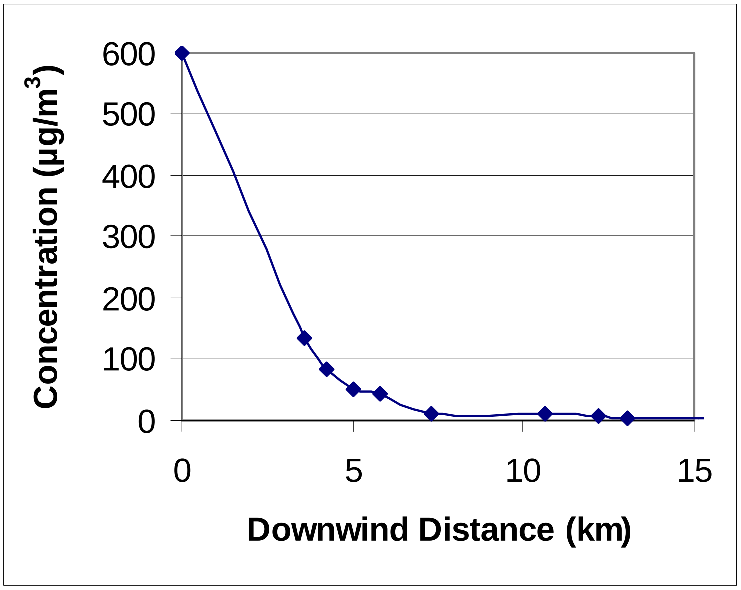
Figure I-13. Diurnal profile of hourly maximum concentration at the SSFL property boundary. Rocket engine test simulation is of increase testing from 6 a.m. to 7 p.m.



I-9.4.4 Worst Case Impact from a Single Rocket Engine Test

Analysis of a single emission event during the day with the highest emission was undertaken to assess the impact of a single rocket engine test testing during the period of 6 p.m. to 7 p.m. A shown in **Fig. I-14.**, the resulting concentrations (for an emission rate of 1 g/s) decline away from SSFL (downwind distance) reveals a concentration decline by a factor of ten over a distance of less than five kilometers (3 miles).

Figure 0-1. Worst impact from a single rocket engine test. Hourly maximum concentration as a function of downwind distance. Downwind distance starts from the highest impacted populated area.



I-9.4 Summary of Sensitivity Analysis

A relative ranking of the potential importance of alternative air dispersion modeling treatments compared with the baseline estimate of airborne concentrations is summarized in Table I-6. For the baseline estimate emission scenario, the hourly maximum concentration is 100 times the hourly average concentration. The four-year daily concentration distribution identifies the possible daily average on years with four tests as being 5 times greater or 1000 times less compared with the baseline estimate of hourly averages. Neither atmospheric degradation chemistry, dry deposition nor wet deposition are likely to significantly reduce near-field concentrations. For example, atmospheric degradation reduces hydrazine concentrations by 1 to 3% in the near field, a factor of two on average, and in least impacted areas by a factor of ten. Dry deposition of particulates reduces concentrations by 0.5% to 0.8% in the near field, 15%-30% on average, and in least impacted areas by a factor of two. Wet deposition is expected to reduce annual averaged concentrations by no more than about 2.1%.

The results of the sensitivity studies should prove useful in guiding refinement of expanded sensitivity studies and future modeling efforts. It is important to note that, in order to refine the sensitivity analysis, there is need for accurate information regarding the number and timing of rocket tests and the meteorology associated with those tests. Unfortunately, the meteorology associated with individual tests may be difficult to reconstruct lacking routine nearby meteorological measurements from the start of testing (1948) to present (2004).

Table I-6. Ranking the Importance of Alternative Simulation Scenarios

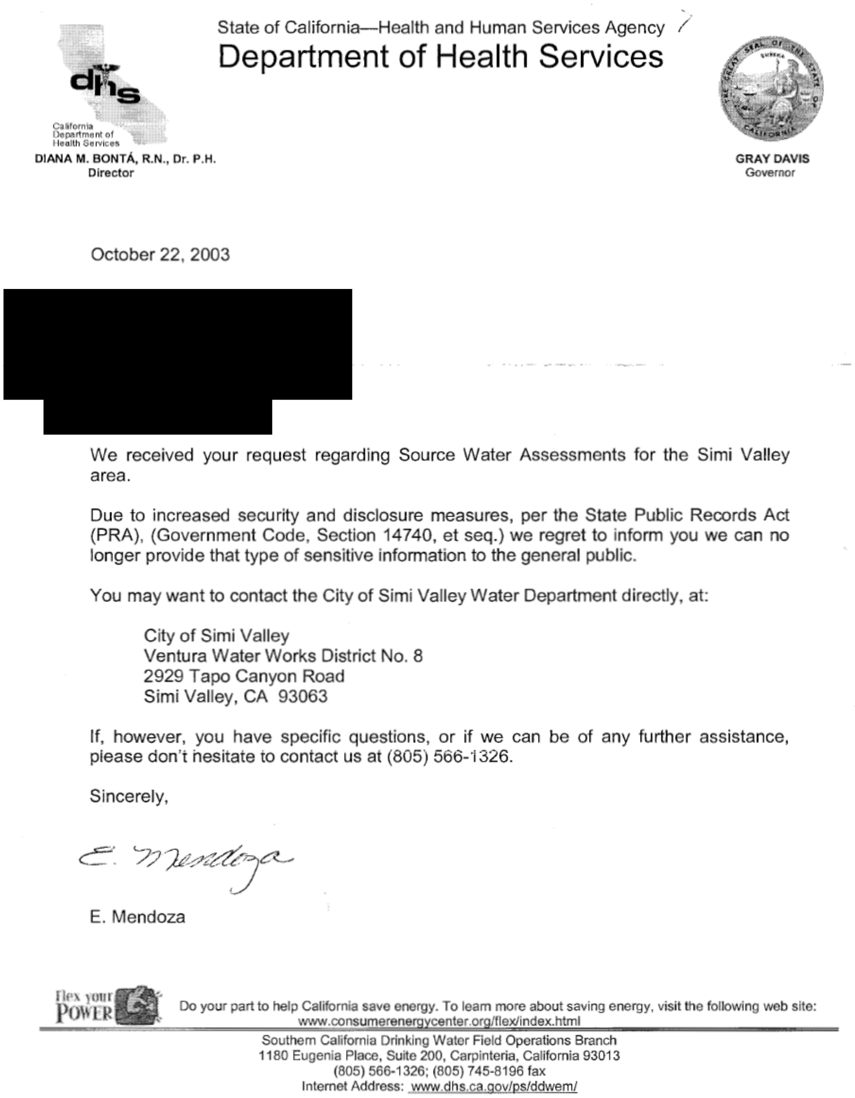
Alternative Simulation Scenarios	**Concentration Decrease (except as noted)**
Hourly Maximum compared with Hourly Average	
Maximum Impact in Populated Area	Increase by factor of 100
Average Impact in Populated Areas	Increase by factor of 100
Minimum Impact in Populated Areas	Increase by factor of 100
Frequency Distribution effect of Meteorology	Potential decrease from 1.36 to 0 μg/m^3; potential increase by factor of 5
Chemistry[a] – Hydrazine and 1,3-Butadiene	
Maximum Impact in Populated Area	1%-3%
Average Impact in Populated Areas	Factor of 2
Minimum Impact in Populated Areas	Factor of 2-10
Dry Deposition – Particulates	
Maximum Impact in Populated Area	0.5%-0.8%
Average Impact in Populated Areas	15%-30%
Minimum Impact in Populated Areas	Factor of 1.7-2.1
Wet Deposition	2.1%

[a] – atmospheric degradation

Appendix J. Requests for Well-Related Information

Requests for groundwater well information were requested from a number of agencies and municipal water companies, including the California Department of Health Services (DHS), Ventura Water Works District No. 8 (VWWD), the Central Coast Regional Water Quality Control Board, Los Angeles County Department of Public Works, the Los Angeles Department of Power and Water (LADPW), Southern CA Water Company, and the California Department of Water Resources. Groundwater monitoring results and well histories were requested for wells within 3 miles of SSFL. Information was obtained from VWWD and LADPW, but it was either out of date or incomplete. Personnel from VWWD were reluctant to reply to requests from the study team. Information was subsequently requested again and partial information was obtained later under an assumed identity. However, requests to make photocopies of VWWD well histories and monitoring data were denied; it was claimed that well-related info was confidential. The request for source water information from the California DHS was also denied as documented in the reply letter from DHS below (Figure J-1).

Figure J-1. Response Letter from the Department of Health Services



State of California—Health and Human Services Agency
Department of Health Services

California Department of Health Services
DIANA M. BONTÁ, R.N., Dr. P.H.
Director

GRAY DAVIS
Governor

October 22, 2003

[redacted]

We received your request regarding Source Water Assessments for the Simi Valley area.

Due to increased security and disclosure measures, per the State Public Records Act (PRA), (Government Code, Section 14740, et seq.) we regret to inform you we can no longer provide that type of sensitive information to the general public.

You may want to contact the City of Simi Valley Water Department directly, at:

City of Simi Valley
Ventura Water Works District No. 8
2929 Tapo Canyon Road
Simi Valley, CA 93063

If, however, you have specific questions, or if we can be of any further assistance, please don't hesitate to contact us at (805) 566-1326.

Sincerely,

E. Mendoza

E. Mendoza

Southern California Drinking Water Field Operations Branch
1180 Eugenia Place, Suite 200, Carpinteria, California 93013
(805) 566-1326; (805) 745-8196 fax
Internet Address: www.dhs.ca.gov/ps/ddwem/

Appendix K. Groundwater Well and Surface Water Station Background

Following the discovery of TCE in groundwater (1984), a network of 214 monitoring wells was installed to map groundwater flow and the distribution of contaminants. Of these 214 monitoring wells, there are 13 facility water supply wells (WS), 11 Engineering Chemistry Lab wells (SH), 27 alluvial series wells (RS), 31 Chatsworth series wells (RD), 32 extraction wells (ES), and 33 hydro-geological assessment report wells (HAR). The offsite wells where contaminants were detected are presented in the following table (Table K-1). Details associated with these wells can be found from the following references: Boeing, 1990–2003, 2002; CDHS, 1999; GRC, 2000; McLaren/Hart, 1993; Rocketdyne, 1959–1989, 1995.

Wells labeled using “OS” prefixes are “offsite” private wells monitored by Rocketdyne to ascertain contaminant mobility from SSFL. For example, wells OS-17 and OS-27 are drinking water supply wells, and are not owned by Rocketdyne. Wells labeled using “RD” are Rocketdyne-constructed monitoring wells; “RD” signifies Rocketdyne’s “deep” wells. (Rocketdyne’s shallow wells, not presented here, are designated “RS.”) Due to acquisitions of neighboring property, wells previously considered off site may currently by regarded as on site. For example, contaminants were detected in wells RD-56AB, RD-34ABC, RD-57, and RD-33ABC, which were previously located on the Brandeis-Bardin Institute property; this land was acquired by Rocketdyne/Boeing after the contaminants were detected and is now considered on site.

SSFL also has a National Pollutant Discharge Elimination System (NPDES) permit (No. CA0001309) allowing it to discharge up to approximately 180 million gallons of treated water per year. These offsite sampling stations are noted using the NPDES prefix followed by the number of the specific “outfall” (e.g., NPDES 001). Approximately 90% of the facility’s surface water is discharged via NPDES outfalls 001 and 002 to areas south of SSFL (into Bell Canyon via Bell Creek); 10% of the facility’s surface water is discharged via NPDES outfalls 003 through 007 to areas north of SSFL (into Simi Valley via Runckle and Meier Canyons) (Rockwell International, 1987; Boeing, 2003).

Offsite wells where significant contaminant levels were detected include RD-32 and -43 (Sage Ranch and Woolsey Canyon Wells, respectively); OS-2 and -5 (offsite wells used for livestock northwest of SSFL at Brandeis-Bardin); RD-56A and RD-38A (Santa Monica Mountains Conservancy wells); and RD-59A (a deep well on Brandeis-Bardin property). Additional offsite groundwater well data are provided in Section 4.1.1.

Onsite wells where significant contaminant levels were detected include RD-13 (by Building 55); RD-25 and -24 (by Building 59); RS-11, -16, -18, -23 through -25, and ES-31 (in Area IV); RS-26 (by the Old Conservation Yard); RD-7, WS-7, and RS-27 and -28 (Chatsworth Formation wells); and OS-14 (in Area II, about 3,000 feet upstream of the southern boundary).

Table K-1. Offsite Surface Water and Groundwater Sampling Stations with Significant Contaminant Detections

Direction	**NW**	**N**	**NE, E, SE**	**S, SW**
Location	**Brandeis-Bardin Institute**	**Santa Monica Mountains Conservancy**	**Private Lands Woolsey, Dayton Canyons**	**Bell Canyon Area**
Groundwater wells	OS-1 to -10 RD-59ABC RD-68AB	OS-24-27 RD-36ABCD RD-38AB,71 RD-39AB,66	OS-15, -16, -17, -19, -20, -27 RD-32, -43	OS-21
Surface water stations	NPDES 003– 007 OS-8	No surface water drainage into this area	NPDES Near Well 13, OS-12, -13	Bell Creek NPDES # 001, 002 OS-14

Appendix L. Fate and Transport Information Sources for Contaminants of Concern (COCs)

COCs:

Aliphatic and Cyclic Hydrocarbons

Trichloroethene (TCE)
Carbon tetrachloride
1,2- and 1,1-dichloroethane
Trans- and cis-1,2-dichloroethene
1,1-Dichloroethene (vinylidene chloride)
Methylene chloride (dichloromethane)
Chloromethane (methyl chloride)
Methyl chloroform (1,1,1-TCA)
Tetrachloroethene (perchloroethene)
Vinyl chloride (VC)

Aromatic Compounds

Xylene
Toluene
Benzene
Polychlorinated biphenyls (PCBs)
Bis(2-ethylhexyl)phthalate (DEHP)
Polycyclic aromatic hydrocarbons (PAHs)
Benzo(a)pyrene

Nitrogen-Containing Organic Compounds

Hydrazines (MMH, UDMH, and NDMA)

Oxygenated Organic Compounds

Polychlorinated dibenzo-p-dioxins (PCDDs)
Dibenzofurans (PCDFs)
Perchlorate

Inorganic Compounds

Arsenic
Mercury
Lead
Beryllium
Chromium
Manganese
Nickel
Cadmium
Selenium

Radioactivity

Tritium
Cesium-137
Strontium-90
Plutonium-238
Radium-226, -228
Potassium-40
Thorium-228, -232

Information compiled from the National Library of Medicine’s TOXNET® Web site (http://toxnet.nlm.nih.gov/) was used to assess chemical fate and transport. Chemical and physical factors necessary to determining environmental fate and transport were derived from the Hazardous Substances Data Bank (HSDB), which is a comprehensive, peer-reviewed database of about 5,000 chemicals. HSDB is accessible via TOXNET. It is enhanced with information on human exposure, industrial hygiene, emergency handling procedures, toxicology, and regulatory requirements. All data are referenced and derived from a core set of books, government documents, technical reports and selected scholarly journals.

Appendix M. SCRAM Ranking: Chemical, Uncertainty, Composite Scores, Ranking, and Weightings

M-1. SCRAM Ranking Results

Table M-1. COPC Ranking via SCRAM

Chemical Name	Chemical Score	Uncertainty Score[1]	Composite Score	Ranking
Benz(a)anthracene	41	30	71	1
Dibenzo(a,h)anthracene	42	28	70	2
p,p-DDD	48	19	67	3
Ethion	45	22	67	3
p,p-DDE	53	10	63	4
Hexachlorobenzene	53	9	62	5
Toxaphene	53	9	62	5
PCBs	53	8	61	6
Chlordane	52	8	60	7
p,p-DDT	53	7	60	7
2-Methylnapthalene	27	30	57	8
Anthracene	36	18	54	8
Heptachlor epoxide	40	13	53	10
Hexachloro-1,3-butadiene	37	16	53	10
Mercury	45	7	52	11
Chlorobenzene	26	26	52	11
Dibromochloromethane	18	34	52	11
1-Methylnapthalene	29	23	52	11
Aldrin	37	13	50	12
2,3,7,8-TCDD	45	4	49	13
Fluoranthene	32	16	48	14
Acenapthylene	8	40	48	14
Trifluralin	36	12	48	14
Bromodichloromethane	20	28	48	14
p,p-Methoxychlor	36	11	47	15
Hydrazine	27	19	46	16
1,1,2-Trichloroethane	21	25	46	16
Endrin	37	9	46	16
1,3-Dichlorobenzene	30	16	46	16
Di-n-octylphthalate	30	16	46	16
1,2,3-Trichlorobenzene	30	16	46	16
Bromoform	18	27	45	17
Fluorene	24	20	44	18

---

[1] Uncertainty is taken into account in all SCRAM scores. The type of information that is available for scoring determines an uncertainty score. For example, in SCRAM, bioaccumulation is scored on the basis of bioaccumulation factors (BAF), bioconcentration factors (BCF), or octanol/water partition coefficients (K_{ow}). A bioaccumulation chemical score is assigned according to the range of the variable used. For example, measured values for bioaccumulation are given priority over predicted values. If a measured BAF is available, no uncertainty points are assigned. If the value available is a BCF, 1 uncertainty point is assigned: a BCF gives less information for higher trophic levels, where effects of bio-accumulative chemicals are generally greater. If only surrogate information in the form of a K_{ow} is available, 2 uncertainty points are assigned. If only an estimated BAF is available, a factor of 4 is assigned; if only an estimated BCF is available, a factor of 5 is assigned.

Chemical Name	**Chemical Score**	**Uncertainty Score**[1]	**Composite Score**	**Ranking**
Heptachlor	38	6	44	18
Hexachloroethane	33	11	44	18
Dieldrin	38	5	43	19
Phenanthrene	30	12	42	20
Toluene	31	10	41	21
Endosulfan	30	11	41	21
Pyrene	26	15	41	21
Lindane	38	3	41	21
Styrene	18	23	41	21
1,2,4-Trichlorobenzene	30	11	41	21
Trichloroethylene (TCE)	22	16	38	22
1,2-Dichlorobenzene	22	16	38	22
Benzidine	22	15	37	23
Benzene	19	17	36	24
Furan	13	23	36	24
Pentachlorophenol	29	7	36	24
Beryllium	23	12	35	25
Bis(2-ethylhexyl)phthalate (DEHP)	26	8	34	26
Di-n-butylphthalate	21	13	34	26
N-Nitrosodimethylamine	13	20	33	27
Benz(a)pyrene	19	14	33	27
Silvex	19	14	33	27
Perchlorate	8	24	32	28
Biphenyl	17	15	32	28
Butylbenzylphthalate	18	14	32	28
Phenol	21	9	30	29
Carbon tetrachloride	18	12	30	29
Ethylbenzene	10	20	30	29
Molybdenum	21	9	30	29
Selenium	23	7	30	29
Carbofuran	20	10	30	29
1,1-Dichloroethane (DCA)	8	21	29	30
Silver	18	11	29	30
Tetrahydrofuran	7	22	29	30
Arsenic	22	6	28	31
Chromium	23	5	28	31
1,2-DCA	19	9	28	31
Cyanide	12	16	28	31
Manganese	19	9	28	31
1,2-Dichloropropane	15	13	28	31
1,2-Dichloroethane	19	9	28	31
Chloroform	17	10	27	32
Trans-1,2-DCE	15	12	27	32
Trichlorotrifluoromethane (freon-113)	15	12	27	32
Copper	21	6	27	32
Nickel	21	6	27	32
Vanadium	18	9	27	32
Alachlor	19	8	27	32
Antimony	16	11	27	32
Atrazine	22	5	27	32
2,4,6-Trichlorophenol	20	7	27	32

Chemical Name	Chemical Score	Uncertainty Score[1]	Composite Score	Ranking
Tetrachloroethene	16	10	26	33
Barium	16	10	26	33
Cadmium	23	3	26	33
1,4-Dichlorobenzene	15	11	26	33
Dichloromethane	17	12	26	33
Hexachlorocyclopentadiene	15	11	26	33
Cobalt	15	10	25	34
Xylene	9	16	25	34
Vinyl chloride	15	10	25	34
Methylene chloride	15	10	25	34
Strontium	11	14	25	34
Naphthalene	13	12	25	34
1,3-Dichloropropene	11	14	25	34
Lead	23	1	24	35
Titanium	15	9	24	35
1,1,1-Trichloroethane (TCA)	12	12	24	35
Acrylonitrile	11	12	23	36
1,1,2,2-Tetrachloroethane	12	10	22	37
Diethylphthlate	11	10	21	38
Isophorone	7	11	18	39

Notes: The composite score was the sum of the final chemical score and the final uncertainty score. The SCRAM model preserves the final chemical and uncertainty scores as separate values because they are useful in the interpretation of the final composite scores and rankings.

Example of Site-Specific SCRAM Weighting*s*

(See Section 2.2 for other site-specific weightings and ranking results)

Table M-2. Air Contaminant Rankings: SCRAM Score Weighted by (Air Emissions / Inhalation Reference Concentrations × Daily Inhalation Rates)

Contaminant	Emissions (lbs/yr)	Inhalation RfC (mg/m^3)	Emissions/ (RfC × I)	SCRAM Composite	Weighted Rank	Revised Ranking
Benzene	107.86	0.03	180	36	6472	1
Beryllium	0.03	0.00002	75	35	2625	2
Toluene	144	0.4	14	22	312	3
Chromium	0.0019	0.000008	74	28	208	4
Mercury	0.02	0.0003	3	52	173	5
Vinyl chloride	0.02	0.1	0.01	25	0.25	6

Table M-3. Air Contaminant Rankings: SCRAM Scores Weighted by Emissions

Chemical Name	SCRAM Composite Score	SCRAM Ranking	Air Emission Rate Estimates (1990–1992) (lbs/year)	Ranking × Emissions	Emission-Weighted Ranking	Chemicals in Order of Ranking
PCBs	61	1	1×10^{-5}	6.3×10^{-4}	20	Hydrazine
Mercury	52	2	0–0.02	1.04	18	1,1,1-TCA (methylchloroform)
Hydrazine	46	3	*170,570	7.8×10^{6}	1	TCE
Trichloroethylene (TCE)	38	4	4,305.32–7,756.61	294,751	3	1,2-DCA
Benzene	36	5	107.86–92.1	3,883	8	Methylene chloride (dichloromethane)
Beryllium	35	6	0.03	1.05	17	Carbon tetrachloride
Carbon tetrachloride	30	7	304.56–0.04	9,137	6	Xylene
Selenium	30	7	0.07–0.04	2.1	14	Benzene
Arsenic	28	8	0.07	1.96	15	Toluene
Chromium	28	8	†1.19×10^{-3}	0.0333	19	Manganese
1,2-DCA	28	8	6,770	189,560	4	Nickel
Manganese	28	8	†3.7×10^{-1}	10.36	10	Lead
1,1,1-Trichloroethane (TCA)	27	9	37,399.95	1,009,799	2	Cadmium
Nickel	27	9	0.44–0.56	15.12	11	Selenium
Cadmium	26	10	0.15	3.9	13	Arsenic
Xylene	25	11	215.95–49.53	5,399	7	Vinyl chloride
Vinyl chloride	25	11	0.02–0.05	1.25	16	Beryllium
Methylene chloride	25	11	1,732.23–1,070.54	43,306	5	Mercury
Lead	24	12	0.23–0.30	7.2	12	Chromium
Toluene	22	13	144–71.25	3,168	9	PCBs

Notes: SCRAM ranks chemicals based on toxicity, persistence, mobility, and bioaccumulation. Contaminants with the same SCRAM ranking had the same SCRAM composite score. The composite score is the sum of the final chemical score and the final uncertainty score.

Sources: RD Hot Spots Emission Reports for 1990–1992;
* 1955–1961 RD average yearly use reports; †1996 RD TRI Report (lb/year).

Appendix N. Standards Used for Chemical Ranking and Exposure Analysis

Table N-1. Health-Based Standards Used to Compare and Evaluate Detected Contaminant Levels

Contaminant	**[1]MCL μg/L (ppb)**	**[5]Tap Water Screening Level, μg/L (ppb)**	**[2]Ambient Air Quality Standards, μg/m^3 (ppm)**	**[3]Ambient Air Screening Level, μg/m^3 (ppm)**	**[4]RfC, mg/m^3**	**[3]Residential Soil Screening Level, mg/kg (ppm)**	**Potential Health Effects/ Critical Target Organs**
Acenapthalene	[13]2,000	370		220		3,700	
Acetaldehyde		1.7		0.87		0.11	
Acetone		610		370		1,400	
Alachlor	2			0.084		6	
Aldrin	[10]0.002	0.004		0.00039		0.029	Probable carcinogen
Alpha particles	15 pCi/L						Increased risk of cancer
Aluminum	1,000			5.1		75,000	
Anthrocene		1,800		1,100		22,000	
Aroclor 1242		0.34		0.0034		0.22	
Aroclor 1254		0.34		0.0034		0.22	
Arsenic	50; 10 (as of 1/23/05)			0.00045		0.39	Reproductive/developmental endpoint; skin damage; circulatory problems; increased risk of cancer
Asbestos	[11]7 MFC						
Atrazine	3			0.031		2.2	
Barium	1,000			260		5,200	Increase in blood pressure
Benz(a)anthracene		0.092		0.0092		0.62	
Benzene	1	0.34		0.23	6.0×10^{-3}	0.66	Reproductive/developmental; immune system; hematologic system (anemia); increase in cancer risk; nervous system
Benzidene	0.00029			0.000029		0.0021	
Benzo(a)pyrene	0.2	0.0092		0.00094		0.062	
Benzo(b)fluoranthene		0.092		0.0092		0.62	
Benzo(k)fluoranthene		0.056		0.017		0.062	
Beryllium	4	73	[8]0.01 (30-day avg)	0.0008		150	Intestinal lesions; respiratory system; immune system
Beta particles	4 millirems per year or 50 pCi/L						Increased risk of cancer
Biphenyl		300		180		3,000	
Bis(2-ethylhexyl) phthalate (DEHP)	6			48		35	Detected in Bell Canyon (not used; a byproduct)
Boron	[10]1,000	7,300		21		16,000	
Bromoform	100	805		107		62	
1,3-Butadiene	0.011			0.0096		0.0065	
Cadmium	3.7			0.0011		9	Kidney damage; respiratory system
Cadmium-109	9.52 pCi/L					0.266 pCi/g	
Carbaryl	[10]700			400		6,100	
Carbofuran	18			18		310	
Carbon tetrachloride	0.5		0.13			0.25	Reproductive/developmental; nervous system; alimentary tract; liver problems; increased risk of cancer
Cesium-137	[9]1.57 pCi/L			[9]2×10^{-7} μCi/ml		6.1 pCi/g	
Chlordane	0.1					1.6	

Contaminant	**[1]MCL µg/L (ppb)**	**[5]Tap Water Screening Level, µg/L (ppb)**	**[2]Ambient Air Quality Standards, µg/m^3 (ppm)**	**[3]Ambient Air Screening Level, µg/m^3 (ppm)**	**[4]RfC, mg/m^3**	**[3]Residential Soil Screening Level, mg/kg (ppm)**	**Potential Health Effects/ Critical Target Organs**
Chloroform	70			0.084		0.24	Reproductive/developmental; nervous system; alimentary system; kidney development
Chloromethane		1.5		1.1		1.2	
Chromium (total)	100 (or 50 for CA water utilities)			0.00016		210	Allergic dermatitis; respiratory system
Chromium VI (~ 34% of total chromium; EPA)	50			0.000023		30	
Chrysene		0.56		0.17		3.8	
Cobalt				6.9×10^{-4}		900	
Cobalt-60	[9]3.03 pCi/L			[9]5×10^{11} µCi/ml		0.000901 pCi/g	
Copper	1,000					2,800	Respiratory irritation; gastrointestinal illness; liver or kidney damage; Wilson's disease
Cyanide	22			3.1		1,200	
1,1-DCA	5	810		520		510	
1,2-DCA	0.5			0.074		0.28	Increased cancer risk
1,1-DCE or vinylidene chloride	6			210		120	Liver problems
Cis-1,2-DCE	6			37		43	Liver problems
Trans-1,2-DCE	10			73		69	Liver problems
4,4-DDE		0.2		0.02		1.7	
DDT	590			0.02		1.7	
Dibenz(a,h)anthracene		24		0.00094		0.062	
Dibenzofuran				15		290	
Dibromochloro-methane	60			0.08		1.1	
Dibromochloro-propane	0.1	0.0092		0.00096		0.019	
1,2-Dichlorobenzene	5			210		370	
1,4-Dichlorobenzene	5			0.31		3.4	
Dichlorodifluoro-methane	[10]1,000			210		94	
1,2-Dichloropropane	5			0.099		0.34	
1,3-Dichloropropene	0.5			0.48		0.78	
Dieldrin	[10]0.002	0.0042		0.00042		0.03	
Di(2-ethylhexyl) phthalate	4			5.6		410	
2,4-dimethylphenol	[10]100			73		1,200	
Di-n-butylphthalate	3,700			370		6,100	Found at Bell Canyon (not used; byproduct?)
1,4-Dioxane	[10]3			0.61		44	
Endrin	0.2			1.1		18	
Ethion	[10]4			1.8		31	
Ethylbenzene	680			1.7	1	8.9	Liver or kidney problems; endocrine system
Ethylene dibromide	0.002						
Ethylene glycol	[10]14,000			7,300		100,000	
Ethylene oxide		0.024		0.019		0.14	
Fluoranthene		1,500		150		2,300	
Fluoride	2,000					3,700	
Fluorine		240		150		2,700	
Formaldehyde	[10]100			0.15		9,200	Eye and respiratory irritation; immune system
Gamma radiation	15 pCi/L						
HCHα		0.011		0.0011		0.09	
HCHβ		0.037		0.0037		0.32	

Contaminant	[1]MCL µg/L (ppb)	[5]Tap Water Screening Level, µg/L (ppb)	[2]Ambient Air Quality Standards, µg/m^3 (ppm)	[3]Ambient Air Screening Level, µg/m^3 (ppm)	[4]RfC, mg/m^3	[3]Residential Soil Screening Level, mg/kg (ppm)	Potential Health Effects/ Critical Target Organs
HCHγ (Lindane)	4	0.052		0.0052		0.44	
HCH (technical)		0.037		0.0038		0.32	
Heptachlor	0.01			0.0015		0.11	
Heptachlor epoxide	0.01			0.00074		0.053	
N-Heptane		350		210		110	
Hexachlorobenzene	1			0.0042		0.3	
Hexachlorocyclopentadiene	50			0.21		370	
Hydrazine		0.022		0.00039		0.16	Alimentary system; endocrine system
Hydrogen sulfide		110	0.03 ppm (42 µg/ m^3) 1-hr avg.	1			Respiratory irritation; headache/nausea
Indeno(1,2,3-cd)pyrene		0.92		0.0092		0.62	
Iodine-129	[9]0.32 pCi/L			[9]4×10^{-11} µCi/ml		0.0000276 pCi/g	
Iodine-131	[9]1.05 pCi/L			[9]2×10^{-10} µCi/ml		0.0833 pCi/g	
Isopropylbenzene	[10]770					160	
Lead	15		1.5 µg/ m^3 30 day avg.			130	Infants/children: delays in physical or mental development; adults: kidney problems, high blood pressure
Lithium		730				1,600	
Manganese	50			0.051		1,800	Nervous system
Mercury	2			0.31	0.0003	23	Reproductive/developmental endpoint; nervous system, kidney
Methoxychlor	40			18		310	
Methylene chloride		4.3		4.1		8.9	CNS (mild); cardiovascular system
4-Methylphenol		180		18		310	
Molinate	20			7.3		120	
Monochlorobenzene	30						
Naphthalene	[10]170	6.2		3.1		56	
Nickel	100			0.008		150	Respiratory irritation; immune response; targets hematopoietic system
Nitrobenzene		3.4		2.1		20	
Nitroglycerin		4.8		0.48		35	
N-Nitrosodimethylamine (NDMA)	[10]0.01			0.00014		0.0095	
4-Nitrosodiphenylamine (NDPA)		14		1.4		99	
Parathion	[10]40			22		370	
PAHs—benzo(a)pyrene	0.2			0.00092		0.0092	Reproductive difficulties; increased cancer risk
PCBs	0.5			0.0034		0.22	Chloroacne; thymus gland problems; immune deficiencies; reproductive or nervous system difficulties; increased risk of cancer
Pentachlorophenol	1			0.056		3	
Perchlorate	[10]2	307				[10]20	Thyroid interference; developmental and metabolic problems
Phenol	[10]4,200			2,200		37,000	
Plutonium-238, -239, -240	Pu238=0.36 Pu239=0.35 Pu240=0.56 pCi/L			[9]2×10^{-14} µCi/ml		[3]Pu-238=0.0073 Pu-239-0.006 Pu-240=0.006 pCi/g	
Potassium-40	[9]1.93 pCi/L			[9]6×10^{-10} µCi/ml		0.0445 pCi/g	
N-Propylbenzene	[10]260					240	

Contaminant	[1]**MCL µg/L (ppb)**	[5]**Tap Water Screening Level, µg/L (ppb)**	[2]**Ambient Air Quality Standards, µg/m³ (ppm)**	[3]**Ambient Air Screening Level, µg/m³ (ppm)**	[4]**RfC, mg/m³**	[3]**Residential Soil Screening Level, mg/kg (ppm)**	**Potential Health Effects/ Critical Target Organs**
Pyrene		180		110		2,300	
Radium-226, -228	Ra-226= 0.000823 Ra-228= 0.0458 pCi/L			[9]9×10^{-13} µCi/ml		Ra-226=0.00067 Ra-228=0.0017 pCi/g	Increased risk of cancer
Selenium	10					390	
Silver	100					390	
Silvex (2,4,5-TP)	10						
Strontium-90	0.852 pCi/L			[9]3×10^{-11} µCi/ml		0.00192 pCi/g	
Styrene	100			1,600		1,700	
Sulfates			25 µg/m³ 24-hr avg.				Respiratory irritation
Tert-butyl alcohol	[10]12						
1,1,1,1-Tetrachloroethane	1						
1,1,2,2-Tetrachloroethane		0.055		0.033		0.41	
Tetrachloroethylene	5	0.66		0.67		1.5	
Thallium	2					5.2	
Thorium-228, -230, -232	[9]Th228=0.4 Th230=0.5 Th232=0.5 pCi/L			[9]6×10^{-15} µCi/ml		Th-228=0.123 Th-230= 0.0105 Th232= 0.00942 pCi/g	
Toluene	150			400		520	CNS (mild); eye and respiratory irritation; kidney or liver problems
Toxaphene	5	0.061		0.006		0.44	
1,2,4-Trichlorobenzene	70			210		650	
1,1,1-Trichloroethane	200			2300		1,200	Liver, nervous, or circulatory problems
1,1,2-Trichloroethane	5			0.12		0.73	
Trichloroethylene	5	0.28		0.017	0.04	0.043	Kidney; alimentary system (liver) increased risk of cancer; eyes
Trichlorofluoro-methane	150			730		390	
1,2,3-Trichloropropane	[10]0.005			0.0034		0.005	
Trichlorotrifluoro-ethane (freon-113)				31,000		5,600	
1,1,2-Trichloro-1,2,2-trifluoromethane	1,200						
Trihalomethanes (total)	80						
Tritium	[9]20,000 pCi/L					[9]6.01 pCi/g	
TCDD-TEQ (total) 2,3,7,8-TCDD	3×10^{-8}			4.5×10^{-8}		3.9×10^{-6}	Alimentary system (liver); reproductive system; developmental system; endocrine system; respiratory system; hematopoietic system
Uranium-233, -234, -235, -238	U233=0.66 U234=0.67 U235=0.68 U238=0.74 pCi/L			[9]6×10^{-14} µCi/ml		U-233=0.00183 U-234=0.00187 U-235=0.00187 U-238=0.00206 pCi/g	Increased risk of cancer; kidney toxicity
Vanadium	[10]50	260				520	
Vinyl chloride	0.5		0.01 ppm (26 µg/m³) 24-hr avg.		0.1	0.079	CNS (mild); eye and respiratory irritation; increased risk of cancer
Xylene	1,750			110		270	Eye and respiratory irritation; nervous system damage

Contaminant	**[1]MCL µg/L (ppb)**	**[5]Tap Water Screening Level, µg/L (ppb)**	**[2]Ambient Air Quality Standards, µg/m^3 (ppm)**	**[3]Ambient Air Screening Level, µg/m^3 (ppm)**	**[4]RfC, mg/m^3**	**[3]Residential Soil Screening Level, mg/kg (ppm)**	**Potential Health Effects/ Critical Target Organs**
Zinc	110	11,000				22,000	
Zirconium hydride						23,000	

Notes:

[1] Maximum Contaminant Level (1/6/2003); EPA, 40 CFR Part 141.

[2] California Air Resources Board (1/9/2003). Used when lower than National Ambient Air Quality Standards (NAAQS) or National Emission Standards for Hazardous Air Pollutants (NESHAPs); see #4. NAAQS for Hazardous Air Pollutants (40 CFR Part 50) regulates SO_2, NO_2, CO, O_3, Pb, and PM.

[3] Region 9 Human Medium Specific Screening Levels or Primary Remedial Goals (11/22/2002). Used where no California state or national standards exist.

[4] NESHAPs, 40 CFR Part 61. Establishes standards for hazardous air pollutants for which no ambient air quality standards exist.

[5] Region 9 Human Medium Specific Screening Levels (11/22/2002). Used as a comparison to MCL standard.

[6] Reference dose (oral): chronic non-carcinogenic oral doses (11/22/2002). (Used as a comparison to standards; for radioactive material, refer to note #9.) Reference concentration: chronic non-carcinogenic inhalation dose (11/22/2002). (Used as comparison to air standards.)

[7] Cancer potency factor: chronic exposure cancer risk. (Used as a comparison to standards.)

[8] 40 CFR 61, National Emission Standards. (For iodine, gross beta, strontium-90, and tritium: 4 mrem/year/person. Other emissions are regulated by EPA/NESHAPS to the limit of 10 mrem/year/person maximum.)

[9] EPA's Radionuclide Toxicity and Preliminary Remediation Goals for Superfund used for agricultural soil used where available, otherwise NRC (Nuclear Regulatory Commission) Regulations used (10 CFR). These are concentrations of radioactive material released in groundwater, surface water, air, soil, plants, or animals that do not exceed an annual dose equivalent of 25 mrem whole body (75 mrem max to thyroid, and 25 mrem max to any other organ (oral = o; inhalation = i; o/I = oral standard / inhalation standard).

[10] California Action Levels (1/14/2003). Used only to screen high soil levels—not a risk standard.

[11] MFC = million fibers per liter with fiber strength > 10 microns (9/8/94).

[12] EPA Standards, 40 CFR 192, Soil Cleanup Criteria (2/12/98).

[13] Water Health Based Limits (EPA, 1995).

Key: ***Abbreviations:*** DOE = U.S. Department of Energy; mrem = millirems; NE = not established; NPDES = National Pollutant Discharge Elimination System (regulates point source discharges of surface water to drainage channels).

Chemical Synonyms: 1,1-DCA=1,1-dichloroethane; 1,2-DCA=1,2-dichloroethane; 1,1-DCE= 1,1-dichloroethylene; cis-1,2-DCE and trans-1,2-DCE = cis/trans-1,2-dichloroethylene; PAHs = polyaromatic hydrocarbons; PCBs = polychlorinated biphenyls; 1,1,1-TCA = 1,1,1-trichloroethane; TCDD-TEQ = TCDD-toxic equivalency.

Table N-2. Standard Requirements

Standard	**Citation**	**Requirements**
National Primary Drinking Water Standards—MCL	Safe Drinking Water Act:40 CFR Part 141	Establishes health-based standards (maximum contaminant levels, or MCLs), monitoring requirements, and treatment techniques for public water systems.
National Primary and Secondary Ambient Air Quality Standards—NAAQS	Clean Air Act: 40 CFR Part 50	Establishes standards for ambient air quality to protect public health and welfare (including standards for particulate matter and lead).
National Emissions Standards for Hazardous Air Pollutants—NESHAPs	Clean Air Act: 40 CFR Part 61	Establishes emissions standards for those hazardous air pollutants for which no ambient quality standards exist, but which cause, or contribute to air pollution that may increase mortality or serious irreversible or incapacitating reversible illness.
Protection of the General Population from Release of Radioactivity	Clean Air Act: 10 CFR 61.41	Concentrations of radioactive material that may be released to the general environment must not result in an annual dose exceeding 25 mrem to the body or any organ of a member of the general public.
U.S. EPA Reference Dose—RfD	U.S. EPA, 1995	The dose of a substance or chemical that is unlikely to cause toxic effects in humans who are exposed to this dose daily over a lifetime. The RfD is expressed in units of milligrams of the substance or chemical per kilogram of body weight per day
U.S. EPA Cancer Potency Factor—CPF	U.S. EPA, 1995	"Slope factor" or "potency slope" is the measure of potency for carcinogens. This number is projected from a mathematical extrapolation model that uses data for each carcinogen. It is expressed as the cancer risk per unit dose where the dose is typically expressed in units of milligrams of the substance or chemical per kilogram of body weight per day.

Appendix O. Compilation of the Data and Reports Reviewed

Table O-1. Environmental Sampling for Chemicals Surrounding Santa Susana

Media Sampled (Date and Laboratory of Monitoring)					
Location	**Soil**	**Groundwater**	**Surface Water**	**Airborne Particles**	**Chemical Exposure**
On site	•1954–1998 (Rocketdyne) •1992–1998 (Ogden) •1993, 1995 (McLaren/Hart) •1996 (ORISE)	•1960–1986 (Rocketdyne) •1984–1998 (GRC)	•1970–1998 (Rocketdyne)	•1957–1998 (Rocketdyne) •1990–1992 (Rocketdyne)	•1971–present (Rocketdyne) •1981–present (DHS-RHB)
Off site: north	•1959–1989 (Rocketdyne) •1992–1998 (Ogden) •1993, 1995 (McLaren/Hart) •1997 (Rocketdyne)	•1984–1998 (GRC)	•1984–1998 (Rocketdyne) •1993, 1995 (McLaren/Hart)	•1989 (Rocketdyne) •1989 (DHS) •1989 (LLNL)	•1974–present (Rocketdyne) •1992–1994 (EPA-ORIA)
Off site: east	•1959–1989 (Rocketdyne) •1992–1998 (Ogden) •1994 (Rocketdyne) •1996 (ORISE) •1999 (LLNL)	•1984–1998 (GRC)	•1984–1998 (Rocketdyne) •1984–1998 (GRC)	•1959–1998 (Rocketdyne)	•1974–present (Rocketdyne)
Off site: south	•1954–1998 (Rocketdyne) •1992–1998 (Ogden) •1993, 1995 (McLaren/Hart)	•1984–1998 (GRC)	•1954–1998 (Rocketdyne)	•1989 (Rocketdyne) •1989 (DHS) •1989 (LLNL)	•1974–present (Rocketdyne)
Off site: west	•1959–1964 (Rocketdyne) •1992–1998 (Ogden) •1993, 1995 (McLaren/Hart)	•1984–1998 (GRC)	None	None	•1971–present (Rocketdyne)

Table O-2. Environmental Sampling for Radiation/Radioactivity Surrounding Santa Susana

Media Sampled (Date and Laboratory of Monitoring)					
Location	**Soil**	**Groundwater**	**Surface Water**	**Airborne Particles**	**Radiation Exposure**
On site	•1956–present (Rocketdyne) •1975, 81, 84 (ANL) •1986–1987 (ORAU) •1992–present (ORISE) •1993 (RWQCB) •1992–present (DHS-RHB) •1992–1995 (DHS-EMB)	•1960–1986 (Rocketdyne) •1984–present (GRC) •1998 (EPA-ORIA)	•1970–present (Rocketdyne) •1993–1998 (RWQCB)	•1956–present (Rocketdyne)	•1971–present (Rocketdyne) •1975, 81, 84 (ANL) •1981–present(DHS-RHB) •1986–1987 (ORAU) •1992–present (ORISE)
Off site: north	•1956–1989 (Rocketdyne) •1992–1994 (McLaren-Hart) •1992–1994 (EPA-ORIA) •1992–1994 (DHS-EMB) •1991–1997 (Cehn) •1995 (Rocketdyne) •1995 (ORISE)	•1984–present (GRA) •1991–1996 (Cehn) •1998 (EPA-ORIA)	•1992–1994 (McLaren-Hart) •1992–1994 (EPA-ORIA) •1992–1994 (DHS-EMB) •1992–1997 (Cehn)	•1989 (DHS-RHB and LLNL)	•1974–present (Rocketdyne) •1992–1994 (EPA-ORIA) •1995 (ORISE)
Off site: east	•1956–1989 (Rocketdyne) •1986 (ORAU) •1994 (Rocketdyne) •1995 (ORISE) •1997 (LLNL)	•1984–present (GRC)	•1961–1971 (Rocketdyne)	•1959–present (Rocketdyne)	•1974–p–present (Rocketdyne) •1986 (ORAU) •1995 (ORISE)
Off-site: south	•1956–1989 (Rocketdyne) •1992–1994 (McLaren-Hart) •1992–1994 (EPA-ORIA) •1992–1994 (DHS-EMB) •1992–1994 (Cehn) •1995 (Rocketdyne) •1998 (Ogden)	•1984–present (GRC)	•1966–1989 (Rocketdyne)	•1989 (DHS-RHB and LLNL)	•1974–present (Rocketdyne)
Off site: west	•1956–1964 (Rocketdyne) •1992–1994 (McLaren-Hart) •1992–1994 (EPA-ORIA) •1992–1994 (DHS-EMB) •1992–1994 (Cehn) •1995 (Rocketdyne)	•1984–present (GRC)	None	None	•1974–present (Rocketdyne)

Appendix P. Regulatory Oversight

The information summarized in this appendix comes primarily from a report titled "Perchlorate Source Evaluation and Technical Report, Santa Susana Field Laboratory, Ventura County, California," prepared by MWG, Pasadena, California, for Rocketdyne, February 2003.

SSFL has conducted various environmental programs under the jurisdiction of several regulatory agencies. Because it is an active facility, there are four environmental programs at SSFL under the authority of the federal Resource Conservation and Recovery Act (RCRA). However, there are other federal, state, and county environmental programs. Both RCRA- and non-RCRA-related programs are described in the following sections.

P-1. Non-RCRA Programs

Environmental programs not related to RCRA include environmental permitting (including air and surface water discharges), other types of site investigation, and closure activities. These programs, under the jurisdiction of various agencies, include the activities described below.

Environmental Permitting

SSFL is an active industrial facility with several types of environmental permits. Surface water discharge from SSFL is regulated under a National Pollutant Discharge Elimination System (NPDES) permit issued by the Regional Water Quality Control Board (RWQCB) in 1984. Surface water discharges from the site are monitored at eight outfall locations. Since 1998, approximately 2,400 laboratory analyses have been performed on over 200 samples collected from those outfalls. The RWQCB issued Waste Discharge Requirements (WDR) to regulate sewage and industrial waste discharge on site (i.e., non-hazardous leach fields). There are no longer any active sewage discharge or leach fields at SSFL, and the WDR permit was rescinded by the RWQCB in 1994. Air discharge permits and asbestos compliance permits are under the jurisdiction of the Ventura County Air Pollution Control District (VCAPCD). Regular emissions monitoring for carbon monoxide, nitrogen and sulfur oxides, reactive organic compounds, particulate matter, and radiological components is performed at SSFL in compliance with these permits. In addition, lead and asbestos abatement work at the facility is done under permits issued by the VCAPCD and/or California Occupational Safety and Health Administration.

Landfills

Non-hazardous solid waste landfills are regulated by the RWQCB and the Ventura County Environmental Health Division (VCEHD). Currently, SSFL has two inactive non-hazardous landfills, which are inspected quarterly by VCEHD. These landfills are to be investigated as part of the RCRA Corrective Action Program under the oversight of the California EPA's Department of Toxic Substances Control (DTSC), RWQCB, and VCEHD. There are no designated hazardous waste landfills at SSFL.

Fuel Tank Investigation/Closure

Two tank investigation programs are being conducted at SSFL. The underground storage tank (UST) program includes soil investigation and cleanup associated with fuel USTs at SSFL; fuel UST closures were under the jurisdiction of VCEHD. VCEHD transferred oversight and closure of fuel USTs at SSFL to DTSC as part of the ongoing RCRA Corrective Action Program.

Mixed and Radioactive Waste Monitoring and Closure Activities

Radioactive materials have been used in Area IV of SSFL. The only remaining nuclear-related activity at SSFL is decontamination and decommissioning of former nuclear facilities. DOE owns some buildings and equipment in Area IV and has primary jurisdiction over monitoring radioactive materials in this area. The California Department of Health Services' Radiologic Health Branch (DHS-RHB) oversees Boeing's Radioactive Materials License, radioactive facility cleanup, and environmental monitoring. Solid Waste Management Units (SWMUs) identified in the RCRA Facility Assessment (RFA) with potential radioactive contamination (SAIC, 1994) are being addressed by the DOE site closure programs. Potential chemical contamination at these sites is being addressed under the RFI under the DTSC oversight.

P-2. RCRA Programs

The RCRA-related activities include four major environmental programs at SSFL, all under the oversight and jurisdiction of DTSC.

Groundwater Characterization and Remediation

This ongoing program consists of groundwater monitoring and remediation. Approximately 381 wells, springs, and shallow piezometers are included in the monitoring program. As part of the site characterization program, Boeing monitors groundwater in these wells according to the DTSC-approved groundwater monitoring plan. To date, approximately 12,000 chemical analyses have been performed on over 7,800 samples collected from groundwater wells. Groundwater monitoring and remediation are also performed in support of the surface impoundment Post-Closure Permits. Thirty-two of the onsite wells serve as extraction wells for the eight RCRA-permitted groundwater treatment systems (GWTS). Three of the GWTS are on standby. Effluent sampling at the GWTS locations has been conducted since 1986. To date, approximately 6,900 samples have been collected under the auspices of this program. These samples have been analyzed for volatile organic compounds, but also for perchlorate at three of the treatment systems.

RCRA Corrective Action

This program includes the RFA, RCRA facility investigation (RFI), corrective measures study, and corrective measures implementation phases. The RCRA Corrective Action Program at SSFL is being conducted in response to requirements specified in three Hazardous Waste Facility

Permits issued to Boeing by the DTSC. The three permits governing the RCRA Corrective Action Program at SSFL are (1) the Areas I and III Post-Closure Permit issued in 1995, (2) the Area II Post-Closure Permit issued in 1995, and (3) the Area IV Hazardous Waste Management Facility Operating Permit issued in 1993.

The first phase of the RCRA Corrective Action process, the RFA, was conducted for the U.S. Environmental Protection Agency (EPA) in 1989 by SAIC (1994). This program identified 122 SWMUs and areas of concern at SSFL. These include units at SSFL that have used, stored, or handled various hazardous materials. Since 1984, approximately 16,500 laboratory analyses have been performed on over 8,300 samples collected from surficial media. RFI reports presenting these data and evaluating potential risks to human health and the environment will be submitted to DTSC review.

Closure of Inactive RCRA Units

This program includes the closure of 12 units used to manage RCRA-regulated wastes. These units include 10 surface impoundments, a polychlorinated biphenyls (PCB) storage area, and a hazardous waste storage area. Nine of the surface impoundment have been issued Post-Closure Permits administered by DTSC. Two Post-Closure Permits have been issued for the surface impoundments at SSFL. The first applies to five Boeing impoundments in Areas I and III, and the second to four NASA impoundments in Area II. These Post-Closure Permits were finalized and issued to Boeing in May 1995. One of the surface impoundments has been closed without requiring post-closure care.

Compliance/Permitting of RCRA Units

This program includes the permitting and compliance of active and inactive RCRA-regulated units at SSFL, including storage areas and waste disposal practices. The three current permits issued by DTSC for active RCRA facilities at SSFL include the Areas I and III Post-Closure Permit and the Area II Post-Closure Permit for groundwater treatment system operations, and the Operating Permit for the Area IV Hazardous Waste Management Facility. Interim status authorization has also been issued to Boeing by DTSC to operate the DOE-owned Area IV Radioactive Materials Handling Facility.

Appendix Q. Comments on EPA's Hazard Risk Scoring (HRS) for SSFL

The following letter contains comments on EPA's HRS for ETEC. The HRS evaluation is generally done when a site is being considered for Superfund status. The letter was written by Dr. Yoram Cohen to John Beach of EPA Region 9.

From the Desk of Dr. Yoram
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MEMORANDUM

December 9, 2003

To: John Beach
Environmental Scientist
US EPA Region 9, WST-5
75 Hawthorne St.
San Francisco, CA 94105

From: Dr. Yoram Cohen
Chemical Engineering Department
UCLA

Re: SSFL – EPA HRS Report

We have reviewed EPA's Site Inspection Report by ETEC and the HRS Score Sheets. We have some concerns regarding the basis on which certain conclusions were made as detailed below.

1. The HRS report is based exclusively on radionuclides. We believe it is inappropriate to assess an HRS ranking of this site without simultaneous consideration of all contamination. Radionuclide and chemical contamination should be evaluated regardless of whose jurisdiction the chemical contamination is under.

2. It appears that some waste characteristics (e.g., decay products) and bioaccumulation potential) may have not been used in this assessment as mandated under SARA, 1986, Section 105 (C) (1).

3. Groundwater beneath the site has historically been used for livestock. Due to the bio-accumulative nature of compounds detected north of ETEC we believe that not all pathways to human exposure were considered. In fact, the EPA's HRS protocol stipulates that effects through the food chain (livestock watering and food crop irrigation) be given adequate consideration (SARA, 1986, Section 105 (C) (1)).

4. The second conclusion was that no offsite contamination of air, soil and water was identified. This conclusion appears to have been based on three reports used in the assessment. However, there are two concerns with this statement:
    a. The accuracy and thoroughness of the monitoring on which these conclusions were based is in question. It is well known that the lack of data or uncertainty in inputs tends to skew HRS results towards lower values (Haness and Warwick, 1991).
    b. No air monitoring was conducted, nor was potential air contamination considered. There is mention of continuous air monitoring for radioactivity along the perimeter of Area IV, however, no data were shown or discussed.
    c. Potential emissions of subsurface organic solvents were not assessed.

5. The quantitative basis for the decision (the HRS scores for individual pathways) was not presented in the report that we received. Therefore, it is inappropriate to accept the conclusions of the report at face value.

6. It was concluded that cesium-137 and strontium-90 were detected at concentrations “significantly above background”. These samples were taken from the former Rocketdyne Employee shooting range and the orange groves at Santa Monica Mountains Conservancy. Potential existed for employee-transport of contamination (as suggested by detection at the shooting range) and for indirect human exposure through the food chain (orange grove). It is also noted that sampling was limited (only four sites were sampled). Given the above, the HRS report should have addressed such information. Considering that the re-sampling effort was not conducted until 2 years later and that at that time the only radionuclide monitored for was tritium, there are also concerns regarding the potential for continued exposure due to insufficient follow-up.

7. The 1998 Bell Canyon surface water study is deficient since it relied on backgrounds near potential air dispersion points between SSFL and Bell Canyon. If the object was to detect mobility of contaminants from SSFL to Bell Canyon, backgrounds should not have been taken between these areas.

8. The 1992 BBI surface water sampling study was also deficient due to lack of water sampling downstream from the SRE and RD-51 watershed (McClaren-Hart, ’93). Indeed, radiation was found north of these areas (significantly above background) in ’92 soil samples from (McClaren-Hart,’93).
    a. Cs-137: 0.23 and 0.34 pCi/g at BB-19 north of SRE watershed;
    b. Plu-138: 0.22 pCi/g at BB-15 north of RD-51 watershed.

    The above monitoring study is also subject to criticism for the lack of surface water samples north of NPDES outfalls 005-007 (BB-18) and the area of Meier Creek downstream of these areas.

9. It is customary to consider future threats associated with contamination sites. However, the future use of the SFFL site was not considered.

10. Monitoring protocols used in the studies on which the HRS assessment relied were found to be deficient. EPA, Las Vegas identified problems with the sampling techniques used in

> the Area IV characterization survey. Specific problems were related to survey instrument calibration procedure, use of large grid spacing, and filtration of water samples, all of which could have resulted in under-reporting and inaccuracies in detection of contamination.

The above comments reflect our concern that the EPA HRS analysis, as reflected in the report that we reviewed, is incomplete. A more complete HRS analysis is needed with considerations for re-sampling areas using standard EPA protocols and methods. Other radionuclides should be included in grid-sampled soil and water monitoring. Moreover, chemical contamination needs to be considered as well potential future site use.

Appendix R. Dose and Dose Ratio Estimations

R-1. Dose Estimation

Three scenarios were selected for exposure dose analysis: residential, occupational, and recreational. Assumptions regarding exposures for these scenarios are based on EPA guidelines and are listed in Table R-1.

Dose analysis was carried out using concentration data or estimated concentrations (e.g., for air). Concentrations in air were estimated from air dispersion modeling (Appendices I and S). The Risk Assessment Information System (RAIS) was first used to screen all offsite contaminant concentrations (Appendix H; offsite monitored surface water, groundwater, and soil concentrations). Only contaminant concentrations that resulted in dose levels above EPA-suggested standards (e.g., as determined based on cancer risk exceeding 10^{-6} and Hazard Indices exceeding unity for systemic diseases) were considered for further analysis. Contaminant concentrations (from monitoring data for offsite groundwater, surface water, and soil) that exceeded health-based standards or guidelines are provided in Appendix N, with the corresponding detection levels provided in Appendix H and Table R-2. Air inhalation doses are given in Appendix T. Exposure doses and dose ratios were estimated for recreational, occupational, and residential exposure scenarios. The estimated potential air exposure (inhalation) doses were divided by the Average Lifetime Acceptable Daily Dose (ALADD) to derive dose ratios, which were used to compare conservative exposure scenarios for chemical and location screening purposes. ALADDs were calculated as follows:

Carcinogens: ALADD = 1×10^{-6} cancer risk / EPA's cancer potency factor
Systemic contaminants: ALADD = EPA's reference dose

Specific health-based standards or guidelines for the ALADD calculations are listed in Table R-3, and the ALADD values are given in Table R-4. Dose ratios exceeding unity are presented in Table R-5.

R-2. Estimations of Doses from Exposure to Contaminated Offsite Soil and Groundwater

Exposure pathways for the various scenarios were as follows:

- Residential: (1) soil ingestion, (2) ingestion of edible crops, (3) groundwater ingestion,[R-1] (4) groundwater dermal contact while showering, (5) groundwater inhalation during household use,[R-2] and (6) surface water dermal contact.

- Recreational: (1) soil ingestion, (2) groundwater ingestion, and (3) surface water dermal contact.

- Occupational: (1) soil ingestion and (2) groundwater ingestion.

[R-1] Groundwater ingestion, inhalation, or contact would only apply to residents or workers using water that taps into a private well which uses groundwater as a source. This condition applies to residential scenarios 3, 4, and 5, residential scenario 2, and occupational scenario 2.

[R-2] "Household use" refers to cleaning, mopping, etc., with private well water (see footnote 1).

Table R-1. Deviation from the General Equation Where Applicable

Medium	Pathway	Scenario					
		Recreational		Occupational		Residential	
		Dose Eqn	Exposure Assumptions	Dose Eqn	Exposure Assumptions	Dose Eqn	Exposure Assumptions
SW	Dermal contact	(C × CF × PC × SA × ET × EF × ED) / (AT × BW)	C = SW conc. (mg/L) CF = 1 m/100 cm × 1000 L/m^3 PC = chem. spec. permeab. factor (cm/h) SA = 1.94 m^2 ET = 1 h/d; EF = 45 d/yr	NA		(C × CF × PC × SA × ET × EF × ED) / (AT × BW)	C = SW conc. (mg/L) CF = 1 m/100 cm × 1000 L/m^3 PC = chem. spec. permeab. factor (cm/h); EF = 45 d/yr SA = 1.94 m^2; ET = 1 h/d
Soil	Ingestion	(C × FI × EF × ET × CF × ED × IR) / (AT × BW)	C = soil conc. (mg/kg) FI = fraction ingested (1) EF = 75 d/yr; ET = 1 hr/d; CF = 1 d/24 hr IR = 0.0001 kg/d	(C × FI × EF × ED × IR) / (AT × BW)	C = soil conc. (mg/kg) FI = fraction ingested (1) EF = 225 d/yr IR = 0.0001 kg/d	(C × FI × EF × ED × IR) / (AT × BW)	C = soil conc. (mg/kg) FI = fraction ingested (1) EF = 350 d/yr; IR = 0.0001 kg/d
	Vegetable ingestion	NA		NA		(C × BUF × FI × IR × EF × ED) / (AT × BW)	C = soil conc. (mg/kg)* BUF = chem. spec. soil to plant biouptake factor FI = fraction ingested (0.4) IR= 0.2 kg/d; EF = 350 d/yr
GW	Ingestion	(C × IR × EF × ET × ED) / (AT × BW)	C = conc. in GW (mg/L) IR = 0.05 L/d EF = 45 d/yr; ET = 1 hr/d	(C × IR × EF × ED) / (AT × BW)	C = conc. in GW (mg/L) IR = 0.8 L/d EF = 225 d/yr	(C × IR × EF × ED) / (AT × BW)	C = conc. in GW (mg/L) IR = 2 L/d; EF = 350 d/yr
	Indoor inhalation	NA		NA		(C × IR × K × EF × ED) / (AT × BW)	C = conc. in GW (mg/L) K = 0.0005 × 1000 L/m^3 EF = 350 d/yr; IR = 20 m^3/d
	Dermal contact during showering	NA		NA		(C × CF × PC × ET × SA × ED × EF) / (AT × BW)	C = conc. in GW (mg/L) CF = 1 m/100 cm × 1000 L/m^3 PC = chem. spec permeab. factor ET = 0.24 h/d SA = 1.94 m^2; EF = 350 d/yr

Notes: Eqn = equations; **SW** = surface water; **S** = soil; **GW** = groundwater; **C** = contaminant concentration; **CF** = unit conversion factors; **PF** = permeability factor (chemical-specific; see Table R-4); **SA** = skin surface area (EPA, 1992); **ET** = exposure time (EPA, 1992); **EF** = exposure frequency (EPA, 1991a–c); **ED** = exposure duration (30 yr) (EPA, 1991a–d); **AT** = averaging time (365 d/yr × ED for non-carcinogens, 365 d/yr × 70 yr for carcinogens) (EPA, 1989b–d, 1991a–d); **BW** = body weight (70 kg) (EPA, 1991a–c); **FI** = fraction ingested (Exposure Factors Handbook, EPA, 1995); **IR** = intake rate (EPA, 1995b); **BUF** = plant biouptake factors, which is the ratio of contaminant concentration in a plant to the contaminant concentration in soil; represents the amount fraction of contaminant in soil uptake by the plant [(mg/kg) / (mg/kg) = unitless]; **K** = volatilization factor (0.0005 × 1000 L/m^3) (EPA, 1991a–c); **NA** = not applicable. * Ingestion of vegetables from groundwater contamination calculated directly from RAIS. *All chemical-specific factors were taken from the EPA Web site: http://rais.ornl.gov/homepage/rap_tool.shtml.*

Table R-2. Offsite Monitored Concentrations and Detection Locations Used to Estimate Doses and Dose Ratios

Contaminant	Medium	Detection Location		
		South	**East**	**North**
Lead	S (mg/kg)	383		280
	GW (mg/L)		0.05–2.239	
Beryllium	S (mg/kg)	500–1000		
	SW (mg/L)			0.005–0.008
	GW (mg/L)		0.007–0.123	
Arsenic	S (mg/kg)	1–14		8.2–24
	GW (mg/L)		0.0727–3.217	
Manganese	GW (mg/L)		0.39–35	
Chloromethane	GW (mg/L)			0.019
TCE	GW (mg/L)			0.01–0.9
Vinyl chloride	GW (mg/L)			0.064
Benzene	GW (mg/L)			0.0038
	SW (mg/L)			0.0056
Carbon tetrachloride	GW (mg/L)			0.0045
1,1-DCE	GW (mg/L)			0.019
Cis-1,2-DCE	GW (mg/L)			0.027–0.63
DEHP	SW (mg/L)			0.066–0.17
PCB	SW (mg/L)			0.092–0.12
Perchlorate	GW (mg/L)			0.004–0.15
	V (mg/kg)		32–57	

Notes: SW = surface water; GW = groundwater; S = soil; V = vegetation.

Table R-3. Chronic Systemic Reference Doses, Chronic Cancer Potency Factors, and Biouptake Factors for Dose Ratio Evaluations

		Systemic Reference Doses (RfD)			**Cancer Potency Factors (PF)**			**Biouptake Factors**	
Chemical	**Target Organ**	**Oral RfD** mg/kg-d	**Inhalation RfD** mg/kg-d	**Dermal RfD** mg/kg-d	**Oral PF** Risk per mg/kg-d	**Inhalation PF** Risk per mg/kg-d	**Dermal PF** Risk per mg/kg-d	**k** cm/h	**Soil to Plant (Wet) Uptake**
Arsenic	Skin	3.0E04	—	1.23E-04	1.5	15.1	3.66	1.93E-03	0.01
Benzene	Blood	4.0E-03	8.57E-03	3.8E-03	0.055	0.0273	0.0567	2.07E-02	0.47
Beryllium	Lung	2.0E-03	5.71E-06	2.0E-05	4.3	8.4	430	6.60E-04	0.0025
1,3-Butadiene	CNS	—	5.71E-04	—	—	0.105	—	2.31E-02	0.53
Cadmium	Lung	5.0E-04	—	5.0E-06	—	6.3	—	3.50E-04	0.14
Carbon tetrachloride	Liver	7.0E-04	—	4.5E-04	0.13	0.0525	0.2	2.24E-02	0.18
Chloromethane	Liver	—	2.57E-02	—	0.013	0.0063	0.0163	4.15E-03	2.3
Chromium VI particulates	Lung	3.0E-03	2.86E-05	6.0E-05	—	42	—	1.00E-03	0.0001
1,1-DCA	Liver	1.0E-01	1.43E-01	1.0E-01	—	—	—	8.86E-03	0.7
1,2-DCA	Liver	—	—	—	0.091	0.091	0.091	5.34E-03	1.0
1,1-DCE	Liver	5.0E-02	5.71E-02	5.0E-02	0.6	0.175	0.6	1.59E-02	0.7
1,2-DCE (mixed)	Liver	9.0E-03	—	7.2E-03	—	—	—	1.49E-02	4.1
Cis-1,2-DCE	Liver	1.0E-02	—	1.0E-02	—	—	—	1.49E-02	0.61
Trans-1,2-DCE	Liver	2.0E-02	—	2.0E-02	—	—	—	1.49E-02	4.1
UDMH	Liver	—	—	—	3	17.2	6.0	1.17E-04	3.5
DEHP	Liver	2.0E-02	—	3.8E-03	0.014	—	0.0737	1.97E+00	0.011
Hydrazine	Liver	—	—	—	3	17.2	6.0	4.12E-05	130
Lead	CNS	—	—	—	—	—	—	3.42E-04	0.0007
Manganese	Thyroid	4.6E-02	1.43E-05	1.84E-03	—	—	—	1.28E-03	0.069
Mercury	CNS	—	8.57E-05	—	—	—	—	3.14E-04	0.3
MMH	Liver	—	—	—	3	17.2	6.0	1.79E-04	31
Nickel	All	2.0E-02	—	5.4E-03	—	—	—	3.29E-04	0.05
NDMA	Liver	8.0E-06	—	4.0E-06	51	49	102	2.65E-04	16
Perchlorate	Thyroid	7.0E-04	—	—	—	—	—	8.00E-05	—
PCB	All	—	—	—	2	2	2.22	9.22E-01	0.0025
Toluene	CNS	2.0E-01	1.14E-01	1.6E-01	—	—	—	4.53E-02	0.21
TCE	Liver	3.0E-04	1.14E-02	4.5E-05	0.4	0.4	2.67	1.57E-02	0.31
Vinyl chloride	Liver	3.0E-03	2.86E-02	3.0E-03	1.4	0.0308	1.4	1.13E-02	1.2
Zinc	Enzyme	3.0E-01	—	6.0E-02	—	—	—	3.42E-04	0.26

Notes: All health standards and chemical-specific factors were taken from the EPA Web site: http://risk.lsd.ornl.gov/homepage/rap_tool.shtml. **k** = permeability factor**.**

Table R-4. Acceptable Lifetime Average Daily Doses (mg/kg-d) as Determined from Reference Doses and Cancer Potency Factors (for 1×10^{-6} risk or one cancer per one million people)

Contaminant	Dermal ALADD	Oral ALADD	Inhalation ALADD
Arsenic	2.73×10^{-7}	6.67×10^{-7}	6.6×10^{-8}
Benzene	1.76×10^{-5}	1.8×10^{-5}	3.66×10^{-5}
Beryllium	2.0×10^{-9}	2.33×10^{-7}	1.19×10^{-7}
Carbon tetrachloride	5.0×10^{-6}	7.6×10^{-6}	1.9×10^{-5}
Chloromethane	6.14×10^{-5}	7.69×10^{-5}	1.59×10^{-4}
Cis 1,2-DCE	1.0×10^{-2}	1.0×10^{-2}	—
1,1-DCE	1.667×10^{-6}	1.67×10^{-6}	5.7×10^{-6}
DEHP	1.36×10^{-5}	7.14×10^{-5}	—
Lead	—	—	—
Manganese	1.84×10^{-3}	4.6×10^{-2}	1.43×10^{-5}
PCB	4.5×10^{-7}	5.0×10^{-7}	5.0×10^{-7}
Perchlorate	—	7.0×10^{-4}	—
TCE	3.75×10^{-7}	2.5×10^{-6}	2.5×10^{-6}
Vinyl chloride	7.14×10^{-7}	7.14×10^{-7}	3.25×10^{-5}

Note: ALADDs were calculated from reference doses for manganese, perchlorate, and cis-1,2-DCE.

Table R-5. Estimations of Dose and Dose Ratios for Monitored Offsite Groundwater, Surface Water, and Soil Concentration

Chemical	**Location**	**Medium**	**Pathway**	**Scenario**					
				Recreational		**Occupational**		**Residential**	
				Dose (mg/kg-d)	Dose Ratio	Dose (mg/kg-d)	Dose Ratio	Dose (mg/kg-d)	Dose Ratio
Lead	South	S	Ingestion	See LeadSpread[1] results for residential concerns (Table R-7)					
	East	GW	Ingestion						
	North	S	Ingestion						
Arsenic	South	S	Ingestion	5.0×10^{-9} to 7.0×10^{-8}	<1	3.8×10^{-7} to 5.3×10^{-6}	1 to 8	5.9×10^{-7} to 8.2×10^{-6}	1 to 12
			Veg. ing.	—	—	—	—	4.7×10^{-6} to 6.6×10^{-5}	7 to 99
	North	S	Ingestion	4.1×10^{-8} to 1.2×10^{-7}	<1	1.0×10^{-6} to 3.0×10^{-6}	2 to 5	4.8×10^{-6} to 1.4×10^{-5}	7 to 21
			Veg. ing.	—	—	—	—	$3.9\times10^{-45}$to 1.1×10^{-4}	58 to 170
Chloromethane	North	GW	Ingestion	7.2×10^{-7}	<1	5.7×10^{-5}	1	2.2×10^{-4}	3
			Inhalation	—	—	—	—	1.1×10^{-3}	7
			Dermal	—	—	—	—	2.2×10^{-6}	<1
			Veg. ing.	—	—	—	—	8.4×10^{-4}	11
TCE	Northeast	GW	Ingestion	3.8×10^{-7} to 3.4×10^{-5}	0 to 14	3.0×10^{-5} to 2.7×10^{-3}	12 to 1,100	1.2×10^{-4} to 1.1×10^{-2}	48 to 4,200
			Inhalation	—	—	—	—	5.9×10^{-4} to 5.3×10^{-2}	230 to 21,000
			Dermal	—	—	—	—	4.5×10^{-6} to 4.0×10^{-4}	12 to 1,000
			Veg. ing.	—	—	—	—	1×10^{-4} to 1×10^{-2}	44 to 4,000
Vinyl chloride	Northeast	GW	Ingestion	2.4×10^{-6}	3	2.0×10^{-4}	270	7.5×10^{-4}	1,100
			Inhalation	—	—	—	—	3.8×10^{-3}	120
			Dermal	—	—	—	—	2.1×10^{-5}	29
			Veg. ing.	—	—	—	—	1.7×10^{-3}	2,400
Perchlorate*	North	GW	Ingestion	3.5×10^{-7} to 1.3×10^{-5}	<1	2.8×10^{-5} to 1.1×10^{-3}	<1 to 20 to 1	1.1×10^{-4} to 4.1×10^{-3}	<10 to 62
	East	V	Ingestion	—	—	—	—	9.3×10^{-3} to 1.7×10^{-2}	13 to 24

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[1] LeadSpread 7 was used to evaluate blood lead levels from potential environmental exposure to lead. LeadSpread is a software tool, developed by the California Department of Toxic Substances Control, to estimate blood lead concentrations resulting from lead exposure via dietary intake, drinking water, soil and dust ingestion, inhalation, and dermal contact. The above five pathways are added to obtain estimate of median blood lead concentration resulting from the multi-pathway exposure. Ninetieth, ninety-fifth, ninety-eighth, and ninety-ninth percentile concentrations are estimated from the median by assuming a log-normal distribution with a geometric standard deviation of 1.6. LeadSpread can be downloaded from http://www.dtsc.ca.gov/AssessingRisk/leadspread.cfmhttp://www.dtsc.ca.gov/AssessingRisk/leadspread.cfm.

Chemical	Location	Medium	Pathway	Scenario					
				Recreational		Occupational		Residential	
				Dose (mg/kg-d)	Dose Ratio	Dose (mg/kg-d)	Dose Ratio	Dose (mg/kg-d)	Dose Ratio
Benzene	North	GW	Ingestion	1.4×10^{-7}	<1	1.1×10^{-5}	1	4.5×10^{-5}	3
			Inhalation	—	—	—	—	2.2×10^{-4}	6
			Dermal	—	—	—	—	2.2×10^{-6}	<1
			Veg. ing.	—	—	—	—	5.5×10^{-5}	3
Carbon tetrachloride	North	GW	Ingestion	1.7×10^{-7}	<1	1.4×10^{-5}	2	5.3×10^{-5}	7
			Inhalation	—	—	—	—	2.6×10^{-4}	14
			Dermal	—	—	—	—	2.9×10^{-6}	1
			Veg. ing.	—	—	—	—	4.1×10^{-5}	5
1,1-DCE	North	GW	Ingestion	7.2×10^{-7}	<1	5.7×10^{-5}	23	2.2×10^{-4}	89
			Inhalation	—	—	—	—	1.1×10^{-3}	200
			Dermal	—	—	—	—	8.6×10^{-6}	5
			Veg. ing.	—	—	—	—	3.4×10^{-4}	20
Cis-1,2-DCE	Northeast	GW	Ingestion	2.38×10^{-6} to 5.5×10^{-5}	<1	1.9×10^{-4} to 4.4×10^{-3}	<1	8.0×10^{-4} to 1.7×10^{-2}	0 to 2
			Dermal	—	—	—	—	1.4×10^{-5} to 3.2×10^{-4}	<1
			Veg. ing.	—	—	—	—	1.0×10^{-3} to 2.4×10^{-2}	0 to 2

Notes: SW = surface water; GW = groundwater; S = soil; V = vegetation (plant material); Veg. ing. = ingestion of vegetation. Hazard indices were calculated for contaminants for which cancer potency factors were not available. These include manganese, cis-1,2-DCE, and perchlorate. In these cases the reference dose, a systemic toxicity health-based standard, was used to compare the doses. Dose ratios above unity represent potential exposure scenarios of concern.

* There is no evidence of perchlorate detection in edible plants. The indicated value is only provided to demonstrate a hypothetical case, since the Dayton canal flows into Orcutt Ranch (see also footnote b in Table 6-5 of Chapter 6).

Table R-6. Inhalation Dose Ratio (DR) Ranges[a] for Lifetime Residents (Since 1953) Based on Max Receptor Air Concentrations (Appendix T)[b]

Receptor Location	Hydrazines and UDMH: Rocket Engine Testing (RET) and Thermal Treatment Facility (TTF)	TCE: Stripping Towers (ST) and Rocket Engine Testing (RET)
West Hills	2-14	47-314
Bell Canyon	3–35	40-241
Dayton Canyon	2-11	36-265
Simi Valley	0–4	30-229
Santa Susana Knolls	<0	10-75
Canoga Park	0–7	10-72
Chatsworth	0-1	8-72
Woodland Hills	0–8	7-74
Hidden Hills	0–3	30-86
Black Canyon	1-5	8-304
Sage Ranch (SR)	0-2	2-87
Brandeis Bardin Institute (BBI)[c]	1-3	17-503

Notes: ***a.*** Dose ratio = LADD/ALADD. ***b.*** Dose ratios are based on single to multiple source emissions.; DR calculations are presented in Appendix T).
c. DRs for BBI were multiplied by 0.25 to reflect summer only residency. DRs for SR were multiplied by 2/7 to reflect weekend use only.

R-3. Exposure to Lead

The standard elevated blood lead level (BLL) for adults set by the Centers for Disease Control and Prevention is 25 µg/dL of whole blood. This level recognizes that every adult has accumulated some lead contamination. The recommended BLL for a child is currently 10 µg/dL of blood. For lead, which does not have consensus systemic or cancer standards, the LeadSpread 7 model (developed by the California Department of Toxic Substances Control) can be used to estimate potential blood lead levels and the associated Dose Ratios (DRs) from relevant offsite monitoring data (Table R-7). This model estimates potential blood lead levels resulting from exposure to lead via dietary intake, drinking water, soil and dust ingestion, inhalation, and dermal contact. The contributions via the above pathways are added to estimate the median blood lead concentration resulting from the multi-pathway exposure.

The LeadSpread 7 model calculations indicate that for Bell Canyon and the Chatsworth area, the blood lead in children could exceed the recommended health standard of 10 µg/dL blood (Table R-7). For example, at the reported lead level of 383 mg/kg at a residence in Bell Canyon (see Appendix H, Table H-4), the LeadSpread results indicate, that pica children (children eating dirt) may have up to an estimated 13.7 µg/dL and 19.5 µg/dL lead BLL if they were playing outside every day, eating dirt, or eating food from gardens in areas with these lead levels. It is noted that recent monitoring of groundwater at the Chatsworth Reservoir (DWP, 2004) indicated groundwater lead levels of 59 to 2,239 µg/L (Appendix H, Table H-5). LeadSpread calculations suggest that ingestion of untreated and undiluted groundwater from private wells in the areas between SSFL and the Chatsworth Reservoir could result in BLLs between 13 and 315 µg/dL. The above scenario would be expected to occur if residents obtained their water from private wells and did not treat the groundwater before use or consumption. Unfortunately, the likelihood of occurrence of such exposure scenarios is unknown.

It should be noted that that Francek (1992) measured median soil-lead concentration in roadside soils of 280 mg/kg (range: 100 to 840 mg/kg), compared to 200 mg/kg (range: 100 to 220 mg/kg) in background soils. Elevated soil-lead levels are generally due to a combination of sources, it is often difficult to determine whether elevated soil-lead levels are a function of a point source emitter, lead-based paint, or leaded gasoline emissions (EPA, 1998). In addition, soil composition and background levels may vary substantially from region to region.[R-3] Therefore, it is often difficult to identify the existence of a point source by determining if there is a decrease of lead concentration with distance from a suspected source. Although lead levels in soils offsite to SSFL have been found to exceed the recommended health standard of 10 µg/dl blood for children[R-4], given the limited monitoring of lead in offsite soils, it is not possible to determine the source of this lead contamination. It is plausible that some lead contamination is the result of various contributions included, but not limited to, past usage of leaded gasoline, lead-based paints, lead containing batteries, or potential transport with stormwater drainages from SSFL.[R-5]

[R-3] Lead soil levels at the Sodium Disposal Facility (a site of hazardous waste incineration) were detected up to 864 mg/kg (GRC, 1990); this soil sample was taken in 1987 at a depth of 0.5 to 1 foot. A soil sample at one Bell Canyon residence was determined to contain up to 383 mg/kg of lead (CA EPA, 1999). The Residential Soil Screening Level is 150 mg/kg.

[R-4] Lead levels in Bell Canyon resulted in potential blood lead levels of up to 14 and 20 µg/dL for children and soil-eating children, respectively.

[R-5] Lead levels in stormwater runoff at NPDES Outfall 001 were measured at 40 µg/L (MCL = 12 µg/L) in 1995 analytes (Boeing, 1995).

Table R-7. Results from Evaluation of Offsite Lead Concentrations Surrounding SSFL

Lead Level	**Medium**	**Primary Exposure Route**	**Location**	**Blood Lead Levels** (μg/dL) **and *Dose Ratios*** (95th percentile)			
				Residential Exposure			**Occupational Exposure**
				Adult	Child	[a]Pica Child	
383 mg/kg	Soil	Soil ingestion	Bell Canyon residence	5 *<1*	14 *1*	20 *2*	3 *<1*
59–2239 μg/L	Groundwater	Groundwater ingestion	Chatsworth Reservoir	9–273 *<1-11*	13–315 *1-32*	16–317 *2-32*	8–271 *<1-11*
50 μg/L	Groundwater	Groundwater ingestion	Woolsey Canyon	8 *<1*	12 *1*	14 *1*	6 *<1*

Notes: ***a.*** A pica child is a child (1 to 2 years old) who eats soil.

R-4. Exposure to Radionuclides

Offsite radionuclide monitoring data are insufficient to provide a reliable exposure analysis. It is also noted that high tritium levels—in excess of health-based standards—were recently detected in offsite groundwater northwest of Area IV. Despite the lack of monitoring data, an approximate analysis was undertaken by the study team with the results provided in Table R-8 with an indication of the likelihood of such exposures.

There is significant uncertainty in the estimated dose ratios (Table R-8) given that available offsite monitoring data are insufficient, monitoring techniques were deficient and background sample locations were inappropriate. Although dose ratios above unity were encountered, the potential exposure pathways leading to such exposures were highly conservative and in some cases unlikely to occur. For example, dose ratios above unity that were estimated for radiological contaminants detected in surface water NPDES outfalls were the consequence of ingestion of contaminated fish from recreational fishing. Although recreational fishing has been reported further downstream of these outfalls, it is not known to occur at the outfalls. Exposures of potential concern in the Ahmanson Ranch area include exposures to K-40 via crop, milk, or livestock ingestion. While such exposures may have been a concern in the past, this land has been recently designated open space and consequently the above exposure scenarios are unlikely. Exposures of concern at Brandeis-Bardin include intake of plutonium-238 via crop ingestion. However, the area in which this radionuclide was detected was sold to Rocketdyne for use as a buffer land, and hence does exposure via the above scenario is unlikely at present.

Table R-8. Offsite Radiological Contaminants

Chemical	Phase	Concentration pCi/L (W) or pCi/g (S)	Year	Location / Sample ID	Ref	Is Exposure Likely?	Exposure Scenario/ Pathway	Dose Ratio
Radium (combined 226/228)	W	<500	1993	NPDES Outfall 002	2	Unlikely	Recreational/fish ingestion	30,000
Thorium-228	S	1.8	1998	Bell Canyon	3	Yes	Residential/crop ingestion	0.0021
							Occupational/excavation	0.4
							Residential/incidental soil ingestion/inhalation	0.07
Thorium-232	S	1.5					Residential/crop ingestion	0.017
							Occupational/excavation	0.2
							Residential/incidental soil ingestion/inhalation	0.44
Tritium	S	0.36					Occupational/excavation	0.000024
							Residential/incidental soil ingestion/inhalation	0.000048
Potassium-40	S	8.3–23	2000	Ahmanson Ranch	1	Unlikely	Residential/crop ingestion	84
						Yes	Occupational/excavation	0.13
Thorium-228	S	0.5–0.90				Unlikely as detected 0.5 ft depth.	Recreational/incidental soil ingestion/inhalation	<<1
Thorium-232	S	0.54–0.97				Unlikely as detected 0.5 ft depth.	Recreational/incidental soil ingestion/inhalation	<<1
Cesium-137	S	ND–0.32				Unlikely as detected 0.5 ft depth.	Recreational/incidental soil ingestion/inhalation	<<1
Plutonium-238	S	0.19–0.22	1992	BBI	5	Unknown	Residential/ crop ingestion	1.6
						Yes	Occupational/excavation	0.0004
Radium (total 226/228)	W	3.4 ± 3.8 to 15 ± 25	1992–1993	Outfall 003-006	2	Unlikely	Recreational/ fish ingestion	1400
Strontium-90	W	5.1 ± 5.7 to <500	1992–1995				Recreational/ fish ingestion	1200
Cesium-137	S	0.016–0.27	1997	Canoga Park SSFL Recreation Center	4	Yes	Recreational/ incidental soil ingestion/ inhalation	<<1

Notes: ND = not detected * Background samples from Ogden, 1995. † DHS-based health comparisons. **Phase Designations:** W = water; S = soil; A = air.
Location Designations: MW = monitoring wells at Las Virgenes Creek and East Las Virgenes Creek in Ahmanson Ranch; BBI = Brandeis-Bardin Institute.
Comments: IDM = insensitive detection method.
References: ***1.*** Klinefelder, 2000. ***2*** NPDES Annual Monitoring Reports. ***3.*** Ogden Inc., 1998a. ***4.*** Lawrence Livermore National Laboratory, 1997. ***5.*** McLaren/Hart, 1993, 1995.

Appendix S. Air Emissions

S-1. Overview

This appendix describes the estimation of toxic organic and toxic heavy metal air emissions from the late 1940s to the present from the following SSFL activities: (a) rocket engine tests; (b) pre- and post-degreasing of rocket engines; (c) storage tanks, stripping towers, and other evaporative sources of toxic organic emissions; and (d) open pit burning of waste material. Before developing the emission inventory, the UCLA study team reviewed the available activity reports and plotted the known activities on a timeline.

S-2. Rocket Engine Exhaust

One can estimate emissions from rocket engine exhaust by multiplying fuel use by emission factors. Data regarding the fuel used at SSFL by fuel type and year were obtained from the facility operators. Air toxic emission test data by fuel type were obtained from literature reviews and specific reports of testing at SSFL. Estimates of air toxic emissions released to the atmosphere from rocket engine tests were computed from these data.

Fuel Types and Historical Annual Usage

No fuel usage data are available for the time before 1955 or after 1990. In analyzing the available data (Sullivan, 1999), the study team learned that more than 60% of the fuel combusted in rocket engine tests—by weight in tons, from 1955 to 1990—was liquid kerosene (**Table S-1**). The second most common fuel used at SSFL was liquid hydrogen (35%). Lesser amounts of isopropyl alcohol (1.4%), hydrazine derivatives (0.5%), and pentaborane fuel (0.006%) were also combusted.

A more in-depth analysis of the available fuel usage data (**Figure S-1**) reveals that more than 80% of fuel usage took place prior to 1970:

- 80% of kerosene fuel usage took place from 1956 through 1969.
- 80% of unsymmetrical dimethylhydrazine usage took place between 1956 and 1965.
- 96% of pentaborane usage took place in 1963.

Because no fuel usage data were made available to the study team for 1948 to 1954 and all years after 1990, the amount of air toxic emissions resulting from fuel combustion from 1948 to 1954 and 1991 to the present cannot be determined. Review of the ATSDR report (1999) establishes that ethanol, kerosene, and hydrazine fuels were combusted in engines before 1955 and fuels using ethanol, kerosene, and MMH (a hydrazine derivative) were combusted in engines after 1990 (**Table S-2**).

Table S-1. Reported Fuel Usage at SSFL from 1955 through 1990

Fuel Name	Tons
Kerosene	173435
Liquid hydrogen	98351
Isopropyl alcohol	3765
Hydrazine and derivatives	1491
Pentaborane	16

Note: No data were reported for beryllium or ethanol; no data were reported for any fuels from 1948 to 1954 or beyond 1990. **Source:** Sullivan, 1999.

Figure S-1. Percent of Fuel Consumed over Life of Facility by Fuel Type

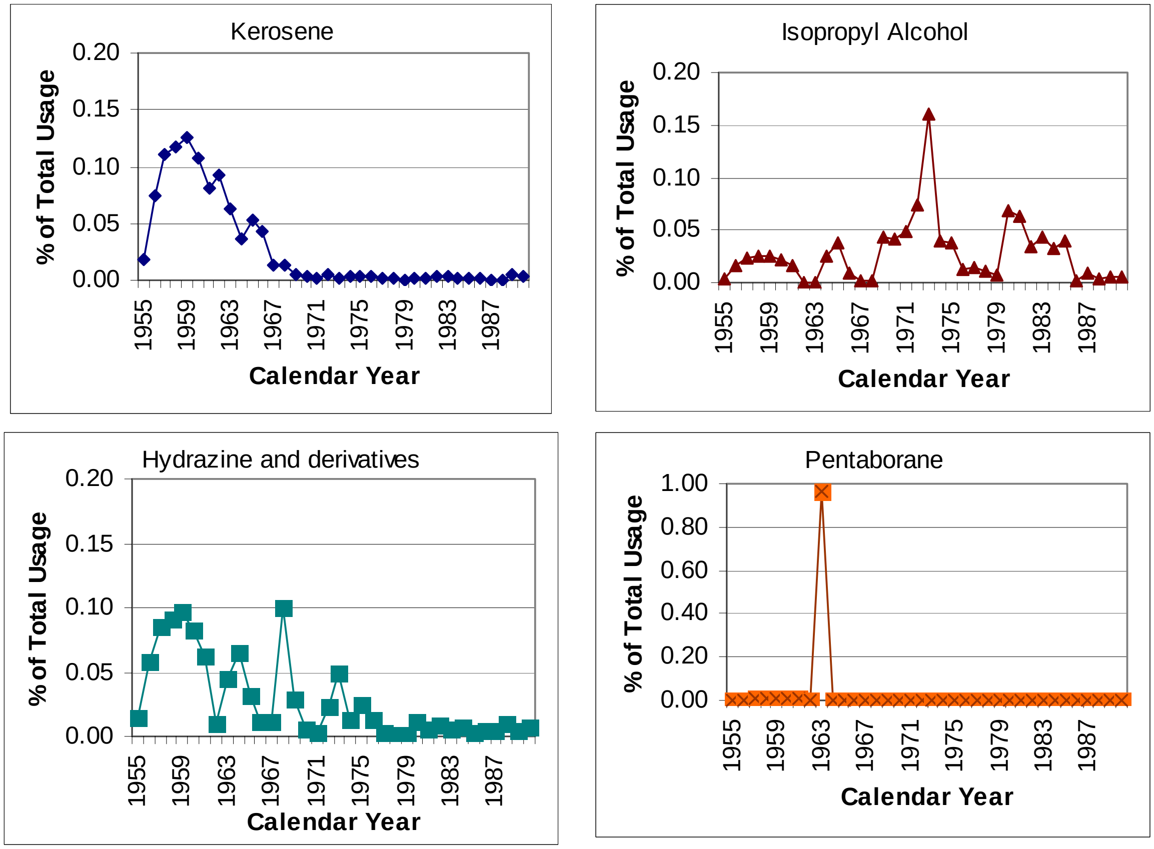

Table S-2. Overview of Rocket Engine Testing Programs at SSFL

Program	**Fuel**	**Oxidizer**	**Duration**	**Test Area**
RS-27 Delta	Kerosene	LOx	1971–present	Alfa
Atlas	Kerosene	LOx	1954–present	Alfa, Bravo, Bowl, Coca, and Delta
Navaho	Kerosene	LOx	1949–57	Alfa, Bravo, Bowl
Jupiter	Kerosene	LOx	1958–63	Alfa, Delta, Canyon
Thor	Kerosene	LOx	1956–79	Alfa, Delta, Canyon, and Bravo
3.5-inch injectors	Kerosene	LOx	1978–79	APTF
5.7-inch injectors	Kerosene	LOx	1989–91	APTF
HHC Hit with Azine	Kerosene	LOx	1991	APTF
Liquid flyback booster	Kerosene	LOx	1998	APTF
OMS	Ethanol	LOx	1998	APTF
RS-44	Hydrogen	LOx	1984–89	APTF
RS-68 gas generator	Hydrogen	LOx	1997	APTF
Advanced Experimental Thrust Program	MMH	NTO	1967	APTF
Pulse engine	MMH	NTO	Early 1980s	APTF
Static Pulse Engine	MMH	NTO	1983–86	APTF
MK-51 Turbopump	MMH	NTO	1984–85	APTF
XLR-132	MMH	NTO	1989–91	APTF
Lance	UDMH	IRFNA	1962–70	APTF, Delta
Redstone	Ethanol	LOx	1951–59	Bowl
F-1 Saturn V components	Kerosene	LOx	1959–71	Bravo
H-1 Saturn 1B	Kerosene	LOx	1958–68	Canyon
J-2 Saturn V	Hydrogen	LOx	1960–71	Coca and Delta
SSME	Hydrogen	LOx	1971–88	Coca
L-1 and L-4	Kerosene	LOx	1956–61	Delta
E-1 (pre F-1)	Kerosene	LOx	1956–60	Delta and Bravo
Transtage	Hydrazine*	NTO	1953	STL IV
Gemini	Hydrazine*	NTO	1953–54	STL IV
Liquid aircraft rockets	Hydrazine*	NTO	1955–58	STL IV
Beech	Hydrazine*	NTO	1959–66	STL IV
SE5	Hydrazine*	NTO	1960–68	STL IV
Apollo reentry	Hydrazine*	NTO	1962–69	STL IV
Condor (RS-19)	Hydrazine*	CTF	1967–70	STL IV
LEM	Hydrazine*	NTO*	1967–70	STL IV
RS-14 Minuteman	Hydrazine*	NTO*	1968–77	STL IV
OEM-6K	Hydrazine*	NTO*	1973	STL IV
RCS-600	Hydrazine*	NTO*	1973	STL IV
LE3	Hydrazine*	NTO*	1973–76	STL IV
RS21	Hydrazine*	NTO*	1975	STL IV
X70	MMH	NTO	1977–78	STL IV
EXO	MMH	NTO	1978	STL IV
MX Peacekeeper	MMH	NTO	1978–94	STL IV
MKV	MMH	NTO	1979	STL IV
HOE	MMH	NTO	1979	STL IV
KEW	MMH	NTO	1993–present	STL IV

* Other types of fuels, such as pentaborane and oxidizers, were used in these tests. **Source:** ATSDR Draft Preliminary Site Evaluation of the Santa Susana Field Laboratory (SSFL), Ventura County, California, December 3, 1999.

Table S-3. Estimates of Toxic Organics Emissions (Tons/Year) Associated with Liquid Kerosene Rocket Engine Test Exhaust

Year	Benzene	1,3-Butadiene	Chloroform	Vinylidene Chloride	Methylene Chloride	Toluene	Trichloroethylene	Vinyl Chloride	Xylene (Total)
1955	1.0	0.3	0.001	0.000	0.000	0.3	0.006	0.000	0.2
1956	4.0	1.3	0.003	0.001	0.001	1.0	0.027	0.001	0.7
1957	5.9	2.0	0.004	0.001	0.001	1.5	0.040	0.001	1.0
1958	6.3	2.1	0.005	0.001	0.001	1.6	0.042	0.001	1.1
1959	6.7	2.2	0.005	0.001	0.002	1.7	0.045	0.002	1.1
1960	5.7	1.9	0.004	0.001	0.001	1.5	0.038	0.001	1.0
1961	4.3	1.4	0.003	0.001	0.001	1.1	0.029	0.001	0.7
1962	5.0	1.7	0.004	0.001	0.001	1.3	0.033	0.001	0.8
1963	3.4	1.1	0.002	0.001	0.001	0.9	0.022	0.001	0.6
1964	1.9	0.6	0.001	0.000	0.000	0.5	0.013	0.000	0.3
1965	2.9	1.0	0.002	0.001	0.001	0.7	0.019	0.001	0.5
1966	2.3	0.8	0.002	0.000	0.001	0.6	0.016	0.001	0.4
1967	0.8	0.3	0.001	0.000	0.000	0.2	0.005	0.000	0.1
1968	0.7	0.2	0.001	0.000	0.000	0.2	0.005	0.000	0.1
1969	0.2	0.1	0.000	0.000	0.000	0.1	0.002	0.000	0.0
1970	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1971	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1972	0.2	0.1	0.000	0.000	0.000	0.1	0.002	0.000	0.0
1973	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1974	0.2	0.1	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1975	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1976	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1977	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1978	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1979	0.0	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.0
1980	0.1	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.0
1981	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1982	0.2	0.1	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1983	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1984	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1985	0.1	0.0	0.000	0.000	0.000	0.0	0.001	0.000	0.0
1986	0.1	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.0
1987	0.0	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.0
1988	0.0	0.0	0.000	0.000	0.000	0.0	0.000	0.000	0.0
1989	0.2	0.1	0.000	0.000	0.000	0.1	0.002	0.000	0.0
1990	0.2	0.1	0.000	0.000	0.000	0.1	0.001	0.000	0.0

Table S-4. Estimates of Heavy Metal Emissions (Tons/Year) Associated with Liquid Kerosene Rocket Engine Test Exhaust

Year	Arsenic	Beryllium	Cadmium	Chromium (total)	Chromium (hexavalent)	Copper	Lead	Manganese	Mercury	Nickel	Selenium	Zinc
1955	0.001	0.001	0.003	0.004	0.001	0.056	0.001	0.018	0.000	0.011	0.001	0.071
1956	0.003	0.004	0.013	0.018	0.004	0.231	0.002	0.073	0.001	0.046	0.003	0.292
1957	0.004	0.006	0.019	0.027	0.005	0.341	0.004	0.108	0.002	0.068	0.004	0.431
1958	0.004	0.007	0.020	0.029	0.006	0.366	0.004	0.115	0.002	0.073	0.004	0.462
1959	0.004	0.007	0.021	0.031	0.006	0.387	0.004	0.122	0.002	0.077	0.004	0.489
1960	0.004	0.006	0.018	0.026	0.005	0.331	0.004	0.104	0.002	0.066	0.004	0.418
1961	0.003	0.005	0.014	0.020	0.004	0.249	0.003	0.079	0.001	0.050	0.003	0.315
1962	0.003	0.005	0.016	0.023	0.005	0.288	0.003	0.091	0.002	0.058	0.003	0.363
1963	0.002	0.004	0.011	0.015	0.003	0.194	0.002	0.061	0.001	0.039	0.002	0.245
1964	0.001	0.002	0.006	0.009	0.002	0.110	0.001	0.035	0.001	0.022	0.001	0.139
1965	0.002	0.003	0.009	0.013	0.003	0.165	0.002	0.052	0.001	0.033	0.002	0.208
1966	0.001	0.003	0.007	0.011	0.002	0.134	0.001	0.042	0.001	0.027	0.001	0.169
1967	0.000	0.001	0.002	0.003	0.001	0.043	0.000	0.014	0.000	0.009	0.000	0.055
1968	0.000	0.001	0.002	0.003	0.001	0.042	0.000	0.013	0.000	0.008	0.000	0.053
1969	0.000	0.000	0.001	0.001	0.000	0.014	0.000	0.004	0.000	0.003	0.000	0.017
1970	0.000	0.000	0.000	0.001	0.000	0.009	0.000	0.003	0.000	0.002	0.000	0.011
1971	0.000	0.000	0.000	0.001	0.000	0.007	0.000	0.002	0.000	0.001	0.000	0.009
1972	0.000	0.000	0.001	0.001	0.000	0.014	0.000	0.004	0.000	0.003	0.000	0.018
1973	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.002	0.000	0.001	0.000	0.006
1974	0.000	0.000	0.001	0.001	0.000	0.009	0.000	0.003	0.000	0.002	0.000	0.011
1975	0.000	0.000	0.000	0.001	0.000	0.008	0.000	0.002	0.000	0.002	0.000	0.010
1976	0.000	0.000	0.000	0.001	0.000	0.008	0.000	0.003	0.000	0.002	0.000	0.010
1977	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.002	0.000	0.001	0.000	0.008
1978	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001	0.000	0.001	0.000	0.006
1979	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001
1980	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001	0.000	0.001	0.000	0.005
1981	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.002	0.000	0.001	0.000	0.007
1982	0.000	0.000	0.000	0.001	0.000	0.009	0.000	0.003	0.000	0.002	0.000	0.011
1983	0.000	0.000	0.000	0.001	0.000	0.008	0.000	0.002	0.000	0.002	0.000	0.010
1984	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.002	0.000	0.001	0.000	0.008
1985	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.002	0.000	0.001	0.000	0.008
1986	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.001	0.000	0.001	0.000	0.004
1987	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.003
1988	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.001	0.000	0.000	0.000	0.003
1989	0.000	0.000	0.001	0.001	0.000	0.013	0.000	0.004	0.000	0.003	0.000	0.017
1990	0.000	0.000	0.001	0.001	0.000	0.012	0.000	0.004	0.000	0.002	0.000	0.016

Table S-5. Estimate of Hydrazine and Derivatives Emissions (Tons/Year) Associated with Rocket Engine Test Exhaust

Year	Hydrazine	UDMH	MMH
1955	0.01	0.02	0.00
1956	0.04	0.09	0.00
1957	0.06	0.13	0.00
1958	0.06	0.14	0.00
1959	0.06	0.15	0.00
1960	0.05	0.13	0.00
1961	0.04	0.10	0.00
1962	0.02	0.00	0.00
1963	0.07	0.02	0.02
1964	0.06	0.05	0.03
1965	0.01	0.04	0.03
1966	0.01	0.00	0.01
1967	0.01	0.01	0.01
1968	0.10	0.10	0.03
1969	0.02	0.02	0.02
1970	0.00	0.00	0.01
1971	0.00	0.00	0.00
1972	0.03	0.00	0.03
1973	0.04	0.04	0.03
1974	0.01	0.01	0.01
1975	0.03	0.02	0.00
1976	0.02	0.01	0.00
1977	0.00	0.00	0.00
1978	0.00	0.00	0.00
1979	0.00	0.00	0.00
1980	0.00	0.00	0.02
1981	0.00	0.00	0.01
1982	0.00	0.00	0.02
1983	0.00	0.00	0.01
1984	0.00	0.00	0.02
1985	0.00	0.00	0.01
1986	0.00	0.00	0.01
1987	0.00	0.00	0.01
1988	0.00	0.00	0.02
1989	0.00	0.00	0.01
1990	0.00	0.00	0.02

Table S-6. Estimate of Trichloroethylene Emissions (Tons/Year) Associated with Rocket Engine Degreasing

Year	Trichloroethylene
1955	56
1956	231
1957	341
1958	366
1959	387
1960	331
1961	249
1962	284
1963	191
1964	114
1965	169
1966	134
1967	43
1968	42
1969	21
1970	16
1971	16
1972	27
1973	34
1974	16
1975	14
1976	10
1977	9
1978	7
1979	2
1980	17
1981	17
1982	15
1983	15
1984	12
1985	2
1986	1
1987	1
1988	0
1989	2
1990	2

Table S-7. Estimates of Emissions (Tons/Year) Associated with Other Evaporative Sources

Year	Methylchloroform	Trichloroethane	Trichloroethylene
1955	18.7	12.8	13.3
1956	18.7	12.8	54.8
1957	18.7	12.8	80.9
1958	18.7	12.8	86.6
1959	18.7	12.8	91.8
1960	18.7	12.8	78.4
1961	18.7	12.8	59.1
1962	18.7	12.8	67.3
1963	18.7	12.8	45.4
1964	18.7	12.8	27.0
1965	18.7	12.8	40.1
1966	18.7	12.8	31.8
1967	18.7	12.8	10.2
1968	18.7	12.8	9.9
1969	18.7	12.8	5.1
1970	18.7	12.8	3.8
1971	18.7	12.8	3.7
1972	18.7	12.8	6.5
1973	18.7	12.8	8.1
1974	18.7	12.8	3.9
1975	18.7	12.8	3.4
1976	18.7	12.8	2.4
1977	18.7	12.8	2.0
1978	18.7	12.8	1.6
1979	18.7	12.8	0.5
1980	18.7	12.8	4.0
1981	18.7	12.8	4.0
1982	18.7	12.8	3.6
1983	18.7	12.8	3.6
1984	18.7	12.8	18.9
1985	18.7	12.8	3.1
1986	18.7	12.8	0.9
1987	18.7	12.8	0.9
1988	18.7	12.8	0.8
1989	18.7	12.8	3.3
1990	18.7	12.8	3.1

Table S-8. Estimates of Emissions (Tons/Year) Associated with Open Pit Burning

Year	Benzene and Derivatives	Hydrazine and Derivatives	Toluene
1955	—	—	—
1956	—	—	—
1957	—	—	—
1958	—	—	—
1959	0.0875	0.658	0.0875
1960	0.0875	0.658	0.0875
1961	0.0875	0.658	0.0875
1962	0.0875	0.658	0.0875
1963	0.0875	0.658	0.0875
1964	0.0875	0.658	0.0875
1965	0.0875	0.658	0.0875
1966	0.0875	0.658	0.0875
1967	0.0875	0.658	0.0875
1968	0.0875	0.658	0.0875
1969	0.0875	0.658	0.0875
1970	0.0875	0.658	0.0875
1971	0.0875	0.658	0.0875
1972	0.0875	0.658	0.0875
1973	0.0875	0.658	0.0875
1974	0.0875	0.658	0.0875
1975	0.0875	0.658	0.0875
1976	0.0875	0.658	0.0875
1977	0.0875	0.658	0.0875
1978	0.0875	0.658	0.0875
1979	0.0875	0.658	0.0875
1980	0.0875	0.658	0.0875
1981	0.0875	0.658	0.0875
1982	0.0875	0.658	0.0875
1983	0.0875	0.658	0.0875
1984	0.0875	0.658	0.0875
1985	0.0875	0.658	0.0875
1986	0.0875	0.658	0.0875
1987	0.0875	0.658	0.0875
1988	0.0875	0.658	0.0875
1989	0.0875	0.658	0.0875
1990	—	—	—

S-3. Emission Test Data by Fuel Type

Liquid Kerosene Rocket Engine Test Results

From 1990 to 1992, ABB Environmental Services, Inc., conducted air sampling of kerosene-combusted rocket engine exhaust to analyze for toxic organics and toxic heavy metal combustion byproducts. Air emission samples were taken from several types of rocket engine exhaust (e.g., booster and sustainer). **Table S-9** lists the average measured emission rate of toxic organics and heavy metals from MA5 and MA5A booster rocket engine tests (ABB Environmental Services, Inc., 1992).

Table S-9. Average Toxic Organic and Heavy Metal Emissions from Liquid Kerosene Booster Rocket Tests as Reported by ABB Environmental Services, Inc. (1992)

Toxic Organic	**Emissions** (g/s)	**Heavy Metal**	**Emission Rates** (g/s)
Benzene	66	Arsenic	0.042 (ND)
1,3-Butadiene	22	Beryllium	0.071 (ND)
Chloroform	0.049	Cadmium	0.21
Vinylidene chloride	0.014 (ND)	Chromium (total)	0.30
Methylene chloride	0.015 (ND)	Chromium (hexavalent)	0.061 (ND)
Toluene	17	Copper	3.8
Trichloroethylene	0.44	Lead	0.41
Vinyl chloride	0.015 (ND)	Manganese	1.2
Xylene (total)	11	Mercury	0.021
Fuel	**Usage Rate** (g/s)	Nickel	0.76
		Selenium	0.042 (ND)
Kerosene	213,000	Zinc	4.8

ND = not detected, reported emissions at detection limit.

Seven chemical species (vinylidene chloride, methylene chloride, vinyl chloride, arsenic, beryllium, hexavalent chromium, and selenium) were not detected in the ABB measurement tests. Because arsenic, beryllium, and selenium exist in the kerosene fuel, it is likely that they are emitted in the exhaust. The conservative assumption made in this study was that the emission rates of these undetected chemicals are just below their measurement detection limits, even though the actual emissions could be lower. Note that reliance on these test results could understate actual emissions in prior years, if environmental regulations on fuel (if any) in effect at the time of testing (1990 to 1992) limited toxic organic and heavy metal content in kerosene relative to earlier time periods (e.g., 1948 to 1969).

Hydrogen

Data for air toxic byproducts from the rocket engine combustion of hydrogen could not be located.

Ethanol and Isopropyl Alcohol

Data for air toxic byproducts from the rocket engine combustion of ethanol and isopropyl alcohol were not found.

Hydrazine and Its Derivatives (MMH and UDMH)

In 1981, Rockwell International (1981) measured MMH in rocket exhaust. Ambient concentrations 20 feet downwind of the exhaust chamber ranged from 0.075 to 0.13 mg/m^3. The corresponding air flow rates necessary to accurately quantify emission rates from these engine tests were not reported. However, the air flow rate at 200 feet downwind of kerosene-combusted rocket engine tests was reported as 2.56×10^4 m^3/s to 8×10^4 m^3/s by Rockwell International (1984). *If SSFL MMH rocket engine tests had comparable air flow rates to those from kerosene rocket engine tests,* MMH emissions would be 1.92 g/s[1] (see **Table S-10**), equivalent to 0.15%[2] of the MMH fuel that was used in rocket engine tests but passed through to the exhaust without being burned.

Table S-10. MMH Concentration at the Exhaust Outlet and Emission Estimate

Concentration (µg/m^3)	**Air Flow Rate** (m^3/s)	**Estimated Emissions** (g/s)	**Uncombusted %**
0.075*	$2.56 \times 10^{4\dagger}$	1.92	0.15

* 20 feet downwind

† 200 feet downwind of a kerosene combusted rocket engine

Beryllium Hydride Solid Rocket Engine Tests

From 1969 to 1973, SSFL sampled engine exhaust from beryllium solid rockets. The SSFL sampling setup consisted of either one large 1,000-gallon tank or two 500-gallon (approximately) tanks in series. Water was sprayed into the tanks to capture solids emitted during a test. After a test, the tank(s) were drained and water passed through both a pre-filter and an ultra-filter to remove any beryllium solids captured. The tanks were rinsed and the rinse water was analyzed for beryllium prior to disposal.

Table S-11 lists average measured beryllium concentrations for each test day of data (Rockwell International, 1984). Individual concentrations ranged from undetected to 0.28 µg/m^3 (Rockwell International, 1999). Neither the minimum detection limit for measuring beryllium nor the corresponding exhaust flow rates from these engines were reported.

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[1] MMH emission rate (g/s) = 0.075 mg/m^3 * 2.56 x 10^4 m^3/s = 1.92 g/s

[2] MMH has a liquid density of 1.01 g/cc, comparable to that of water (1 g/cc). Each MMH combustion test (Rockwell International, 1981) consisted of five separate “rocket” combustions of about 5 seconds’ duration, for a total of 25 seconds of firing. Each firing combusted the contents of a 35-liter (35,000 cc) vessel. If MMH occupied 20% of the vessel (consistent with an optimum oxidizer-to-fuel ratio of roughly 4), then 7,000 grams of MMH were present in each vessel. Given this information, 0.15% is the fraction of MMH released uncombusted. (The study team obtained this by multiplying the MMH by a 5-second combustion process, then dividing the result by the 7,000 grams of MMH expected to be in the vessel.)

As noted previously, measured air flow rates 200 meters downwind of engine combustion with liquid kerosene vary from 2.56×10^4 m^3/s to 8×10^4 m^3/s (Rockwell International, 1984). If solid rocket engine tests had comparable exhaust flow rates to those from kerosene rocket engine tests, then beryllium emissions likely averaged 0.007 g/s.

Table S-11. Beryllium Concentration at Exhaust Outlet and Corresponding Emission Estimate

Date	**Concentration** (µg/m^3)	**Estimated Emissions** (g/s)
December 11, 1968	0.15	0.012
December 12, 1968	0.10	0.008
July 11, 1969	Not detected	0
Average	0.09	0.007

Since the exhaust sampling design used by Rockwell International (1984) did not guarantee 100% capture of beryllium emissions, it is believed that the measurement approach may understate actual beryllium emissions. A more conservative approach would have been to assume all beryllium combusted in the beryllium hydride rocket test entered the atmosphere.

On a comparative basis, worst-case beryllium emissions from liquid kerosene rocket tests were estimated to be 10 times greater (0.071 g/s; see Table S-3) than the 0.007 g/s estimates associated with beryllium hydride rocket tests. This may be physically unrealistic, given the expected greater amount of beryllium in beryllium hydride–fueled rocket tests. This suggests that either greater emissions occurred from beryllium hydride solid rocket tests than was stated in the data analyzed or beryllium emissions from kerosene fuels were well below the minimum detection limit emission estimate used in this report.

S-4. Air Toxic Emissions by Fuel Type

Emission estimates were derived by multiplying supplied fuel consumption data by fuel type and year by air toxic emission factor by fuel type found in the test data. Accordingly, estimates of the amount of air toxic emissions released into the atmosphere from these SSFL rocket engine tests are presented below.

Liquid Kerosene

Table S-12 shows cumulative toxic organic and heavy metal emissions from 1955 to 1990, estimated by multiplying annual kerosene usage rates (see Figure S-1) by the emission factors for toxic organic and metal emissions for kerosene fuel usage from testing[3] (see Table S-12).

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[3] ABB Environmental Services, Inc. (1992) reports that the kerosene fuel usage rate equaled 222 and 205 kg/s for two of the MA5A booster engine tests. The average kerosene fuel usage rate from these two tests is 213 kg/s. Toxic organic and heavy metal emissions were determined by multiplication of the Boeing-provided annual kerosene usage rates (see Figure 5-1) by the ABB Environmental Services, Inc. (1992) toxic organic and heavy metal emissions (see Table 5-2).

Table S-12. Kerosene Fuel Rocket Engine Exhaust Emissions of Toxic Organic and Heavy Metal Emissions (tons) from 1955 to 1990

Toxic Organic	**Emissions** (Tons)
Benzene	54
1,3-Butadiene	18
Chloroform	0.04
Vinylidene chloride	0.01 (ND)
Methylene chloride	0.01 (ND)
Toluene	14
Trichloroethylene	0.36
Vinyl chloride	0.01 (ND)
Xylene (total)	9

Heavy Metal	**Emissions** (Tons)
Arsenic	0.03 (ND)
Beryllium	0.06 (ND)
Cadmium	0.17
Chromium (total)	0.24
Chromium (hexavalent)	0.05 (ND)
Copper	3.1
Lead	0.03
Manganese	1.0
Mercury	0.02
Nickel	0.6
Selenium	0.03 (ND)
Zinc	3.9

ND = not detected

Benzene is the greatest source of toxic organic emissions from kerosene engine tests. Cumulative benzene emissions from liquid kerosene rocket test exhausts total 54 tons[4] from 1955 to 1990. Cumulative emissions for three other toxic organics (1,3-butadiene, toluene, and xylene) exceed 5 tons during the same time period.

Zinc and copper are non-toxic metals with the greatest estimated metal emissions. From 1955 to 1990, cumulative zinc and copper emissions totaled 3.9 and 3.1 tons, respectively. Cumulative emissions of cadmium and chromium during the same time period totaled 0.17 and 0.24 tons, respectively. Because the ambient concentrations of arsenic, beryllium, hexavalent chromium, and selenium were not detected in the tests performed, a conservative assumption was made that those concentrations equaled the measurement detection limit. Beryllium emissions determined in this manner total 0.06 tons (that is, 120 pounds or 54,000 grams).

Liquid Hydrogen Rocket Engine Test Data

Toxic organics and toxic metal emissions from the combustion of liquid hydrogen are assumed to be negligible. However, if fuel combustion resulted in temperatures conducive to metal vaporization from the walls of combustion and exhaust chambers, then toxic metal emissions would be present in the exhaust.

Ethanol and Isopropyl Alcohol

While combustion of ethanol and isopropyl alcohol with LOX would likely result in toxic organic emissions, it was not possible to estimate emissions of toxic organics from the combustion of ethanol and isopropyl alcohol, since no exhaust samples were ever taken.

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[4] For comparison purposes, these results can be calculated by multiplying the reported kerosene fuel usage at SSFL from 1955 to 1990 of 170,000 tons by the EPA-recommended benzene emission factor from rocket engine tests of 0.0002 lb/lb kerosene (http://www.epa.gov/ttn/chief/le/benzene/benz_apa.pdf).

Hydrazine and Its Derivatives (MMH and UDMH)

The reported annual quantity of hydrazine, MMH, and UDMH fuel usage in rocket tests at SSFL (Table 3-2) was multiplied by 0.15% to estimate hydrazine, MMH, and UDMH uncombusted air emissions. Using this method, cumulative 1955 to 1990 hydrazine, MMH, and UDMH air emissions totaled 0.74, 0.41, and 1.1 tons respectively.

Beryllium

Emission estimates of beryllium are uncertain. In the 1950s and 1960s, some limited research and testing of solid fuel engines was performed at SSFL (Agency for Toxic Substances and Disease Registry, 1999; ERG, 2001). Because the amount of beryllium consumed during these rocket tests was not provided, it was not possible to estimate beryllium emissions for this time period. Beryllium release controls were not in place in the 1950s and 1960s.

Another source of beryllium emissions was a 1967 malfunction incident during which Froines (1999) reports that 0.87 pounds (395 grams) of beryllium were released. This one incident released the equivalent of 15.6 hours of 0.007 g/s of beryllium emissions from solid fuel rocket engine tests. Beryllium emissions may also have resulted at SSFL from separate Peacekeeper program tests, as at least one of the rocket engine parts (the thrust chamber) in the upper stage was made from metallic beryllium.

S-5. TCE Evaporation from Cleaning of Rocket Test Engines

TCE applications were made to rocket engines[5] prior to and after tests. Analysis of records (CH2M Hill, 1993) suggests 50 to 100 gallons of TCE, on average, was applied per engine flush. TCE air emissions result from evaporation of the applied TCE liquid.

If 50 gallons of TCE were applied both before and after each engine test, 1.1 million gallons of TCE would have been consumed[6] on site for the purpose of kerosene rocket engine test flushes from 1955 to 1990. While TCE was also applied both before and after ethanol engine tests, no data were provided for the number of ethanol engine tests made. Therefore, the study team was unable to estimate the likely quantity of TCE used to clean ethanol-fueled engine tests.

Sullivan (1999) reports that 3,765 tons of isopropyl alcohol were consumed during rocket engine tests. The minimum quantity consumed was 6 tons in any one year. If 6 tons of isopropyl alcohol were consumed per test, then 628 tests were made. Assuming that 50 gallons of TCE were applied both pre- and post-testing to degrease these engine tests, 62,800 gallons of TCE were applied to clean isopropyl alcohol rocket engine tests.

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[5] Hydrocarbon fuels (e.g., kerosene, ethanol, and isopropyl alcohol) combusted with liquid oxygen (LOx).

[6] This estimate was developed as follows. ABB Environmental Services, Inc. (1992) test data reveal that roughly 15,000 kg of kerosene were consumed per engine test conducted. SSFL records show that total kerosene consumption from 1955 to 1990 equals 170,000 tons (160 million kg). In other words, kerosene was probably combusted with LOx in 11,000 rocket engine tests (160 million kg kerosene consumed / 15,000 kg kerosene per test). 11,000 tests multiplied by 100 gallons equals 1.1 million gallons.

Combining the above uses, the total estimated TCE consumed was 1.16 million gallons. Note that this is nearly twice the 530,000 gallons reported by CH2M Hill (1993) and above the upper range of 400,000 to 800,000 gallons reported by GRC (1988a-b). It is estimated that about half of the TCE applied to clean the engines immediately evaporated into the atmosphere (i.e., 3,200 tons), as shown in **Table S-13.**

Table S-13. Estimate of Trichloroethylene Atmospheric Emissions from Cleaning Ethanol-, Isopropyl Alcohol–, and Kerosene-Combusted Engine Tests for 50% of 50 Gallons Applied Before and After Each Engine Test Entering the Atmosphere

Statistic	**Usage** (U.S. Tons)				
	1955–1961	**1962–1972**	**1973–1983**	**1984–1990**	**Total**
Ethanol	—	—	—	—	—
Isopropyl alcohol	16	33	57	5*	111
Kerosene	1,946	1,025	99	15*	3,085
Total	1,962	1,058	156	20*	3,196

* SSFL installed a recovery system in 1984 that reportedly provides an 85% control factor.

S-6. Other Evaporative Activities

The Rockwell International (1992a-b, 1994) Toxic Release Inventory (TRI) submittals for 1990 and 1992 were examined to identify other potentially significant evaporative sources of toxic organics. In 1990, the principal source of TCE emissions (**Table S-14**), excluding engine flushes, was storage tank releases (95%) followed by stripping towers (5%).

Table S-14. Trichloroethylene Emissions for 1990 and 1992 from Engine Flush, Storage Tanks, and Stripping Towers as Reported by Rockwell International

Year	**Engine Flush** (Tons/Year)	**Storage Tank** (Tons/Year)	**Stripping Towers** (Tons/Year)
1990	1.7	0.42	0.022
1992	0.38	0.06	0.022

TCE storage tanks would have to have been present since 1948 at the start of TCE engine flushes. Given the higher volume of TCE usage (up to 25 times more) reported in years prior to 1990, it is reasonable to assume that TCE evaporation emissions from storage tanks were greater in earlier years. To correct for this expectation, the study team estimated earlier years of TCE emissions by multiplying 1990 emissions by the ratio of the TCE volume applied in earlier years to flush engines relative to 1990. According to this method, an estimated 134 tons of TCE were emitted to the atmosphere from storage tanks from 1955 to 1990 (see **Table S-15)**—about 5% of what was estimated from engine flushes.

Table S-15. Trichloroethylene Atmospheric Emissions from Storage Tanks

Statistic	**Usage** (tons)				
	1955–1961	**1962–1972**	**1973–1983**	**1984–1990**	**Total**
Total	79	43	6	5	134

The TRI documents show that methyl chloroform and TCA were also emitted from SSFL in 1990 and 1992. These toxic organics were emitted (Rockwell International, 1992b, 1994) in excess of TCE in 1990 and 1992 (see **Table S-16**). Since no documentation of the history of emissions of these two chemicals could be found, the annual methyl chloroform and TCA emission rates reported in the TRI documents were used as the annual emission rates of these chemicals from 1955 to present. Emissions of methyl chloroform or TCA could have been significantly greater or lower in earlier years.

Table S-16. Evaporative Chemicals Emitted in Substantial Quantities in 1990 or 1992 as Reported by Rockwell International (1992b, 1994)

Year	**Methyl Chloroform** (tons)	**TCA** (tons)	**TCE** (tons)
1990	18.7	N/A	2.1
1992	N/A	12.8	3.9

Notes: N/A = not available.

Accidental spills of TCE also occurred at the SSFL site. A search of TCE releases reported by CH2M Hill (1993) revealed that as many as 8,865 gallons (50 tons) were accidentally spilled from 1975 to 1990. Although reports of accidental releases are unavailable from 1948 to 1974, there is no basis for assuming that such releases did not take place over the above time period. The TCE volume accidentally spilled from 1955 to 1974 was potentially 600 tons, assuming that volume was proportional to the amount applied for engine flushing. In total, 650 tons of TCE may have been accidentally spilled from 1955 to 1990. Other toxic organics may have been spilled as well, but these but are unquantifiable from the data made available.

S-7. Thermal Treatment Facility

The Thermal Treatment Facility (TTF) is an open pit area constructed in 1958 to dispose of waste. An analysis of monthly disposal records (Rocketdyne, 1960) for 1959 and 1960 show that, during that period, 1,900 gallons, 130 pounds, and 5 cylinders of material were disposed of by burning each month on average (see **Table S-17**). Note that an additional 30 gallons of toluene should be added to this amount for occasions when disposal of pentaborane took place.[7]

For illustrative purposes, the study team used individual monthly records to make a more detailed analysis of the assorted materials disposed of. These records show that 45 drums and 1,650 gallons of assorted mixtures of UDMH and hydrazine were disposed of in September 1958 and March 1960. In May 1960, Rocketdyne (1960) reports, 951 gallons and 180 pounds of material were processed (see **Table S-18**). In May 1960, materials disposed of in this manner included chemicals, fuels, oxidizers, and explosives. In August 1959, Rocketdyne (1959) reports, 220 gallons of a combination of benzene and ethyl benzene were disposed of, among other items. In December 1959, 300 pounds of magnesium shavings (again, among other items) were disposed of in this manner.

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[7] Before disposing of pentaborane, the SSFL operating manual recommends personnel deposit and ignite 30 gallons of toluene (North American Aviation, Inc., 1960). Based on available historical records, pentaborane appears to have been disposed of in the TTF in two out of every three months.

Table S-17. Quantity of Material Disposed Of at the TTF by Month in 1959 and 1960

Calendar Month and Year	Quantity Disposed Of		
	Liquid Gallons	Solid Pounds	Gas Cylinders
February 1959	385	none	5
March 1959	> 4,000	none	none
April 1959	2,460	none	none
May 1959	2,545	none	none
July 1959	505	none	none
August 1959	5,750	none	6
September 1959	3,870	150	23
October 1959	1220	150	none
November 1959	851	none	none
December 1959	1,181	325	none
January 1960	10	none	none
February 1960	1,950	318	3
March 1960	3,685	none	27
April 1960	770	none	18
May 1960	951	180	none
June 1960	1,265	710	none
July 1960	1,560	456	none
August 1960	991	none	none
Average	1,900	130	5

Table S-18. List of Materials Disposed Of at the TTF for Certain Months (Rocketdyne, 1959, 1960)

Chemical and/or Fuel	**September 1958** (Gallons)*	**March 1960** (Gallons)*	**May 1960** (Gallons)*
Nitrogen tetroxide	—	—	350
Hydrochloric and nitric acid	—	1,160	250
Acteone, pentaborane, and RP-1	—	330	126
RP-1 and TEA	—	—	55
UDMH and hydrazine	45 drums	1,650	100
Lab, hydraulic, and lube oil	—	520	—
Solid propellant and heptane	—	25	—
TEA	—	—	20
Propane	—	—	50
Bromine pentafluoride, chlorine trifluoride, fluorine	—	—	180 pounds
Total	45 drums	3685 gallons and 27 cylinders	951 gallons and 180 pounds

* Except as noted.

Table S-19 presents the monthly average amount of toxic material estimated to have been emitted from the open pit burning operation. The study team developed this estimate by averaging September 1959 and March and May 1960 material processing records; it was assumed that 10% of all volatile organics (e.g., benzene, toluene) deposited in the pit either evaporated prior to burning or went uncombusted. In 1990, SSFL received permission to conduct open burning of explosive waste in 5-pound batches on designated burn days. This permit substantially limited the amount of material that could be disposed of in this manner.

Table S-19. Estimate of Monthly Average Amounts of Material Disposal at the TTF and Annual Average Air Emissions

Chemical and/or Fuel	**TTF Monthly Inventory** (Gallons)*	**Toxic Emission (Tons/Year)**†
Benzene (and derivatives)	20	0.0875
Nitrogen tetroxide	120	NT
Hydrochloric and nitric acid	570	NT
Acteone, pentaborane, and RP-1	150	NT
RP-1 and TEA	150	UN
UDMH and hydrazine	650	NDMA and NMA
Lab, hydraulic, and lube oil	200	NT
Solid propellant and heptane	10	NT
TEA	10	UN
Propane	20	NT
Bromine pentafluoride, chlorine trifluoride, and fluorine	130 pounds	NT
Total disposed of	1,520 gallons and 130 pounds	0.0875 tons/year + NDMA and NMA
Toluene for pentaborane combustion	20 gallons	0.0875 tons/year‡
Overall total	1,900 gallons	0.175 tons/year + NDMA and NMA

* Except as noted. † 300 pounds of magnesium emitted in 1959; inventory applies from 1959 to 1989. ‡ Limited to period of pentaborane usage.

NT = Not a toxic or expected not to produce significant toxic byproducts relative to other known sources of toxic missions at SSFL. UN = The study team does not know what "TEA" stands for, and therefore cannot say whether TEA is toxic.

S-8. Summary of SSFL Air Toxic Emission Inventory (1955–1990)

A total of 4775 tons of toxic organics (including hydrazine derivatives) and 9.2 tons of heavy metal emissions were released from SSFL to the atmosphere from 1955 to 1990 (see Table 3-4, Chapter 3). TCE air releases from engine flushes are by far the largest source of toxic organic emissions, at 3,196 tons. Other evaporative losses total 1,918 tons from the release of methyl chloroform (673 tons), TCA (461 tons), and TCE (784 tons). Rocket engine tests and the Thermal Treatment Facility released the following additional organics in sufficient quantity: benzene (57 tons), hydrazine and hydrazine derivatives (23 tons), 1,3-butadiene (18 tons), toluene (17 tons), and xylene (9 tons). The most significant source of heavy metal emissions is kerosene rocket engine tests. Zinc (3.9 tons), copper (3.1 tons), and manganese (1.0 tons) represent the largest sources of heavy metal emissions. Cadmium and chromium emissions totaled 0.17 and 0.24 tons, respectively.

Appendix T. Estimation of Receptor Air Concentrations and Doses

T-1. Introduction

Dispersion modeling using estimated emissions (Appendix S and Chapter 3) served to identify offsite locations where the inhalation dose ratios (Chapter 6) were above unity. Receptor locations identified in Figure T-1 were specifically addressed in the study. Inhalation dose ratios were derived for offsite area screening purposes only and do not necessarily represent realistic exposure levels for people residing near SSFL.

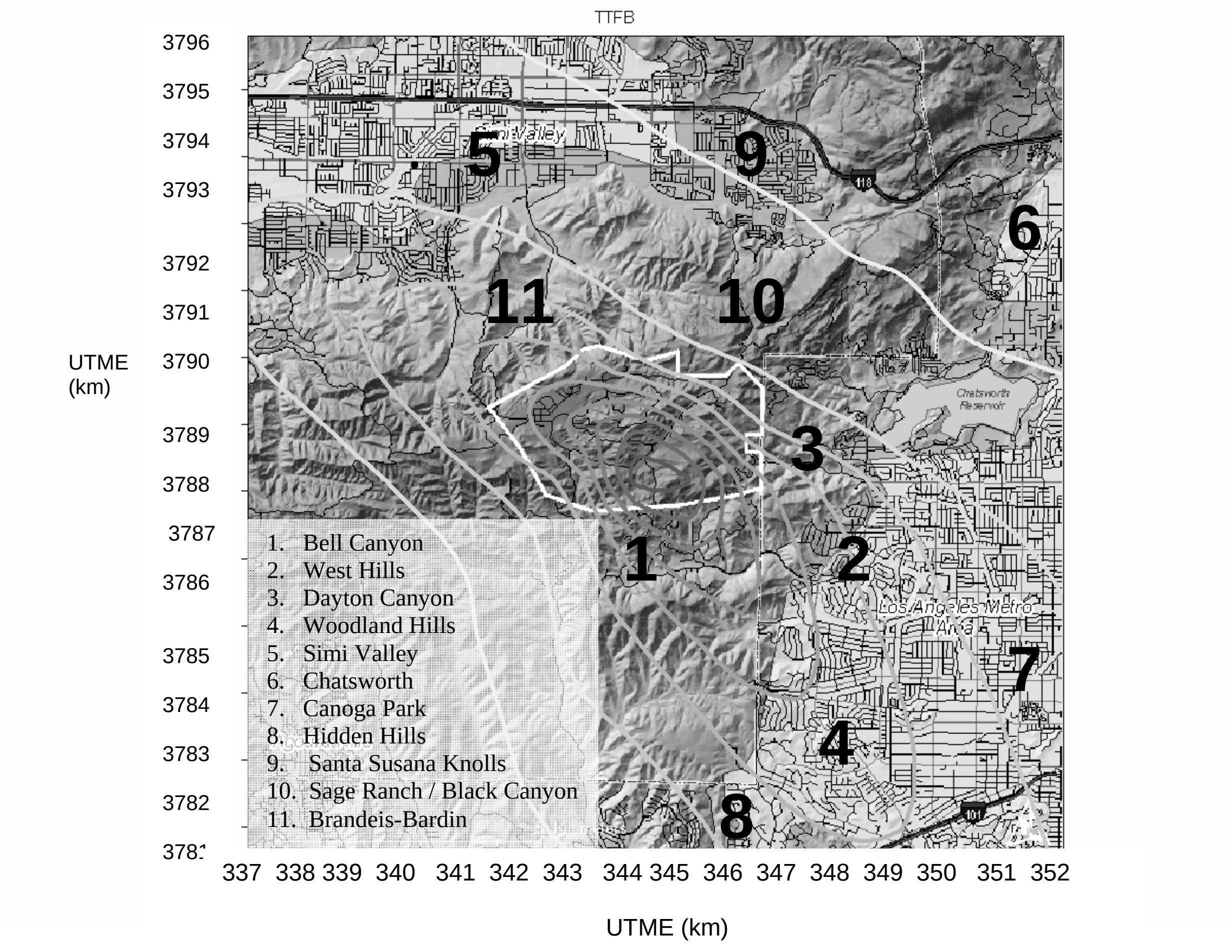

Figure T-1. Coordinates of Receptor Communities Used in Dose Analysis

The following communities were specifically addressed with respect to exposure linked to SSFL air emissions:

1. Bell Canyon (south/southwest): population ~3000. Covers 0.5 to 10 miles south and southeast of SSFL.
2. West Hills (southeast; includes Lakeside Park): population ~13,000. Covers ~0.5 to 4.0 miles to the east and southeast of SSFL.
3. Dayton Canyon (southeast): population ~2,000. Residential area ranging from 0.2 to 2 miles east of SSFL.
4. Woodland Hills (southeast): population ~45,000. Covers 5 to 10 miles southeast.
5. Simi Valley (northwest): population ~100,000. Covers areas 5 to 20 miles northwest.
6. Chatsworth (northeast): population ~50,000. Covers areas 5 to 10 miles northeast.
7. Canoga Park (southeast): population ~50,000. Covers areas 10 to 20 miles southeast.
8. Hidden Hills (south): population ~2,000. Covers areas 8 to 10 miles south.
9. Santa Susana Knolls (northeast): population ~20,000. Covers areas 3 to 5 miles northeast.
10. Sage Ranch/Black Canyon (northeast): population unknown~0 (recreational/residential). Covers areas 0.1 to 2 miles northeast.
11. Brandeis-Bardin Institute (northwest): population ~0 (recreational). Covers areas 0.1 to 2 miles northwest.

The protocol for identifying areas of exposure concern based on estimated maximum potential doses to communities from air contaminants originating from SSFL is outlined below.

- Maximum concentrations resulting from unit emission rates for each activity—rocket engine testing (RET), TCE solvent use during RET, activities at the Thermal Treatment Facility (TTF), and groundwater stripping of TCE in the stripping towers (ST)—were identified at various receptor locations (Chatsworth, Simi Valley, etc.) from all potential emission-specific sources (e.g., sources of kerosene-related emissions from RET included STL-IV, APTF, Bravo). (See Table T-1.) From this it could be ascertained for each activity (TCE use, for example) which source (in that case, APTF) contributed the greatest chemical-specific emissions (in that case, TCE) to each residential area (in that case, West Hills).

- Maximum emission rates for each activity, from emissions during years of similar activity levels (Appendix S), were identified. The information for chemicals which resulted in potential exposure doses within all potential exposure periods exceeding EPA-recommended doses are presented in Table T-2.

- Maximum chemical-specific concentrations (μg/m^3) were estimated from dispersion modeling of source-specific emissions for each activity (CALPUFF) (Table T-4).

- Maximum chemical- and activity-specific receptor doses (mg), D, were calculated (Table T-4) as follows:

  D = [receptor concentration (mg/m^3)] × [inhalation rate (m^3/yr)] × [activity time (yr)]

- Lifetime Average Daily Doses (LADDs in mg/kg-d) was derived by dividing maximum total lifetime inhalation doses (see Table T-4) by the average adult male weight (70 kg) and lifetime averaging period (70 years for carcinogens and the exposure duration for non-carcinogens).

- Dose ratios were derived by dividing the LADDs by the Acceptable Lifetime Average Daily Doses (ALADDs in mg/kg-d); see Table T-3.

Estimates of maximum doses in specific receptor locations were thus based on the maximum emission rates. Emission rates for chemicals which resulted in potential exposure exceeding EPA-recommended doses are presented in Table T-2; maximum potential concentrations for these chemicals are presented in Table T-4.[1] The reported relative doses (Table T-4) are conservative and represent the potential upper-limit lifetime maximum dose estimates with respect to estimated emission rates.

Table T-1. Coordinates of Approximate Maximum Concentration Resulting from Unit Emission Rates from the Indicated Sources

Emission Type	**Receptor Location**	**Receptor Coordinates**	**Maximum Concentrations Resulting from Unit Emission Rates at Receptor Locations from Indicated Source** (μg/m^3)
TCE volatilization from soil/ groundwater (area source, uniform emission)	Sage Ranch	(346, 3790)	2.91 (from APTF)
Rocket engine testing (area, daytime increasing emissions	Bell Canyon	(344, 3787)	5.34x10^{-1} (from STL-IV)
	Canoga Park	(347, 3784)	1.50x10^{-1} (from STL-IV)
	Chatsworth	(349, 3789)	1.04x10^{-1} (from APTF)
	Simi Valley	(341, 3791)	9.39x10^{-2} (from Alfa)
	Hidden Hills	(345, 3782)	9.75x10^{-2} (from STL-IV)
	Santa Susana Knolls	(346, 3792)	5.03x10^{-2} (from APTF)
	Woodland Hills	(347, 3783)	1.57x10^{-1} (from Delta)

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[1] For example, hydrazine was used in rocket engine testing from 1953 to 1977. There are no emission estimates for the years 1953 to 1954 and unreliable emission estimates for 1977, when testing activity was associated with the RS-14 Minutemen RET program. Therefore, the year of maximum recorded hydrazine emissions (1968), during the period in which there was RET using hydrazine fuels (1953–1977), was applied to all years associated with the activity under consideration. The maximum emission rate from a source was used to derive a potential exposure doses to offsite communities. This is a conservative approach, in that it assumes that the year of maximum emissions was indicative of activity levels for all relevant years. However, it must be acknowledged that doses presented in Table T-4 are used to represent potential exposure from an activity based on emissions from *only one source* (i.e., emissions from RET with hydrazine fuels were based on emissions from the STL-IV testing grounds only and do not take into account emissions from other testing grounds). As such, the doses presented here may under-represent potential lifetime exposure for residents residing near SSFL since 1953 with exposures to emissions from multiple RET areas (STL-IV, APTF, Alpha, etc.). The purpose of this analysis was not to represent community inhalation exposure doses, but rather to screen for offsite areas of potential exposure concern.

Emission Type	**Receptor Location**	**Receptor Coordinates**	**Maximum Concentrations Resulting from Unit Emission Rates at Receptor Locations from Indicated Source** (μg/m^3)
	Sage Ranch	(346, 3790)	3.44x10^{-1} (from APTF)
	Brandeis-Bardin	(344, 3790)	7.89x10^{-1} (from Alfa)
	West Hills	(347, 3787)	4.16x10^{-1} (from APTF)
		(348, 3787)	2.86x10^{-1} (from STL-IV)
	Dayton Canyon	(347, 3788)	5.14x10^{-1} (from APTF)
TCE emissions from rocket testing (area, uniform)	Simi Valley	(341, 3791)	5.43x10^{-1} (from STL-IV)
		(340, 3791)	4.32x10^{-1} (from STL-IV)
		(342, 3791)	6.47x10^{-1} (from Bravo)
	Woodland Hills	(347, 3783)	1.31x10^{-1} (from Coca)
	Chatsworth	(349, 3790)	2.07x10^{-1} (from APTF)
	Hidden Hills	(345, 3782)	9.62x10^{-2} (from STL-IV)
	Dayton Canyon	(347, 3788)	7.46x10^{-1} (from Canyon)
	Bell Canyon	(344, 3787)	6.54x10^{-1} (from Coca)
		(344, 3787)	5.98x10^{-1} (from Delta)
	Sage Ranch	(346, 3790)	9.64x10^{-1} (from Canyon)
	Brandeis-Bardin	(344, 3790)	6.32 (from (Alfa)
	Santa Susana Knolls	(346, 3792)	2.10x10^{-1} (from APTF)
	West Hills	(347, 3789)	8.68x10^{-1} (from Canyon)
		(347, 3787)	4.89x10^{-1} (from Canyon)
		(348, 3788)	4.98x10^{-1} (from Canyon)
	Canoga Park	(348, 3784)	1.80x10^{-1} (from Bowl)
		(348, 3785)	2.02x10^{-1} (from Bowl)
Stripping towers (point, uniform)	West Hills	(347, 3787)	3.68x10^{-1} (from Happy Valley)
		(348, 3788)	3.58x10^{-1} (from Happy Valley)
		(347, 3789)	6.66x10^{-1} (from Happy Valley)
			5.85x10^{-1} (from Area I Road)
	Woodland Hills	(347, 3783)	1.03x10^{-1} (from Delta)
	Sage Ranch	(346, 3790)	1.07x10^{-1} (from Delta)
	Brandeis-Bardin	(344, 3790)	9.62x10^{-1} (from Area I Road)
	Chatsworth	(349, 3790)	1.10x10^{-1} (from Happy Valley)
	Hidden Hills	(345, 3782)	7.92x10^{-2} (from Delta)
	Canoga Park	(349, 3785)	1.33x10^{-1} (from Happy Valley)
	Dayton Canyon	(347, 3788)	1.62x10^{-1} (from STL-IV)
			5.13x10^{-1} (from Happy Valley)
	Santa Susana Knolls	(345, 3792)	1.35x10^{-1} (from Happy Valley)
	Bell Canyon	(344, 3787)	5.69x10^{-1} (from Delta)
	Simi Valley	(341, 3792)	2.55x10^{-1} (from Bravo)
		(340, 3792)	1.91x10^{-1} (from Delta)
			1.44x10^{-1} (from Alfa)
		(341, 3792)	1.40x10^{-1} (from Area I Road)
		(341, 3791)	4.23x10^{-1} (from STL-IV)
Thermal Treatment Facility (TTF) (point, uniform)	West Hills	(347, 3785)	1.97x10^{-1} (from Area I TTF)
	Simi Valley	(341, 3791)	8.23x10^{-2} (from Area I TTF)
	Chatsworth	(349, 3790)	2.00x10^{-2} (from Area I TTF)
	Santa Susana Knolls	(346, 3792)	2.05x10^{-2} (from Area I TTF)
	Sage Ranch	(346, 3790)	4.23x10^{-2} (from Area I TTF)
	Brandeis-Bardin	(344, 3790)	6.86x10^{-2} (from Area I TTF)
	Hidden Hills	(345, 3782)	6.25x10^{-2} (from Area I TTF)
	Woodland Hills	(347, 3784)	1.69x10^{-1} (from Area I TTF)
	Canoga Park	(348, 3784)	1.38x10^{-1} (from Area I TTF)
	Dayton Canyon	(347, 3788)	1.15x10^{-1} (from Area I TTF)
	Bell Canyon	(346, 3786)	3.19x10^{-1} (from Area I TTF)
		(345, 3787)	5.97x10^{-1} (from Area I TTF)

Table T-2. Maximum Emission Rates(a) Assigned for Various Time Periods and SSFL Activities

Event	**Release**	**Chemical**	**Emission Rate**		
			Yr Max Emission Rate and Yrs Est. Exposure(b)	**Tons / Year**	**Grams / Second**
Rocket engine testing (RET)	Area/ daytime increasing	Hydrazine	1968 (STL-IV) (1955–1976; 20 yrs)	0.1	0.003
		UDMH	1955 (APTF/Delta) (1955–1976; 22 yrs)	0.15	0.004
TCE emissions from RET stands	Area/ uniform	TCE	1959 (1953–1966; 14 yrs)	387	11.15
			1967 (1967–1992; 26 yrs)*	43	1.24
Stripping Towers (ST)	Point/ uniform	TCE	1959 (1955–1967; 13 yrs)	91.8	2.64
			1968 (1968–1983; 16 yrs)	9.9	0.2
			1984 (1984–1989; 6 yrs)	18.9[†]	0.54
			1990 (1990–2004; 15 yrs)	3.1	$8.9\text{x}10^{-2}$
Thermal Treatment Facility (TTF)	Point/ daytime increasing	Hydrazine	All (1959–1994; 36 yrs)[‡]	0.66	$1.9\text{x}10^{-2}$

(a) The unit maximum emission rates at receptors from sources were derived from Appendix T, Table T-1, or other sources (as noted here) when conflicting reporting was encountered. Maximum emission rates reported in Appendix T (Table T-1) (tons per year) are averages of 4-year estimates (1994–1997). However, maximum emission rates were utilized in a conservative analysis within a given time period, particularly when there were either conflicting reporting or uncertain or lack of reporting. [†]For example, as noted in Appendix E,, there were no air permits for two stripping towers in 1988 and 1989, even though these were required. *Also, there are conflicting reports of annual TCE emissions from the RETs. Estimates derived from information supplied by Boeing were lower than those estimated by DOE (various years) as reported by ATSDR (1999). ATSDR (1999) reported that “estimated annual TCE emissions for the years 1988, 1989, 1990, 1991, 1992 were 2, 10.5, 7.5, 4.9, 42 tons per year (tpy), respectively (DOE, various years).” Given the lack of confidence in the reported emissions, the DOE-estimated value for 1967 was used for the 1967-1992 time period. [‡]Another example of conflicting information was with regards to TTF activity. The TTF was obligated to shut down in 1993 but did not actually terminate activity till 1994. This violation is cited in Appendix E.

(b) The exposure periods exclude years in which there were negligible emissions.

It is noted that atmospheric degradations were neglected in the dispersion analysis. This approximation has merit for most chemicals and generally results in a conservative estimation of receptor concentrations. Note also that the dispersion analysis did not consider toxic degradation byproducts (e.g., the formation of nitroso-amines). Such an analysis was beyond the scope of the present study, especially given the uncertainties in emissions and prevailing air quality during the emission periods. Furthermore, note that there are multiple sources (e.g. RET contaminants could disperse to Bell Canyon from the APTF, Delta, Coca, Bowl, Canyon, STL-IV, Bravo, and Alfa RET sites). Although concentration fields were obtained under various release scenarios, the present dose analysis based maximum receptor doses for each activity on the specific source contributing the greatest potential exposure to each receptor (Table T-1). For example, Table T-1 displays two sources for RET contaminants (STL-IV and APTF) at West Hills. The higher receptor unit emission rate (from APTF) was used, but there are other sources (Bowl, Alfa, TTF, stripping towers, etc.). Therefore, although the maximum source emission rate was used in dose estimations, the concentration at the receptor locations is likely to be underestimated if multiple sources were in operation.

Table T-3. Health-Based Standards for Chronic Exposure to Air Contaminants of Concern

Chemical	**Chronic Inhalation RfC,** (mg/m^3)	**Chronic Inhalation RfD** (mg/kg-d)	**Inhalation CPF** (mg/kg-d)$^{-1}$	**Inhalation Unit Risk** (mg/m^3)$^{-1}$	**ALADD** (mg/kg-d)
TCE	0.04	0.0114	**0.4**	0.114	2.5x10^{-6}
Hydrazine	—	—	**17.2**	4.9	5.8x10^{-8}
UDMH	—	—	**17.2**	4.9	5.8x10^{-8}

Notes: ALADD = Acceptable Lifetime Average Daily Dose for a 1×10^{-6} risk of disease; CPF = cancer potency factor; RfC = reference concentration; RfD = reference dose. (ALADDs were determined from RfDs for non-carcinogens (1,1,1-TCA, toluene, xylene, manganese, and mercury) and from CPFs for carcinogens.) Inhalation risk standards do not exist for copper, selenium, zinc and lead, so estimation of dose ratios was not possible for these contaminants. Lead was evaluated using LeadSpread (see Appendix R).

Table T-4 presents the receptor-specific concentrations derived from CALPUFF modeling of source-specific emissions, the maximum lifetime inhalation dose for each source-receptor, and the dose ratios for each activity specific to general location, chemical and activity. Only those contaminants with dose ratios above unity are presented in Table T-4. Where TCE is noted under RET, dose ratios are from use and dispersion of TCE during engine cleaning.

Table T-4. Maximum Estimated Inhalation Doses (mg) and Source-Specific Dose Ratios Exceeding Unity

Event	**Chemical**	**Receptor Locale**	**Yrs Exp. (T)**	**Receptor Max Concen. (C)** (µg/m^3)	**Maximum Total Lifetime Inhalation Dose (D)** (mg) (C/1000)×I×T×365 where I, inhalation rate= 20 m^3/d	**Dose Ratio (DR)** (dose > EPA acceptable dose by indicated factor)
Thermal Treatment Facility (TTF)	Hydrazine	Bell Canyon (345, 3787)	36	1.13x10^{-2}	2.98	29
		West Hills (347, 3785)		3.74x10^{-3}	0.98	9
		Canoga Park (348, 3784)		2.62x10^{-3}	0.69	7
		Dayton Canyon (347, 3788)		2.19x10^{-3}	0.57	6
		Simi Valley (341, 3791)		1.56x10^{-3}	0.41	4
		Hidden Hills (345, 3782)		1.19x10^{-3}	0.31	3
		Woodland (347, 3784)		3.21x10^{-3}	0.84	8
		Sage Ranch / Black Canyon (346, 3790)		8.04x10^{-4}	0.21	2
		Santa Susana Knolls (346, 3792)		3.89x10^{-4}	0.10	1
		Chatsworth (349, 3790)		3.8x10^{-4}	0.10	1
		Brandeis Bardin (344, 3790)		1.30x10^{-3}	0.34	3
Stripping Towers	TCE	West Hills (347, 3789)	13	1.76	167	47
			16	0.19	22	
			6	0.36	16	
			15	5.93x10^{-2}	6.5	
					211	
		Dayton Canyon (347, 3788)	13	1.35	129	36
			16	0.14	17	
			6	0.28	12	
			15	4.56x10^{-2}	5.0	
					163	
		Santa Susana Knolls (345, 3792)	13	0.35	34	10
			16	3.85x10^{-2}	4.5	
			6	7.34x10^{-2}	3.2	
			15	1.20x10^{-2}	1.3	
					43	
Stripping Tower continued		Bell Canyon (344, 3787)	13	1.50	143	40
			16	0.16	19	
			6	0.31	14	
			15	5.06x10^{-2}	5.5	
	TCE				181	
		Canoga Park (349, 3785)	13	0.35	33	10

Event	**Chemical**	**Receptor Locale**	**Yrs Exp. (T)**	**Receptor Max Concen. (C)** (µg/m^{3})	**Maximum Total Lifetime Inhalation Dose (D)** (mg) (C/1000)×I×T×365 where I, inhalation rate= 20 m^{3}/d	**Dose Ratio (DR)** (dose > EPA acceptable dose by indicated factor)
			16	3.79x10^{-2}	4.4	
			6	7.23x10^{-2}	3.2	
			15	1.18x10^{-2}	1.3	
					42	
		Chatsworth (349, 3790)	13	0.29	28	8
			15	3.13x10^{-2}	3.6	
			6	5.98x10^{-2}	2.6	
			15	9.79x10^{-3}	1.1	
					35	
		Simi Valley (341, 3791)	13	1.12	106	30
			16	0.12	14	
			6	0.23	10	
			15	3.76x10^{-2}	4.1	
					134	
		Hidden Hills (345, 3782)	13	2.09	199	56
			16	0.22	26	
			6	0.43	19	
			15	7.05x10^{-2}	7.7	
					252	
		Woodland (347, 3783)	13	0.27	26	7
			16	2.93x10^{-2}	3.4	
			6	5.60x10^{-2}	2.4	
			15	9.17x10^{-3}	1.0	
					33	
		Sage Ranch / Black Canyon (346, 3790)	13	0.28	27	8
			16	3.05x10^{-2}	3.6	
			6	5.82x10^{-2}	2	
			15	9.52x10^{-3}	1	
					34	
		Brandeis Bardin Institute (344, 3790)	13	2.54	241	68
			16	0.27	32	
			6	0.52	23	
			15	8.56x10^{-2}	9.4	
					306	
Rocket Engine	TCE	West Hills (347, 3789)	14	9.67	989	267
			26	1.07	204	

Event	Chemical	Receptor Locale	Yrs Exp. (T)	Receptor Max Concen. (C) (μg/m^3)	**Maximum Total Lifetime Inhalation Dose (D)** (mg) (C/1000)×I×T×365 where I, inhalation rate= 20 m^3/d	**Dose Ratio (DR)** (dose > EPA acceptable dose by indicated factor)
Testing (RET) Rocket Engine Testing (RET) continued	TCE continued				1193	
		Bell Canyon (344, 3787)	14	7.29	745	201
			26	0.81	153	
					899	
		Dayton Canyon (347, 3788)	14	8.31	850	229
			26	0.92	175	
					1025	
		Canoga Park (348, 3785)	14	2.25	230	62
			26	0.25	47	
					277	
		Chatsworth (349, 3790)	14	2.31	236	64
			26	0.25	49	
					284	
		Simi Valley (342, 3791)	14	7.21	737	199
			26	0.80	152	
					889	
		Hidden Hills (345, 3782)	14	1.07	110	30
			26	0.12	23	
					132	
		Santa Susana Knolls (346, 3792)	14	2.34	239	65
			26	0.26	49	
					288	
		Woodland (347, 3783)	14	1.46	149	40
			26	0.16	31	
					180	
		Sage Ranch / Black Canyon (346, 3790)	14	10.74	1098	296
			26	1.19	226	
					1324	
		Brandeis Bardin Institute (344, 3790)	14	70.45	7200	1942
			26	7.82	1484	
					8684	
	UDMH	Bell Canyon (344, 3787)	22	2.14x10^{-3}	0.30	3
		West Hills (347, 3787)		1.66x10^{-3}	0.27	3
		Dayton Canyon (347, 3788)		2.06x10^{-3}	0.33	3
		Sage Ranch / Black Canyon (346, 3790)		1.37x10^{-3}	0.22	2

Event	**Chemical**	**Receptor Locale**	**Yrs Exp. (T)**	**Receptor Max Concen. (C)** (µg/m^3)	**Maximum Total Lifetime Inhalation Dose (D)** (mg) (C/1000)×I×T×365 where I, inhalation rate= 20 m^3/d	**Dose Ratio (DR)** (dose > EPA acceptable dose by indicated factor)
		Brandeis Bardin Institute (344, 3790)		$3.15\text{x}10^{-3}$	0.51	5
	Hydrazine	Bell Canyon (344, 3787)	20	$1.6\text{x}10^{-3}$	0.23	3
		Dayton Canyon (347, 3788)		$1.54\text{x}10^{-3}$	0.22	2
		West Hills (347, 3787)		$1.25\text{x}10^{-3}$	0.18	2
		Sage Ranch / Black Canyon (346, 3790)		$1.03\text{x}10^{-3}$	0.15	1
		Brandeis Bardin Institute (344, 3790)		$2.37\text{x}10^{-3}$	0.34	3

Appendix U. SSFL Sandstone Sorption and Diffusion Experiments

U-1. SSFL Sorption Experiments

The batch sorption experiments were carried out using a well-documented method (Ball and Roberts, 1991; Harmon and Roberts, 1994). The only deviations from the method were (1) carbon-14 labeled chemicals and (2) flame-sealed ampules (as opposed to screw-top vials) were used in the previous studies but were not used here. Both of these deviations lead to a less precise measurement relative to the methods cited, but also lower the cost of the measurement significantly.

Four replicate samples and two blanks (no solids) were prepared for each of four initial concentrations tested (specified below). All the vials along with the caps were weighed and weight was recorded. The vials were filled approximately to half their volumes with the crushed sandstone. The vial-cap system was reweighed and the weight of solids was recorded. Then the vials were filled with Nano-pure® water till the brim of the vial. The vials were then capped and shaken on a vortex mixer to ensure the removal of the air bubbles and left undisturbed for 12 hours. Later, the vials were filled with water to the top and recapped. The blanks were also filled with water. All the vials are reweighed and the final weight of the solids and the water is noted. These vials were then spiked with TCE spiking solutions of different concentrations, roughly 1170, 5840, and 117700 μg/L and shaken to insure instant mixing. The vials were remixed every 8-10 hours for approximately 24-36 hours. Then the samples were left undisturbed overnight to settle. This equilibration time was believed to be sufficient for crushed sand using previous results for crushed sand for reference (Ball and Roberts, 1991). At the end of 48h, 3 mL of the supernatant water was added to the 4 mL crimped-top vials, which also contained 1 mL of pentane. These vials were then manually shaken for 20 minutes to extract the TCE into the pentane. The pentane from the vials was then transferred to the 1 mL gas chromatograph (GC) sample vials and analyzed on a Hewlett-Packard 6890 GC equipped with an electron capture detector (ECD). Sample concentrations were quantified using a GC response curve generated using calibration standards prepared in pentane. From the initial and final aqueous TCE concentrations and the losses determined from the blanks, the sorbed TCE concentration was determined for each sample. The concentrations in the sorbed phase versus the final aqueous concentrations were then plotted and the value of K_d was obtained as the slope of this curve.

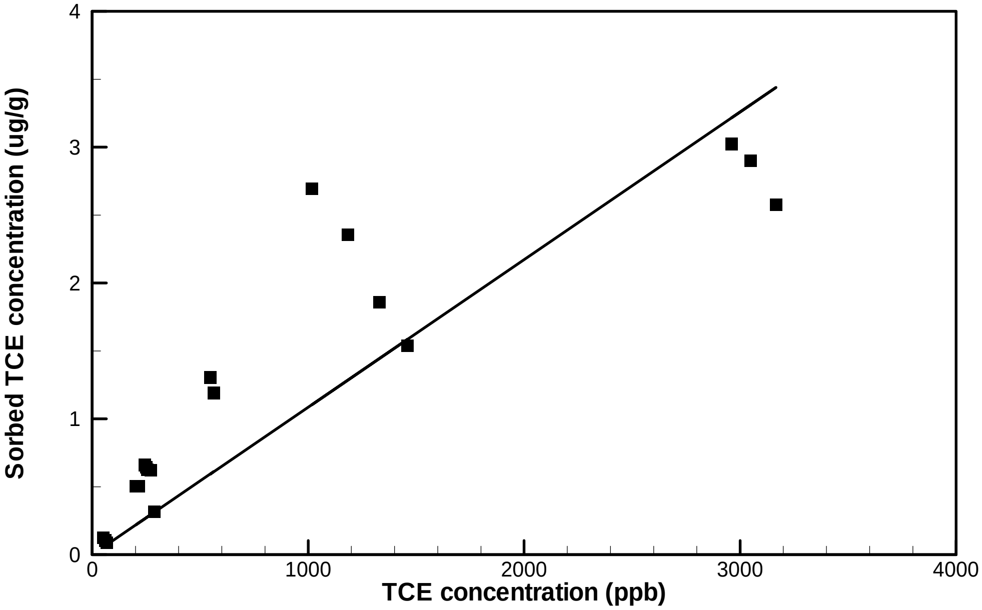

Figure U-1. SSFL sandstone sorption data with linear isotherm estimated for pulverized core material in batch tests (line indicates best-fitting distribution coefficient estimate K_d value of 1.1 mL/g).

U-2. Diffusion of Tritiated Water in SSFL Sandstone

The diaphragm-cell (Figure U.2) is a single unit containing two compartments (~ 40 cm^3 each) separated by a porous barrier. A sampling port, useful in filling and emptying the chambers as well, is connected to the side of each chamber.

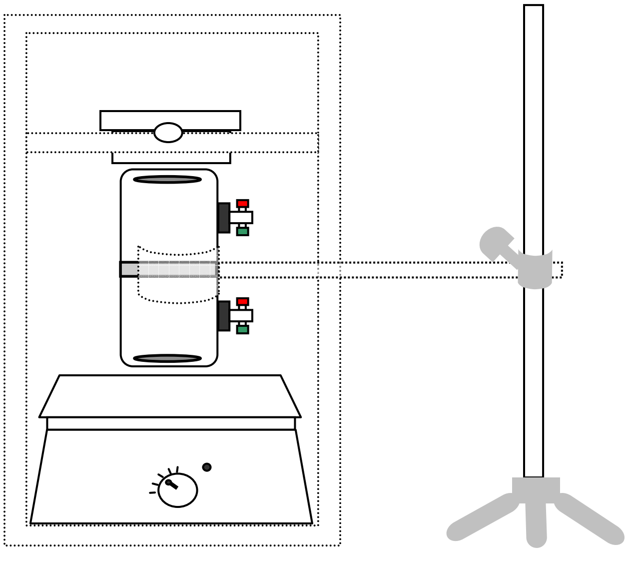

Figure U-2. The diffusion cell setup consisting of two chambers, each with a stop-go valve sampling port, separated by a porous barrier (sandstone) configured in the horizontal plane. Stirring plates atop and below the chambers provide mixing via stir bars.

Assuming that the concentration gradient through the porous barrier achieves steady state soon after the onset of the experiment, the flux across this barrier is can be approximated by the expression for diffusion through a membrane (Cussler, 1997):

$$j_1 = \left[\frac{DH}{l}\right]\left(C_{1,\text{lower}} - C_{1,\text{upper}}\right) \tag{U-1}$$

where H is the fraction of the area of the porous barrier in which diffusion occurs, D is the diffusion coefficient, l is the width of the porous barrier, and C is the concentration in each compartment (upper or lower) after the specified time. The flux can also be expressed as part of a mass balance between the two compartments:

$$\frac{d}{dt}\left(C_{1,\text{lower}} - C_{1,\text{upper}}\right) = A\left(\frac{1}{V_{\text{lower}}} + \frac{1}{V_{\text{upper}}}\right) j_1 \tag{U-2}$$

where A is the area of the porous barrier and V is the volume of each chamber. Equations (U-1) and (U-2) can then be combined to eliminate the flux term:

$$\frac{d}{dt}\left(C_{1,\text{lower}} - C_{1,\text{upper}}\right) = D\beta\left(C_{1,\text{upper}} - C_{1,\text{lower}}\right) \tag{U-3}$$

where the cell geometry constant (β) is given by:

$$\beta = \frac{AH}{l}\left(\frac{1}{V_{\text{lower}}} + \frac{1}{V_{\text{upper}}}\right). \tag{U-4}$$

This geometry constant describes the configuration of the diaphragm cell with the porous barrier; it is a characteristic of the specific diffusion cell and barrier system employed.

At the start of the experiment, the concentration of the solute is zero in the solvent chamber, and the initial condition for (U-3) can be expressed as:

$$C_{1,\text{lower}} - C_{1,\text{upper}} = C^0_{1,\text{lower}} - C^0_{1,\text{upper}} \qquad (t = 0) \tag{U-5}$$

Utilizing this condition (and letting D become D_p, signifying that the diffusion barrier poses resistance to the diffusion process), the solution to (U-3) becomes:

$$D_p = \frac{1}{\beta t}\ln\left(\frac{C^0_{j,\text{lower}} - C^0_{j,\text{upper}}}{C_{i,\text{lower}} - C_{i,\text{upper}}}\right) \tag{U-6}$$

This result describes the effective or pore diffusion coefficient for the solute-barrier system, obtained by measuring the concentrations in each compartment of the diaphragm-cell at a specified time.

Results from the SSFL sandstone diffusion cell test are shown in Figure U.3. The diffusion cell characteristics in this case are as follows: $H = 0.86$, $l = 1.4$ cm, $A = 4.9$ cm^2, $V_{\text{lower}} = 35$ cm^3, $V_{\text{upper}} = 40$ cm^3. C_{lower} and C_{upper} were measured by extracting 5 μL samples from the reservoirs at times ranging from 0 to 60 days. Steady measurements were achieved at around 20 days. Using the geometry above yields $\beta = 0.16$, and an observed effective diffusion coefficient (D) value of about 1.6×10^{-7} cm^2/s. Given that the self-diffusion coefficient for water is about 2.2 x

10^{-5} cm^2/s, and a porosity value of about 0.13, this implies that the tortuosity factor for tritiated water in the sandstone is about 18 for this core sample. Tortuosity factors depend on pore structure, molecular size, and (for molecular scale pores that are extremely restrictive) on steric effects. Thus, because TCE is a larger molecule than water, it will have a larger tortuosity factor for the same pore network. Using the ratio of the square root of molecular weights as a scaling factor (Schwarzenbach et al., 1993), the TCE tortuosity factor will be approximately 2.7 times greater than that for the tiritated water, or a value of 48. TCE will be retarded relative to tritiated water (by roughly a factor of 20, as estimated above). Estimating a free aqueous diffusion coefficient for TCE of 8.6 x 10^{-6} cm^2/s (Hayduk and Laudie, 1974), the value of the apparent diffusion coefficient value for TCE in the sandstone sample tested is about $(0.13*8.6 \times 10^{-6})/(20*48) = 1.15 \times 10^{-9}$ cm^2/s. These estimates are based on room temperature. If the temperature of the groundwater is lower, then this number will be slightly lower. Diffusion coefficients of this order of magnitude suggest that the rate of TCE propagation into the SSFL sandstone is extremely slow (on the order of a gram per square meter per year).

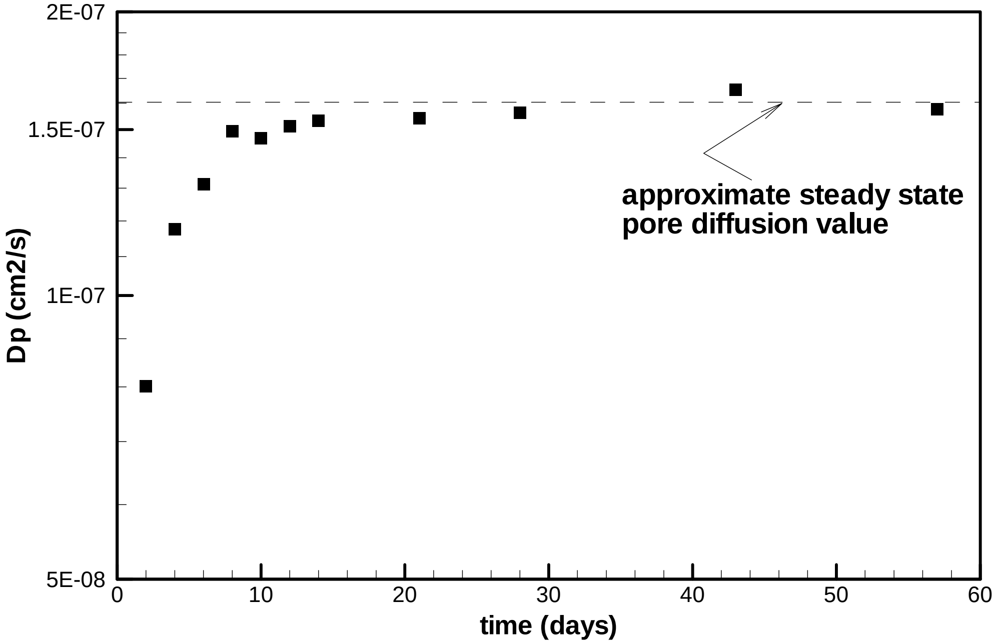

Figure U-3. Experimentally observed approach to steady state behavior for titrated water diffusion through an SSFL sandstone disk.

U-3. TCE Dissolved and Aqueous Mass Estimate for SSFL Plumes

There are three plume areas with different concentration ranges (see MW, 2000 a Fig. 5.1). The total contaminated volume V_i (including sandstone adsorption and dissolved water phase) would be for area plume i (i = 1,2,3)

$$V_i = A_i N 2 P_d \tag{U-7}$$

where A_i is the area (m^2), N is the number of fractures factored by 2 because for each fracture there would be and affected volume above and below, and P_d is the penetration depth.

Penetration depth was estimated using a one-dimensional transient diffusion calculation, where the diffusion model was parameterized using the results from the previous section. The number of fractures is given by $N=T/S$, where T is the assumed plume thickness and S the fracture spacing.

The mass of TCE dissolved in water (W_i) within the sandstone matrix is then

$$W_i = \phi V_i C_i \tag{U-8}$$

The mass of TCE in the solid part of the sandstone (SM_i) is given by

$$SM_i = (1-\phi) V_i C_i^{sm} = (1-\phi) V_i C_i \rho_s K_d \tag{U-9}$$

In these equations ϕ is porosity, C_i is concentration in the water phase and ρ_s is the density of the solid phase, taken as 2.65 g/mL. Total TCE in area i, then can be calculated adding the two previous equations

$$(Total\ TCE)_i = W_i + SM_i = V_i C_i \left[\phi + (1-\phi) \rho_s K_d \right] = V_i C_i \zeta \tag{U-10}$$

for the sorption coefficient (1.1 mL/g) and a matrix porosity of about 0.1:

$$\zeta = \phi + (1-\phi) \rho_s K_d = 0.1 + 0.9 * 2.65 * 1.1 = 2.72 \tag{U-11}$$

The analysis procedure described above was utilized to assess partition coefficient and retardation factor of TCE. This information was utilized to evaluate the partitioning of TCE between the aqueous solid matrix phase and its rate of diffusion in the soil subsurface (see Chapter 7.)