ATSDR
AGENCY FOR TOXIC SUBSTANCES AND DISEASE REGISTRY

Public Health Assessment for

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE
U.S. DEPARTMENT OF ENERGY
GOLDEN, COLORADO
EPA FACILITY ID: CO7890010526
MAY 13, 2005

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
PUBLIC HEALTH SERVICE
Agency for Toxic Substances and Disease Registry

THE ATSDR PUBLIC HEALTH ASSESSMENT: A NOTE OF EXPLANATION

This Public Health Assessment was prepared by ATSDR pursuant to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) section 104 (i)(6) (42 U.S.C. 9604 (i)(6)), and in accordance with our implementing regulations (42 C.F.R. Part 90). In preparing this document, ATSDR has collected relevant health data, environmental data, and community health concerns from the Environmental Protection Agency (EPA), state and local health and environmental agencies, the community, and potentially responsible parties, where appropriate.

In addition, this document has previously been provided to EPA and the affected states in an initial release, as required by CERCLA section 104 (i)(6)(H) for their information and review. The revised document was released for a 30-day public comment period. Subsequent to the public comment period, ATSDR addressed all public comments and revised or appended the document as appropriate. The public health assessment has now been reissued. This concludes the public health assessment process for this site, unless additional information is obtained by ATSDR which, in the agency's opinion, indicates a need to revise or append the conclusions previously issued.

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EPA FACILITY ID: CO7890010526

Prepared by:

Energy Section
Federal Facilities Assessment Branch
Agency for Toxic Substances and Disease Registry
Division of Health Assessment and Consultation
Atlanta, Georgia

Foreword

The Agency for Toxic Substances and Disease Registry, ATSDR, was established by Congress in 1980 under the Comprehensive Environmental Response, Compensation and Liability Act, also known as the *Superfund* law. This law set up a fund to identify and clean up our country's hazardous waste sites. The Environmental Protection Agency, EPA and the individual states regulate the investigation and clean up of the sites.

Since 1986, ATSDR has been required by law to conduct a public health assessment at each of the sites on the EPA National Priorities List. The aim of these evaluations is to find out if people are being exposed to hazardous substances and, if so, whether that exposure is harmful and should be stopped or reduced. If appropriate, ATSDR also conducts public health assessments when petitioned by concerned individuals. Public health assessments are carried out by environmental and health scientists from ATSDR and from the states with which ATSDR has cooperative agreements. The public health assessment program allows the scientists flexibility in the format or structure of their response to the public health issues at hazardous waste sites. For example, a public health assessment could be one document or it could be a compilation of several health consultations—the structure may vary from site to site. Nevertheless, the public health assessment process is not considered complete until the public health issues at the site are addressed.

Exposure: As the first step in the evaluation, ATSDR scientists review environmental data to see how much contamination is at a site, where it is and how people might come into contact with it. Generally, ATSDR does not collect its own environmental sampling data but reviews information provided by EPA, other government agencies, businesses and the public. When there is not enough environmental information available, the report will indicate what further sampling data is needed.

Health Effects: If the review of the environmental data shows that people have or could come into contact with hazardous substances, ATSDR scientists evaluate whether or not these contacts may result in harmful effects. ATSDR recognizes that children, because of their play activities and their growing bodies, may be more vulnerable to these effects. As a policy, unless data are available to suggest otherwise, ATSDR considers children to be more sensitive and vulnerable to hazardous substances. Thus, the health impact to the children is considered first when evaluating the health threat to a community. The health impacts to other high risk groups within the community (such as the elderly, chronically ill and people engaging in high risk practices) also receive special attention during the evaluation.

ATSDR uses existing scientific information, which can include the results of medical, toxicological and epidemiological studies and the data collected in disease registries, to determine the health effects that may result from exposures. The science of environmental health is still developing and sometimes scientific information on the health effects of certain substances is not available. When this is so, the report will suggest what further public health actions are needed.

Conclusions: The report presents conclusions about the public health threat, if any, posed by a site. When health threats have been determined for high risk groups (such as children, elderly, chronically ill and people engaging in high risk practices), they will be summarized in the conclusion section of the report. Ways to stop or reduce exposure will then be recommended in the public health action plan.

ATSDR is primarily an advisory agency, so usually these reports identify what actions are appropriate to be undertaken by EPA, other responsible parties, or the research or education divisions of ATSDR. However, if there is an urgent health threat, ATSDR can issue a public health advisory warning people of the danger. ATSDR can also authorize health education or pilot studies of health effects, full-scale epidemiology studies, disease registries, surveillance studies or research on specific hazardous substances.

Community: ATSDR also needs to learn what people in the area know about the site and what concerns they may have about its impact on their health. Consequently, throughout the evaluation process, ATSDR actively gathers information and comments from the people who live or work near a site, including residents of the area, civic leaders, health professionals and community groups. To ensure that the report responds to the community's health concerns, an early version is also distributed to the public for their comments. All the comments received from the public are responded to in the final version of the report.

Comments: If, after reading this report, you have questions or comments, we encourage you to send them to us.

Letters should be addressed as follows:

Attention: Chief, Program Evaluation, Records and Information Services Branch, Agency for Toxic Substances and Disease Registry, 1600 Clifton Road (E-60), Atlanta, GA 30333.

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List of Abbreviations

aCi/L	attocuries per liter = 1/1,000,000 picocuries per liter
ATSDR	Agency for Toxic Substances and Disease Registry
BNA	Base/neutral and acid extractable organic compounds
CCCR	Colorado Cancer Registry
CDH	Colorado Department of Health
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CESC	Citizens' Environmental Sampling Committee
CFR	Code of Federal Regulations
Ci	curie(s) (1 Ci is equal to 10^{12} pCi)
CREG	ATSDR's Cancer Risk Evaluation Guide
CV	comparison value
DDD	(1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethane)
DDE	(1,1-dichloro-2,2-bis(*p*-chlorophenyl)ethylene)
DDT	(1,1,1-trichloro-2,2-bis(*p*-chlorophenyl)ethane)
DOE	U.S. Department of Energy
DWA	Drinking Water Advisory
EMEG	Environmental Media Evaluation Guide
EPA	U.S. Environmental Protection Agency
F	Fahrenheit
FBI	Federal Bureau of Investigation
g	gram(s)
GWPMPP	Groundwater Protection and Monitoring Program Plan
ICRP	International Commission on Radiological Protection
IMP	Integrated Monitoring Report
kg	kilogram
LTHA	Lifetime Health Advisory
m	meter
m^3	cubic meter
MCL	EPA's maximum contaminant level
mg	milligram
mg/kg	milligram per kilogram
mg/L	milligram per liter
mrem	millirem
mrem/yr	millirem per year
µg	microgram
µg/g	microgram/gram
µg/L	microgram per liter
NRC	Nuclear Regulatory Commission
NIOSH	National Institute for Occupational Safety and Health
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
OU	operable unit

List of Abbreviations

PCE	tetrachloroethylene
pCi	picocurie (1 pCi is equal to 10^{-12} Ci)
pCi/g	picocurie per gram
pCi/L	picocurie per liter
PHA	Public Health Assessment
PHAP	Public Health Action Plan
RBC	Risk-based concentration
RCRA	Resource Conservation and Recovery Act
RFCA	Rocky Flats Cleanup Agreement
RFETS	Rocky Flats Environmental Technology Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RMEG	ATSDR's Reference Dose (or Concentration) Media Evaluation Guide
SARA	Superfund Amendments and Reauthorization Act
SVOC	Semivolatile Organic Compound
TCE	trichloroethylene
TEDE	Total Effective Dose Equivalent
UHSU	Upper Hydrostratigraphic Unit
VOC	Volatile Organic Compound

I. Summary

This public health assessment evaluates past, present and future exposures to environmental contamination associated with the Rocky Flats Environmental Technology Site (RFETS) located in Jefferson County, Colorado. The site was previously called Rocky Flats Plant. Between 1953 and 1989, contractors to the U.S. Department of Energy (DOE) manufactured components of nuclear weapons at Rocky Flats Plant. The manufacturing processes released various contaminants into the environment, both during routine operations and unplanned events, such as fires. These releases decreased considerably in 1989, when Rocky Flats Plant ceased operating and the site's mission shifted to decontamination and environmental clean-up activities. Local community members have long expressed concern about the public health implications of being exposed to contaminants that previously were released into the environment by Rocky Flats Plant.

The Agency for Toxic Substances and Disease Registry (ATSDR) prepared this public health assessment (PHA) because it is required to perform a PHA at all National Priority List (NPL) sites to determine whether local residents who did not work at Rocky Flats Plant could be harmed from contacting environmental contamination and to make recommendations to protect public health in the future. When preparing this PHA, ATSDR gathered and reviewed a large volume of reports, studies and sampling data generated by numerous parties, including the U.S. Environmental Protection Agency (EPA), the Colorado Department of Public Health and Environment (CDPHE), the U.S. Department of Energy (DOE) and its contractors and local community groups, universities and private researchers. A study that weighed heavily in this evaluation was the dose reconstruction study recently completed by the CDPHE contractor. This study presents the most extensive and thoroughly peer-reviewed account of past exposures to contaminants released from Rocky Flats Plant.

Overall, ATSDR believes the available sampling data, epidemiological studies, exposure investigations and other relevant reports paint a consistent picture of the public health implications of environmental contamination near the Rocky Flats Environmental Technology Site (RFETS). Local residents have previously been exposed to trace amounts of site-related contaminants and some exposures continue today; however, past, current and future exposures are below levels associated with adverse health effects. ATSDR's specific findings for past, present and future exposures are the following:

- *Past exposures when Rocky Flats Plant operated (1952–1989).* Rocky Flats Plant previously released contaminants that entered the local groundwater, surface water, soil and air. Residents previously came into contact with contaminants in multiple environmental media, but inhalation of airborne contaminants was the primary exposure pathway for this site. The air contaminants of greatest concern were plutonium and carbon tetrachloride.

Though Rocky Flats Plant released plutonium to the air throughout its history, the overwhelming majority (>99.9%) of plutonium emissions occurred between 1953 and

1969. Exposures to plutonium were well below levels associated with adverse health effects. Residents could have experienced a greater exposure, if they lived immediately east and further southeast of the Rocky Flats Plant between 1953 and 1969 and also worked at the plant.

Between 1953 and 1989, Rocky Flats Plant routinely released large amounts of carbon tetrachloride into the air. These emissions dispersed considerably over the 2 miles that separate the source of the release from the nearest off-site location. A modeling analysis was used to estimate the impact on air quality from past emissions at the Rocky Flats Plant assuming that 100% of the carbon tetrachloride used at the facility evaporated into the air. The estimated air quality impact at off-site locations from Rocky Flats Plant was found to be approximately half the ambient-air concentrations of carbon tetrachloride typically observed in suburban and urban locations throughout the United States today. Thus, past exposures to carbon tetrachloride near Rocky Flats Plant were not considerably different than carbon tetrachloride exposures observed at locations across the country.

Overall, ATSDR finds that past inhalation exposure of nearby residents to plutonium and carbon tetrachloride were below levels associated with health effects. This conclusion is based largely on modeling analyses, which have inherent uncertainties. However, it is reassuring to note that this finding is consistent with that of multiple epidemiology studies that found no clear evidence of cancer incidence being associated with place of residence and several exposure investigations that concluded that residents who live nearest to Rocky Flats Plant do not have unusually high amounts of plutonium in their bodies. Inhalation exposures to all other contaminants and exposures to contaminants in other media were of limited public health significance.

- *Current exposures since Rocky Flats Plant shut down (1989–present).* Though routine operations at Rocky Flats Plant ceased in 1989, contaminants from past releases remain in the local environment and ongoing releases have occurred as a result of site clean-up efforts. CDPHE, DOE and other parties have collected thousands of environmental samples to determine where contamination remains and at what levels. Site access restrictions prevent residents from coming into contact with contamination within RFETS, but trace amounts of site-related contaminants are still found at off-site locations. Though residents can come into contact with these off-site contaminants, residents' exposures are substantially below levels of public health concern.

- *Potential future exposures.* Potential future exposures are expected to decrease as site clean-up efforts continue to remove contaminants from the environment. However, the exact extent of future exposures to site-related contaminants depends upon many factors, such as migration of contamination, effectiveness of site clean-up efforts and changes to current land use patterns. Continued operation of environmental surveillance networks and careful review of any proposal to ease access restrictions at the site will help ensure that residents are not exposed to harmful levels of site-related contaminants in the future.

II. Background

In 1989, the U.S. Environmental Protection Agency (EPA) added the Rocky Flats Plant to the National Priorities List (NPL)—the list of hazardous waste sites that are being cleaned up under EPA's Superfund program. Since 1989, several key studies of environmental contamination at the Rocky Flats Plant have been completed This public health assessment (PHA) draws from many of these key studies and presents the Agency for Toxic Substances and Disease Registry's (ATSDR) conclusions regarding past, current and future conditions at the site.

ATSDR emphasizes that this PHA focuses almost entirely on *environmental* health concerns; i.e., whether local residents have contacted contamination at levels that might cause health problems. ATSDR is aware that some residents also have concerns about past *occupational* exposures. However, ATSDR's mandate does not include evaluating these exposures. Readers who are interested in learning more about occupational health issues for this site should consult with the National Institute for Occupational Safety and Health (NIOSH). Section VI.D of this PHA provides contact information for NIOSH and summarizes some of NIOSH's recent studies.

To evaluate site conditions at the Rocky Flats Plant, ATSDR obtained sampling data, reports and studies from many parties, including EPA, the U.S. Department of Energy (DOE), NIOSH, the Colorado Department of Public Health and Environment (CDPHE), contractors to these parties, local municipalities and independent researchers. The findings generated by these parties largely form the basis of the conclusions in this document.

The approach used to evaluate this site started with collecting background information on several important topics, such as the facility's operational history, community health concerns, the local environmental setting and demographics. This section reviews the background information collected on these and other topics by presenting facts and observations about the site, without any analyses or interpretations. Readers should refer to later sections of this PHA for our evaluation of environmental health issues (Section VI), conclusions (Section VII) and recommendations (Section VIII).

Note: In 1995, the site name changed from Rocky Flats Plant to Rocky Flats Environmental Technology Site (RFETS). This public health assessment (PHA) uses the site name Rocky Flats Plant when referring to past operations and RFETS when referring to current site conditions.

A. Site Description and History

RFETS is the site of a facility that produced components of nuclear weapons between 1952 and 1989. As Figure 1 indicates, RFETS is located in Jefferson County, Colorado. The site spans approximately 6,265 acres. Several cities are located within 10 miles of RFETS, including Arvada, Boulder, Broomfield, Superior and Westminster. Parts of Denver are located within 20 miles of the site. DOE owns RFETS, but the site has always been and continues to be, operated by the following contractors: Dow Chemical Company (1952–1975), Rockwell International Corporation (1975–1989), EG&G Corporation (1990–1995) and Kaiser-Hill Company (1995 to the present).
This section of the PHA summarizes the operational history of the Rocky Flats Plant (Section II.A.1), access restrictions to the site (Section II.A.2) and the history of environmental clean-up efforts at the site (Section II.A.3). ATSDR used this background information to identify and characterize the different ways that residents might have come into contact with site-related contamination.

1. Operational History

In 1951, the U.S. Atomic Energy Commission—the predecessor of the U.S. Department of Energy—acquired farmlands northwest of Denver, Colorado, from six property owners. Extensive construction occurred in the ensuing years and Rocky Flats Plant began operating in 1952. All operations occurred in buildings located in what became known as the "Industrial Area," which spans approximately 400 acres near the center of the site. A "Buffer Zone" of 6,150 acres surrounds the Industrial Area (see Section II.C).

Between 1952 and 1989, the Rocky Flats Plant had two primary missions 1) to produce components of nuclear weapons and 2) to recover plutonium from retired nuclear weapons (ChemRisk 1992). The weapon components manufactured at Rocky Flats Plant were known as plutonium "triggers" or "pits." Once manufactured, these components were shipped to other DOE facilities that assembled nuclear weapons.

Workers at the Rocky Flats Plant manufactured the triggers from many materials, including plutonium, uranium, beryllium, aluminum, tritium and stainless steel. Most of these individual materials were processed, machined and shaped into appropriate sizes in different buildings located in the Industrial Area. The individual processing lines required the use of many additional materials. Cutting oils and carbon tetrachloride, for instance, were used on the plutonium processing line to help machine and wash plutonium components. Site records document uses of many other toxic chemicals on the processing lines, including, but not limited to, benzene, benzidine, cadmium, chromium, ethylene oxide, formaldehyde, hydrazine, lead, mercury, nickel and propylene oxide.

The manufacturing operations at the Rocky Flats Plant generated a wide range of liquid and solid wastes that were handled using various waste management techniques. The site took extensive measures to recover certain materials from wastes, namely those materials (e.g., plutonium) that are extremely expensive and are controlled for national security reasons. In addition, pollution controls were installed in many processing areas to reduce the amounts of radioactive materials that might enter the environment. For instance, air

filters were installed to control particulate emissions from several processing lines and multiple treatment operations were used to remove contaminants from wastewater before it was discharged. Despite these and other measures to minimize environmental releases, the various processing operations at Rocky Flats Plant did release radioactive and nonradioactive contaminants to the air, water and land. As described below, some releases occurred during routine operations at the facility, while others were associated with episodic events (e.g., fires):

- *Releases from routine operations.* During the 1980s, contractors to the agency formerly known as the Colorado Department of Health (CDH) extensively characterized and documented the processes at the Rocky Flats Plant that released contaminants to the environment (ChemRisk 1992). This analysis examined air emissions, discharges to surface water and on-site disposal practices, all of which are summarized below.

  The production operations at Rocky Flats Plant occurred in multiple processes housed in buildings in the Industrial Area of the site. Air emissions from these operations generally consisted of volatile contaminants that evaporated and dusts that were generated during the processes. The majority of air emissions occurred in air ducts that passed through air pollution control devices (e.g., filters, scrubbers) before being vented to the atmosphere. Previous studies have identified various radioactive and nonradioactive contaminants in these air emissions. Detailed analyses of air emissions have been conducted for the following radioactive contaminants: americium-241, thorium-232, tritium (or hydrogen-3) and multiple isotopes of uranium and plutonium. Similarly, air emission rates were estimated for selected nonradioactive contaminants, including beryllium and multiple chlorinated organic solvents. Sections V.B.4 and V.C.4 present more information on past air emissions from Rocky Flats Plant.

  Several operations at Rocky Flats Plant generated wastes that were discharged into local surface waters. These discharges included sanitary wastes, laundry wastewater, process water and cooling tower water. Some of these waste streams contained low-level radioactive contamination, part of which has accumulated in sediments in the local surface waters. Several control measures were implemented at the effluents from Rocky Flats Plant to prevent site wastes from flowing directly into the surface waters that provide drinking water to nearby communities. A series of holding ponds, for instance, were constructed to hold wastewater on site in ponds, in which contaminants could settle to sediments or evaporate before the water flowed off site (Chemrisk 1994d). From 1971 to 1973, however, construction activities at a holding pond caused contaminated sediments to flow downstream toward local drinking water supplies. Since that time, pipelines and diversion ditches constructed at RFETS direct runoff from the main drinking water reservoirs in the area. Sections V.B.3 and V.C.3 present more detailed information on contamination levels in surface-water and drinking-water supplies near the Rocky Flats Plant.

In addition to releasing contaminants to the air and surface waters, Rocky Flats Plant disposed of some waste streams directly onto the land of the site. While the majority of hazardous and radioactive wastes were shipped off site for further waste management, some waste materials were disposed of on site in waste piles, landfills, trenches, land application areas and spray fields. Since 1989, DOE and its contractors have worked extensively under the oversight of environmental regulatory agencies to identify and remediate these various on-site waste management units (see Section II.B.3).

- *Releases during episodic events.* In addition to the releases associated with routine operations, several episodic events—accidents, spills, fires, leaks—caused plutonium and other contaminants from Rocky Flats Plant to enter the environment. Although many episodic release events occurred between 1952 and 1989, the following four events resulted in the largest incremental releases of radioactive contamination into the surrounding environment (ChemRisk 1992):

    - *1957 fire.* On September 11, 1957, plutonium residues in a glove box[1] in Building 71 (now Building 771) ignited, causing a fire that spread through the building's ductwork. The fire destroyed much of the filters that were designed to prevent plutonium and other contaminants from being released into the air. While multiple parties concur that this fire released plutonium into the air, they do not agree on the amount of plutonium that was released (ChemRisk 1994d, Barrick 1981, DOE 1980). Sections V.B.4 and V.C.4 revisit this issue.

    - *Drum leakage at the "903 Pad."* From 1958 to 1969, more than 5,000 drums of waste materials were stored on a pad in the Industrial Area of the Rocky Flats Plant and numerous drums contained spent machining oils containing low-level plutonium contamination. Many drums leaked and released contamination to the soils at the pad and winds then carried this contamination to downwind areas. Some site documents indicate that windblown dust from the 903 Pad is the largest air emission source of plutonium that occurred at the Rocky Flats Plant (ChemRisk 1994d). Surface soil contamination attributed to the 903 Pad extends to off-site locations, as Section V.C.1 describes.

    - *1969 fire.* On May 11, 1969, a fire ignited among plutonium residues in a glove box and the fire quickly spread through several hundred glove boxes in two buildings. The fire did not breach the roof of the buildings, but it damaged part of the exhaust filter system, which allowed some plutonium and other contaminants to be emitted to the air. The amount of plutonium released from this fire is estimated as being considerably less than that

[1] Glove boxes are enclosed working spaces with view panels. The gloves boxes were designed with sealed portholes with protective rubber gloves. Workers could handle radioactive materials inside the glove boxes without being exposed to plutonium dust by using the gloves that stick through portholes.

released during the 1957 fire (ChemRisk 1994d). Section V.C.4 evaluates the health implications of the plutonium released during this event.

- *1973 tritium release.* The Rocky Flats Plant routinely received shipments of scrap plutonium for further processing. In March 1973, at least one shipment had scrap materials contaminated with tritium. Through processing this material, tritium entered the wastewater, discharged into the facility's holding ponds and eventually flowed into reservoirs downstream from Rocky Flats Plant. Section V.C.3 reviews the significance of this release.

The previous discussion focuses on the environmental releases from the Rocky Flats Plant that occurred between 1952 and 1989. The purpose of this section is only to provide general background information on the nature of the releases; far more extensive accounts of releases from the Rocky Flats Plant can be found in various site documents (e.g., ChemRisk 1992, 1994d). Finally, ATSDR emphasizes that both the routine and episodic releases of contaminants from Rocky Flats Plant decreased dramatically in 1989, when the facility ceased its production operations. ATSDR's review of exposure pathways at this site (Section IV) considers information about the operational history of the Rocky Flats Plant to identify ways that local residents might have come into contact with contaminants released from Rocky Flats Plant.

2. Access

Due to the sensitive nature of operations at Rocky Flats Plant, access to the site has always been tightly restricted. Since the facility first began operations, only authorized personnel and visitors with escorts have been allowed on the premises. The entire perimeter of the facility is fenced with signs indicating that trespassing is prohibited. Access to the site occurs primarily through two gates that are guarded to prevent unauthorized entry. Moreover, the Industrial Area of the facility is fenced and guarded.

In addition to security measures around the outer perimeter of the facility, the Protected Area (an area within the Industrial Area in which plutonium production occurred) continues to be guarded and patrolled (RFETS 1998). Due to these access restrictions, ATSDR concluded that residents are not likely to gain unauthorized entry onto RFETS property. Consequently, this PHA does not evaluate exposure scenarios for trespassing onto site property, when and if this activity does occur.

3. Regulatory and Remedial History

Although the Rocky Flats Plant was always subject to applicable state and federal environmental regulations, regulatory oversight became a prominent issue for the site in June 1989, when agents of the Federal Bureau of Investigation (FBI) and the U.S. Environmental Protection Agency (EPA) raided the Rocky Flats Plant to investigate allegations of environmental crimes. Following this raid, regulators identified several violations of waste management regulations, which ultimately resulted in Rockwell

International Corporation (the contractor operating the facility at the time) being fined $18.5 million for past safety and environmental practices.

Later in 1989, EPA added Rocky Flats Plant to the National Priorities List (NPL), the list of hazardous waste sites to be cleaned up under EPA's Superfund program. This listing initiated a series of remediation projects at RFETS, some of which will continue many years into the future. In 1991, DOE, EPA and CDH entered into an Interagency Agreement that outlined schedules and oversight responsibilities for future site investigation and remediation projects. This agreement also grouped the existing 177 waste sites at Rocky Flats Plant into 16 operable units (OUs) on the basis of the sites' locations and types of contamination. Of these OUs, only one (OU3) extends off site. Since 1991, the OUs have twice been regrouped to facilitate the administrative process of conducting remediation projects. Under the current Rocky Flats Clean-up Agreement, DOE is responsible for the remediation activities at each OU, with oversight of activities by either EPA or CDPHE (depending on the OU). For reference, Table 1 presents background information on the sources of contamination for the seven OUs at RFETS.

Another important outcome of the 1989 raid was that Colorado Governor Roy Romer signed an Agreement in Principle with DOE to fund state oversight of various health and environmental studies. CDPHE administered these studies, which included an extensive dose-reconstruction study. The dose-reconstruction study was conducted in several steps: identifying contaminants of concern, estimating releases of these contaminants, modeling exposure pathways, quantifying health risks and assembling results into final documents. Contractors to CDPHE conducted the dose-reconstruction study in phases under the oversight of a Health Advisory Panel, composed of 12 experts who provided independent scientific oversight. The findings from this 10-year effort weigh heavily in the conclusions reached in this PHA.

Since 1989, numerous remediation projects have been proposed or implemented at RFETS. Remediation activities include decontaminating and decommissioning former processing buildings, excavating contaminated soils, pumping ground water encountered during excavation and sending it to a site water treatment plant. There are no pump and treat systems on-site. Action levels established for remediation activities are based on risk to a Wildlife Refuge Worker (WRW), or risk to ecological receptors. DOE removed more than 26,000 cubic meters of low-level radioactive waste from RFETS in 2002 alone. This accelerated clean-up schedule will continue and, by 2006, DOE plans to have demolished all buildings formerly used in the production process[2], to have reached records of decision on all waste sites and to have covered remaining building foundations, parking lots, roads and other structures with at least 3 feet of clean fill dirt.

[2] There is no further mission at Rocky Flats. All buildings, including water treatment facilities, are to be demolished. The wastewater treatment plant is slated for demolition in Fall of 2005.

B. Demographics

ATSDR examines demographic data (i.e., information about the local population) to determine the number of persons who are potentially exposed to environmental contaminants, as well as the presence of any populations (children, the elderly) that might be sensitive to certain exposures. Figure 2 summarizes current demographic data for the vicinity of RFETS, on the basis of data compiled in the 2000 U.S. Census of Population (Bureau of the Census 2002). The data in this figure reflect conditions during 2000. Given the extensive residential development that has taken place over the last few decades in areas northwest of Denver, ATSDR believes the population statistics in Figure 2 overstate past population trends.

Figure 2 presents demographic statistics for different areas surrounding RFETS, including populations that reside within 2.5 and 5.0 miles of the Industrial Area and the facility boundary. These statistics clearly show that few residents live in close proximity to the areas in which plutonium processing used to occur; only 31 residents reportedly live within 2.5 miles of the Industrial Area. The limited number of persons living in this area results largely from the Buffer Zone at RFETS. On the other hand, Figure 2 also demonstrates that a large population (>100,000 residents) lives within 5 miles of the facility's boundary. This population is predominantly white (>90%) and the relative amounts of children aged 6 and under (9.0%) and adults aged 65 or more (7.6%) near RFETS does not differ considerably from the population distribution across the state. The majority of the population located within 5 miles of the Industrial Area lives in the cities of Broomfield, Westminster and Arvada. The nearest residence to RFETS is located ¼ mile east of the site boundary. Further, the nearest school, hospital and park are located 2.7 miles, 3.0 miles and 1.0 mile from the property boundary, respectively. ATSDR found no information about American Indian/Alaska Native tribal reservations within 1 mile of RFETS.

C. Land Use

ATSDR examines land uses to determine what activities might bring residents in contact with environmental contaminants and over what durations these contacts occur. This section summarizes land uses in the RFETS vicinity, first for on-site then for off-site locations. Also presented is the extent to which land uses have changed over time as well as anticipated changes in future land uses.

- *On-site land uses.* From 1951 to 1974, the Rocky Flats Plant occupied approximately 2,500 acres of land around what is now known as the Industrial Area. From 1974 to 1976, the federal government purchased additional 4,000 acres of land that is now known as the Buffer Zone. Currently, the overwhelming majority of RFETS is undeveloped and the former industrial facilities occupy only 6% of the total site area. The Buffer Zone consists almost entirely of open space, although some lands in this area contain monitoring stations, landfills, holding ponds and dirt roads. The DOE National Renewable Energy Laboratory Wind Site includes 280 acres in the northwestern corner of the Buffer Zone. As

noted previously, residents cannot enter any RFETS lands (neither the Industrial Area nor the Buffer Zone) without a site escort because of access restrictions. For reference, Figure 3 shows the site boundary at RFETS and the location of the Industrial Area within the boundary.

There will be no future industrial uses on the Rocky Flats property. The center of the site will be retained by DOE to manage the remedy, and the remainder will be transferred to US Fish and Wildlife Service to become the Rocky Flats National Wildlife Refuge.

- *Off-site land uses.* When Rocky Flats Plant operated, most land immediately surrounding the site was either open space or land used for mining, ranching and grazing. Soil conditions in this area are rocky and shallow and therefore not ideal for farming. Nonetheless, some land in the area was formerly used and continues to be used, for agricultural purposes, namely production of hay and selected crops. Much of the land in the immediate vicinity of the site was small-scale farms and ranches (2–12 acres) with horses, chickens, pigs and sheep (Chemrisk 1994c). This land use continues to exist today.

  Figure 4 depicts current land uses in the vicinity of RFETS. Although open space, mines and ranches continue to occupy lands surrounding RFETS, residential development is becoming increasingly prevalent in the area, especially at locations northeast, east and southeast of the site. In Jefferson County, the public lands bordering RFETS are designated as having one of two possible land uses, 1) "nonresidential: retail, or office, or industrial," or 2) "open space, parks and recreation areas, schools and cemetery." The county zoning regulations require that future development of any land within 4 miles of RFETS be referred to CDPHE for an evaluation of radioactive material concentrations in surface soils (Jefferson County Planning Department 1989).

  Site reports list a number of specific land uses that occur near RFETS. For instance, a report released during the dose reconstruction study indicates that several abandoned mines, gravel pits, pumping stations, the Jefferson County Airport, parks, schools and warehouses are all located within 5 miles of the site (ChemRisk 1994c).

D. Environmental Setting

This section summarizes the environmental setting of RFETS. Background information is presented on meteorology, hydrogeology, surface water and wildlife to provide a general understanding of how contaminants released from RFETS moved through different environmental media (e.g., surface water and sediment, groundwater, soil, air). The extent to which residents contact the various environmental media is also noted. Though this section provides insights on fate and transport patterns, the final conclusions in this PHA are made almost entirely on the basis of our review of actual sampling data (see Section V).

1. Meteorology

Weather conditions at RFETS vary considerably from one season to the next. Average daytime temperatures in the summer and winter are 80°F and 40°F, respectively. The site receives approximately 15 inches of precipitation per year, primarily in the form of rain and most of the precipitation occurs during the spring (Parker-Hall 1997).

Prevailing wind patterns at RFETS have been studied extensively. In the late 1990s, for instance, CDPHE collected continuous wind speed and wind direction measurements at five locations on and near the site. All data collected to date indicate that the prevailing wind direction at RFETS is from the west and the northwest (see Figure 5), although winds in the area have been observed to blow from virtually every compass direction at some time during the year. The prevailing wind patterns suggest that air emissions from the Rocky Flats Plant had their greatest impacts at locations east and southeast of the facility, as Sections V.B.4 and V.C.4 discuss further.

Strong wind gusts are commonly observed at RFETS. In fact, hourly average wind speeds have been found to exceed 20 miles per hour more than 500 times a year (Parker-Hall 1997). Though summertime thunderstorms are typically accompanied by strong winds, wind gusts in the area tend to be strongest and most frequent between November and April. The strong winds that blow over the eastern slopes of the Rocky Mountains are commonly known as “Chinooks” and can reach speeds greater than 75 miles per hour. The occurrence of these winds is significant because strong gusts at this speed are capable of generating significant quantities of windblown dust that can carry surface soil contamination to downwind locations. As Section V.C.1 describes, atmospheric transport of windblown dust is believed to have caused off-site surface soils to be contaminated with plutonium.

2. Hydrogeology

Groundwater refers to the water that exists in the cracks and spaces between soil, clay, sand and rocks beneath the Earth’s surface. The depth below the surface to groundwater, the quality of groundwater and the flow properties vary from one location to the next, depending upon the sizes of the free spaces in the geologic formations and how well these spaces are interconnected. This section describes key groundwater features at RFETS and indicates groundwater uses in the area.

The groundwater beneath RFETS has been studied extensively and the most recent site documents identify two aquifers in the vicinity of the site. The aquifers contain multiple layers of geological material. Water in these aquifers generally flows laterally from west to east, consistent with the slope of the local terrain. Because the aquifers are separated by impermeable rock, vertical flow of groundwater between the aquifers generally does not occur. The following general information on the two aquifers is presented by depth from surface to groundwater:

- *Upper Hydrostratigraphic Unit (UHSU).* The UHSU is the uppermost aquifer beneath RFETS and consists of multiple hydraulically connected geological formations that overlie impermeable rock. The uppermost layers of the UHSU are various types of unconsolidated materials, including the Rocky Flats alluvium, the valley-fill alluvium and colluvium (Kaiser-Hill Company 1994). The UHSU also includes weathered bedrock and sandstones within two formations—the Arapahoe Formation and the upper Laramie Formation—that lie beneath the unconsolidated materials.[3] Groundwater in the weathered bedrock formations moves through sandstone lenses. The shallow upper hydrostatic unit in the Industrial Area seeps above ground on the slopes of the incised valleys of Walnut and Woman Creeks. Any contaminated groundwater in this unit then becomes a potential surface water problem. Ground water also flows in the weathered claystone at a much slower rate but still must be considered for contaminant transport on site.

  The thickness of the UHSU varies across RFETS. The alluvial material within the UHSU, for example, extends 50–70 feet below ground surface in the western portion of RFETS, but this layer thins considerably at the eastern portion of the site (EG&G 1991). The unweathered bedrock located below the alluvial material extends several hundred feet beneath ground surface.

  Groundwater in the UHSU is recharged by precipitation and seepage from ponds and streams. Some groundwater eventually discharges to local surface waters. In the UHSU, groundwater primarily flows in lateral directions (generally to the east), though flow between the layers beneath the UHSU have also been observed. The depth of ground surface to groundwater varies with location at the site.

- *Laramie-Fox Hills Aquifer.* The Laramie-Fox Hills Aquifer occurs in the bedrock that underlies the UHSU. This aquifer includes two geological formations, 1) the lower Laramie formation and 2) the Fox Hills formation. Groundwater in this aquifer is found at depths between 500 and 600 feet below the RFETS Industrial Area. The groundwater at these depths is protected from site-related contamination by hundreds of feet of impermeable claystones in the Laramie Formation that separate this aquifer from the UHSU (RMRS 2001).

ATSDR also evaluated existing and potential uses of groundwater in the vicinity of RFETS. In general, people most commonly come into contact with groundwater by using well water. The extent of groundwater well usage in RFETS varies with location. Groundwater directly beneath RFETS is not used as a water supply and wells drilled on site are used for monitoring purposes only. At locations east (i.e., down gradient) of

[3] Until recently, site documents suggested that the weathered bedrock and the unconsolidated materials within the UHSU were not hydraulically connected and were therefore actually two separate hydrostratigraphic units. However, it has since been established that the two formations have strong hydraulic connections beneath the site and all of these formations are now viewed as a single hydrostratigraphic unit (CDPHE 2000b).

RFETS, groundwater use is limited. Site documents indicate that no private groundwater wells are located within 1 mile of the eastern site boundary of RFETS, but 15 private wells are located between 1 and 2 miles of the boundary (ChemRisk 1994c). The wells provide water for drinking water, irrigation and other non-potable uses. Detailed drilling records are not available for all 15 of these private wells (DOE 1997). However, a recent study has reported that most of the private wells are believed to draw water from depths ranging between 10 feet and 200 feet beneath the ground surface (ChemRisk 1994c). ATSDR also identified reports that municipal drinking-water-supply wells further distant from RFETS draw water from at least 1,000 feet beneath the ground surface from the Laramie-Fox Hills aquifer (ChemRisk 1994b). As Sections V.B.2 and V.C.2 describe further, the fact that no drinking water supply wells are located within 1 mile of RFETS factored heavily into this review of groundwater monitoring data.

3. Surface Water

Surface water near RFETS includes creeks, ponds and reservoirs. These surface waters contain precipitation that does not infiltrate the ground, runoff from improved areas on RFETS property and groundwater discharge. While Rocky Flats Plant operated, the surface waters also contained discharges from certain facility processes. Surface-water flow in the area is primarily in the direction of the terrain, which slopes downward from west to east.

Numerous irrigation ditches traverse RFETS property. Surface water runoff from the site flows into Big Dry Creek, Rock Creek, Woman Creek and Walnut Creek (see Figure 6). All four are intermittent streams. Big Dry Creek and Rock Creek are not discussed further in this PHA, because they do not flow near the Industrial Area, so it is highly unlikely that discharges from the Rocky Flats Plant flowed directly into these streams (DOE 1997).

Surface-water runoff from the Industrial Area and drainage from most of the current and former hazardous waste sites on the site flow primarily into the other two streams. Walnut Creek drains the northern portion of the Industrial Area and Woman Creek drains its southern portion. As Figure 6 shows, these streams flow eastward toward local drinking-water reservoirs, but the surface-water flow patterns have been changed in recent years to prevent potentially contaminated runoff from entering drinking water supplies. A detailed review of the two major surface water drainages from RFETS follows:

- *Walnut Creek.* The north and south branches of Walnut Creek received runoff and industrial discharges from the Industrial Area of Rocky Flats Plant between 1952 and 1989 and both of these branches continue to receive runoff from RFETS today. As Section II.A.1 describes, previous discharges to surface water included laundry waste, sewage-treatment-plant effluent and water from cooling towers. At on-site locations two branches of Walnut Creek merge near the RFETS property line. Flow in both branches was previously controlled using a series of holding ponds (see Figure 3). Construction projects during the early 1970s re-suspended

contaminated sediments in water in the holding ponds, then flowed in Walnut Creek to downstream locations. Section V.C.3 describes the implications of this event in greater detail.

After crossing the RFETS site boundary, Walnut Creek continues to flow eastward, but flow patterns have changed over the years. Before 1989, Walnut Creek flowed approximately ½ mile off RFETS, directly into Great Western Reservoir. After 1989, Walnut Creek was diverted around the reservoir, thus flowing directly into lower Walnut Creek. After the diversion was completed, the Great Western Reservoir was filled almost entirely by Clear Creek, which does not flow across RFETS property.

The Great Western Reservoir has a holding capacity of 3,200 acre-feet of water (DOE 1997). The reservoir was used by the city of Broomfield as a drinking water source from 1955 until 1997. Starting in the 1970s, several measures were taken to protect the drinking water supply; for instance, access and use of the reservoir was limited and fishing was not permitted (DOE 1997). Since 1997, Broomfield discontinued its use of the Great Western Reservoir; drinking water in the city is now pumped from surface waters on the western slope of the Rocky Mountains. Today, most of the water has been drained from Great Western Reservoir; however it is used for limited irrigation purposes. Some water remains to prevent access to contaminated sediments, which is described further in Section V.C.3.

- *Woman Creek.* The flow patterns of Woman Creek have also changed with time. Within RFETS property, Woman Creek flows eastward, through two holding ponds, to the site boundary. Construction projects in these holding ponds in the early 1970s caused contaminated sediments to flow to downstream locations—an issue discussed in greater detail in Sections V.C.3. Mower Ditch previously diverted some of the on-site flow from Woman Creek to an off-site reservoir used for irrigation purposes.

  For the majority of time Rocky Flats Plant operated, Woman Creek received drainage from the southern portion of the Industrial Area and these surface waters eventually flowed into Standley Lake.[4] Standley Lake has a capacity of 43,000 acre-feet of water. Although it was originally constructed to provide irrigation water, the reservoir has provided drinking water to local cities (e.g., Northglenn, Thornton, Westminster) at various times since 1966 and continues to be a drinking water supply today. Standley Lake and the surrounding area are used for various recreational purposes, including camping, boating and fishing, but swimming is not permitted in the reservoir. Natural and stocked fish, including

[4] Some water in Woman Creek flowed directly into Standley Lake, but other water in the creek was first diverted through Mower Ditch into Mower Reservoir—a small (45 acre-feet) reservoir that is used only for irrigation purposes. Outflow from Mower Reservoir then flowed directly into Standley Lake, but the amount of outflow that occurred is not known. After completion of recent construction activities, water from Woman Creek no longer flows into Mower Ditch.

brown trout, rainbow trout, bass, walleye, catfish and yellow perch, are caught in Standley Lake (DOE 1997).

The surface-water flow patterns for Woman Creek changed considerably between 1973 and 1995, through a series of construction projects. These projects ultimately resulted in all runoff from the southern portion of the Industrial Area being collected and diverted away from Standley Lake to ensure that contaminants from RFETS do not enter the drinking water supply. Standley Lake is currently filled almost entirely by water diverted from Clear Creek via multiple canals and ditches.

One outcome of the diversion projects on Woman Creek was the construction of the new Woman Creek Reservoir (completed in 1995). This small reservoir (capacity of 850 acre-feet) is used to prevent Woman Creek waters from entering Standley Lake during high-flow episodes. Water in Woman Creek Reservoir is tested by the city of Westminster (DOE 2002a) before being released into Walnut Creek, downstream of the Great Western Reservoir. The Woman Creek Reservoir is not used for drinking water, irrigation, or recreational purposes (DOE 1997).

4. Terrestrial Biota

When evaluating potential exposures to environmental contamination, ATSDR considers the extent to which contaminants might be taken up by the food chain. The previous section provides background information on locations where fishing occurs in the vicinity of RFETS. This section describes the types of terrestrial wildlife in the area that residents might consume. ATSDR collected background information on two different ways that residents might come into contact with contaminants in terrestrial wildlife, as described below. Sections V.B.5 and V.C.5 indicate what is known about contamination levels in these food items.

- *Hunting.* Wildlife is relatively abundant in the immediate vicinity of RFETS. The area is home to many different mammalian and avian species, including deer, prairie dogs, rabbits, foxes and bald eagles. It is clear that no hunting occurs on RFETS property currently, but this may change in the future. The site boundary does not prevent movement of most wildlife.

  None of the site reports clearly document the extent to which hunting occurs at specific off-site locations. According to the Colorado Division of Wildlife, large game hunted in Jefferson County appears to be mainly elk and deer. In 2002, 143 elk and 280 deer were harvested in state hunting "Unit 38"—the state hunting unit that includes the RFETS property (CDW 2003). It is unclear how many of these animals were harvested near RFETS, because this "unit" spans a large geographic area, including lands quite suitable for hunting at locations west of RFETS. Hunting of large game in the immediate vicinity of RFETS does not appear very likely, given the growing residential population in the area and the fact that hunting is prohibited in Standley Lake Regional Park. The site

documents do not provide detailed information on hunting practices and harvest amounts for small game.

- *Consuming food items from farms, ranches and gardens.* ATSDR also researched the extent to which residents consume locally raised livestock, dairy items, agricultural products, garden vegetables and fruits. The area surrounding RFETS includes many small ranches and small farms. The best available information on farming and ranching activities appears to be documented in a dose-reconstruction study, in which CDPHE contractors interviewed nine long-term landowners who lived in the immediate vicinity of RFETS (ChemRisk 1994c). These interviews revealed that much of the area surrounding the original Rocky Flats Plant was of a "rural agricultural character," with land used for grazing, hay production and dairy farms. Though some agricultural crops were grown in the area, the rocky, shallow soil conditions near RFETS are not favorable for most farming operations. These interviews provide general insights on food items grown near RFETS that might contain site-related contaminants; however, none of the site documents provide specific information on the actual amounts of food items harvested from the local farms and ranches.

E. ATSDR Activities

For more than 15 years, ATSDR has been actively involved with evaluating environmental health issues associated with RFETS. Following is a brief summary of ATSDR's involvement with this site:

- In 1987, the State of Colorado requested that ATSDR review Request for Proposals (RFPs) proposed plan to burn mixed low-level radioactive and toxic waste in a fluidized bed. ATSDR prepared and released a health consultation on this issue. The consultation concluded that public health would not be subject to unacceptable risks from the proposed trial burn provided DOE followed certain recommendations made by an independent scientific panel (ATSDR 1988).

- In March, 1992, ATSDR conducted a scoping visit of the RFETS site. Two environmental health scientists, an environmental engineer and a health physicist from ATSDR's headquarters met with concerned residents and federal, state and local environmental and health agencies to gather information needed to initiate this public health assessment process. From these meetings, ATSDR learned of numerous community concerns, which Section III of this PHA describes in greater detail.

  During the site visit, multiple parties encouraged ATSDR to integrate its health assessment process with the ongoing dose-reconstruction study being managed by CDPHE. This was a key development, as ATSDR determined that it would be counter-productive to prepare and release this PHA until the dose reconstruction study was completed and adequately reviewed. The last volume of the dose-reconstruction study was completed in 1999.

- In 1997, ATSDR released a health consultation for OU3 of RFETS (ATSDR 1997). This document evaluated soil, sediment and surface water contamination found in areas east of the site. The 1997 health consultation concluded that concentrations of uranium, radium and fission products were present at, or near, natural background levels, but that levels of plutonium and americium isotopes were higher than would be normally expected in the environment. ATSDR's dose calculations, however, found that residents are not exposed to plutonium or americium isotopes at levels that would pose a public health hazard for current or anticipated future land uses at the site.

- In August 2002, ATSDR conducted an additional site visit. A health physicist from ATSDR headquarters and the ATSDR Region VIII representative met with concerned citizens at the RFCAB meeting and with CDPHE, EPA, local officials to learn how environmental and health concerns have changed since DOE's continuing remedial activities at RFETS and since the dose-reconstruction study was released.

- ATSDR is currently preparing this PHA, which synthesizes information from the dose-reconstruction study and selected recent air, sediment, surface water and groundwater sampling efforts. The purpose of this PHA is to evaluate the public health implications of potential exposure to site-related contaminants and, if necessary, to recommend actions to reduce exposures.

III. Community Concerns

An integral part of ATSDR's public health assessment process is identifying and addressing community concerns related to environmental health. Since first being involved with the site, ATSDR representatives have been consulting with community members, local officials and other concerned parties to define the specific health issues of concern for RFETS. A major source of information on community concerns was our attendance at and our review of minutes from meetings of the Rocky Flats Citizens Advisory Board, at which residents have expressed various health concerns.

Following is a sampling of the community concerns ATSDR has identified to date:

- For past exposures, residents are particularly concerned about atmospheric releases of plutonium and other radioactive contaminants during routine operations and during episodic release events, especially the fires that occurred in production areas.
- For current exposures, residents expressed concern about whether site clean-up activities will release radioactive contamination into the air that area residents breathe and whether the plutonium and other radionuclides in Standley Lake sediments will enter the drinking water supply.
- A chief concern regarding potential future exposures is how RFETS lands and the surrounding lands will be used after the site is officially closed. ATSDR has heard community members advocate a variety of different land uses in the future, ranging from release of the RFETS lands for public and commercial uses to preserving the lands for the wildlife refuge.
- Some residents have expressed concern about the extent to which community members might be exposed to groundwater contamination, whether through using groundwater wells or by groundwater discharging to surface waters upstream of the drinking water reservoirs.
- Some residents expressed concern about the accuracy and completeness of environmental sampling data collected by DOE and its contractors.
- Residents expressed many specific health concerns to ATSDR staff. The most common concerns identified were whether community members have increased risks of birth defects or cancers that might result from their past or ongoing environmental and occupational exposures. Specific cancers identified among the community concerns include leukemia, lung cancer, brain cancer and prostate cancer.
- Some residents were concerned about possible synergistic effects of being exposed to multiple contaminants through multiple exposure pathways.

IV. Analysis of Exposure Pathways

This section presents ATSDR's analysis of the exposure pathways at RFETS. Exposure pathways are the various ways (e.g., eating/drinking, breathing, contact with) that residents can be exposed to site-related contamination. Analyzing exposure pathways is important because:

- If area residents *are not exposed* to a site's environmental contamination through a particular pathway, then the contaminants in that pathway cannot pose a public health hazard and a detailed evaluation of the pathway is not necessary.

- If residents *are exposed* to site-related contamination through one or more pathways, then further analysis is needed to characterize the exposure and determine whether ATSDR should recommend actions to reduce exposure. However, just because exposure occurs or might occur does not mean that people will have adverse health effects or get sick. In fact, for many contaminants, environmental exposures are often far lower than the exposures people experience through their diets and perhaps through their occupations. Several questions must be answered to understand the health implications of exposure: To what contaminants are people exposed? At what levels of the contaminant(s) are people exposed? How often are people exposed and for how long (duration)? These are some of the issues that ATSDR considers when assessing whether harmful health effects might result from exposure to environmental contaminants at a site.

The remainder of this section presents ATSDR's analysis of exposure pathways for RFETS (Section IV.A) and it reviews the process ATSDR used to evaluate the public health implications of exposures (Section IV.B). Section V then summarizes environmental contamination data and Section VI presents our interpretation of those data from a public health perspective.

A. Evaluation of Exposure Pathways by Location and Environmental Medium

Community members can come into contact with environmental contaminants through multiple environmental media (i.e., soil, groundwater, surface water, sediments, aquatic biota, air and terrestrial biota [plants, fish, animals]). For exposure to occur, a contaminant must move from its source (in this case, RFETS) to a location where someone might come into contact with it. The purpose of this section is to review the likelihood of local residents being exposed to site-related contamination in various environmental media. ATSDR uses the following three terms when classifying exposure pathways:

- *Completed exposure pathways* are pathways in which contaminants have moved from their source to a location where people can and do come into contact with the environmental medium of concern.

- *Potential exposure pathways* are pathways in which ATSDR does not have enough information to determine whether or not people are coming into contact with a contaminant(s). In other words, ATSDR cannot firmly establish if exposure is occurring or not.

- *Eliminated exposure pathways* are those pathways known to be absent at a site, whether it is the result of site access restrictions, institutional controls, or other measures in place at a site. Because no health hazard can exist if exposures do not occur, ATSDR does not evaluate eliminated exposure pathways.

In the remainder of this section, ATSDR classifies the candidate exposure pathways for RFETS, for both on-site (Section IV.A.1) and off-site exposure pathways (Section IV.A.2). For reference, Table 2 summarizes ATSDR's characterization of individual pathways.

1. On-site Exposure Pathways

Extensive sampling projects have characterized the nature and extent of on-site contamination in air, soil, groundwater, surface water and sediment. Environmental contamination with chlorinated solvents, metals and radionuclides clearly exists at many on-site locations. As noted previously, DOE is addressing this contamination through the Superfund program, under EPA and CDPHE oversight.

Although past operations at the Rocky Flats Plant contaminated various on-site locations, access to RFETS continues to be tightly restricted (see Section II.A.2). Because gates, fences and 24-hour guards prevent unauthorized residents from accessing the site, local residents cannot come into contact with the contamination that is currently at on-site areas. As a result, ATSDR considers all on-site contamination to be an **eliminated exposure pathway** and this PHA does not evaluate the public health implications of the past, current and potential future levels of contamination within the RFETS property boundary. Our health evaluations, conclusions and recommendations for this site all account for the possibility that site access might change after site cleanup is complete.

ATSDR recognizes that contaminants at RFETS have in the past and might in the future, move from on-site locations through the air or surface waters to off-site locations. Therefore, Section V.B of this PHA briefly reviews on-site contamination levels at RFETS—not because residents are exposed to these levels, but rather because the contaminants of concern identified at on-site locations should be considered when assessing exposures that actually might occur in the community. Thus, on-site contamination levels were reviewed to evaluate exposures to off-site contaminants.

2. Off-site Exposure Pathways

DOE, CDPHE and other parties have implemented numerous sampling and monitoring projects to characterize levels of environmental contamination at off-site locations. Following is the ATSDR evaluation of the ways that local residents might come into contact with contaminants from RFETS:

- *Surface soil.* Multiple sampling efforts have detected plutonium and americium isotopes in off-site surface soils at concentrations greater than background levels. The highest contamination levels were reported at off-site locations east of the property boundary where access is not restricted. ATSDR classifies the off-site surface soil contamination as a **completed exposure pathway** because contaminants have migrated from their source (the Rocky Flats Plant) to areas where people might come into contact with them. Section V.C.1 reviews the measured contamination levels and Section VI.C.1 comments on the public health implications of this contamination.

- *Groundwater.* Past operations at the Rocky Flats Plant have contaminated the groundwater at several locations beneath ground surface at RFETS. The available monitoring data suggest that the contamination plumes remain on site, though site-related contaminants have sporadically been detected at perimeter monitoring wells along the site boundary. Because it is possible that trace levels of contaminants might migrate off site in the future, ATSDR considers coming into contact with off-site contaminated groundwater to be a **potential exposure pathway**. ATSDR evaluates the current contamination levels and their public health implications in Sections V.C.2 and VI.C.2, respectively.

- *Surface water, sediment and aquatic biota.* When Rocky Flats Plant operated, various liquid wastes were discharged into on-site retention ponds along the Walnut Creek and Woman Creek drainages. Trace levels of contaminants in these ponds could then flow downstream to off-site locations. ATSDR has grouped contamination in surface water, sediment and aquatic biota together, because contaminants often migrate between these media. Various sampling programs in the last 20 years have detected site-related contaminants in the surface water leaving RFETS and in the sediments in off-site reservoirs. Because some local residents' drinking water comes from these reservoirs, ATSDR considers the contamination in off-site surface water, sediment and aquatic biota to be a **completed exposure pathway**. Sections V.C.3 and VI.C.3 evaluate the levels of contamination in these media and the public health implications of coming into contact with the surface water, sediment, or aquatic biota.

- *Air.* Rocky Flats Plant emitted various contaminants into the air. Emissions originated from many sources; e.g., stacks previously vented contaminants generated during routine processing operations, smoke from fires and windblown dust. Airborne contaminants clearly reached the RFETS boundary, as demonstrated by the fact that dusts from the Industrial Area have blown off site

and contaminated surface soils beyond the site boundary. Contaminants released during the time Rocky Flats Plant operated and during subsequent clean-up activities at the site, have reached off-site locations; therefore, ATSDR considers air contamination in off-site areas to be a **completed exposure pathway**. ATSDR summarizes the levels of air contamination in Section V.C.4 of this PHA and the public health implications of breathing in the contaminants in the air are presented in Section VI.C.4.

- *Terrestrial biota (e.g., fruits, vegetables, grains, deer meat).* Food items are grown and harvested in the vicinity of RFETS. These include fruits, vegetables and some crops. The area also includes dairy farms and areas where residents might hunt deer and other game that have foraged on-site. No definitive studies have measured the nature and extent of site-related contamination in these various food items so ATSDR cannot be certain about the extent past releases from RFETS have affected terrestrial biota. Therefore, ATSDR classifies contaminants in terrestrial biota as a **potential exposure pathway**. Sections V.C.5 and VI.C.5 present ATSDR's review of the potential levels of contamination within terrestrial biota.

- *Direct irradiation* is an exposure pathway unique to radioactive materials and radiation-generating machines. There is no analog for chemicals. Given the radionuclides at RFETS, namely Uranium, Plutonium, Americium, and Tritium, one does not expect any significant external irradiation to occur. Uranium, Plutonium, and Americium emit very weak gamma radiation that would not reach off-site receptors; therefore ATSDR classifies Direct Radiation as an **incomplete exposure pathway**.

The previous discussion merely identifies the off-site exposure pathways as being either completed or potential. No further inferences should be drawn. Specifically, if a completed exposure pathway does exist, it does not mean that a health hazard will occur. In Sections V and VI of this PHA, ATSDR reviews the data that must be considered to evaluate the public health implications.

B. Assessment Methodology

ATSDR used established methodologies (ATSDR 1992) to determine the public health implications of exposure to environmental contamination at RFETS. Specifically, the agency followed a three-step approach when addressing the exposure pathways shown in Table 2:

1. Identify concentrations of contaminants in the environment
2. Screen concentrations against health-based comparison values to select contaminants requiring further evaluation
3. Perform toxicological evaluations for those contaminants selected for further evaluation

The first step involves reviewing existing site documents to identify site-related contaminants and their concentrations in the environment. As Section V indicates, information on environmental contamination at RFETS is documented both in sampling studies and modeling analyses. ATSDR generally prefers to base its conclusions on valid, representative sampling results (or actual measurements of environmental contamination). However, some conclusions in this PHA are based on modeling analyses, but only for exposure pathways for which sampling data are not available. Section V documents ATSDR's best estimates of exposure concentrations for the various exposure pathways. That section clearly indicates whether exposure concentrations are based on sampling data or modeling predictions.

The second step in evaluating exposure pathways is selecting contaminants needing further evaluation. This is accomplished by comparing the environmental concentrations of site-related contaminants to health-based comparison values. Comparison values are derived from the scientific literature concerning exposure and health effects. Most of the comparison values used have large safety factors built into them so that the values are certain to be protective of human health. In fact, some comparison values are hundreds or thousands of times less than exposure levels known to produce adverse effects in either humans or laboratory animals. Due to these safety factors, environmental concentrations of a contaminant that are lower than their corresponding comparison values are generally considered to be safe and not expected to cause harmful health effects. However, the opposite is not true. When contamination levels are greater than comparison values, adverse health effects will not necessarily occur. Rather, contaminants found to exceed health-based comparison values require further evaluation (see next paragraph). The text box on the following page presents the approach ATSDR used to select health-based comparison values for this PHA.

The final step in the methodology is evaluating the public health implications of exposure to any of the contaminants identified as requiring further evaluation. For these contaminants, ATSDR puts the public health implications of exposure into perspective by considering site-specific exposure conditions and interpreting toxicological and epidemiological studies published in the scientific literature. In short, this final step is a state-of-the-science review of what the exposure levels mean in a public health context.

V. Environmental Contamination and Other Hazards

Approach to Selecting Health-Based Comparison Values

For each contaminant considered in this PHA, ATSDR attempted to identify an appropriate health-based comparison value to evaluate whether environmental contamination levels, either measured or modeled, warrant a detailed public health evaluation. Concentrations of contaminants that are lower than comparison values are believed to be "safe" or "harmless," and those greater than comparison values need to be evaluated further. ATSDR used the following hierarchy to select appropriate health-based comparison values:

- If the contaminant has comparison values published in ATSDR's most recent collection of comparison values for air, soil and water, then the lowest of these comparison values was selected for the evaluations in this PHA.

- If no ATSDR comparison values are available, the EPA risk-based concentration for the contaminant and medium of concern was selected, if available. These values are published by EPA Region 3 and include screening-level concentrations for various media. Some of these comparison values are cross-route extrapolations of toxicity levels.

- If neither of the previous sources have comparison values, ATSDR researched other relevant sources of information, such as EPA's National Ambient Air Quality Standards, the Nuclear Regulatory Commission's effluent concentrations and occupational exposure limits.

- ATSDR automatically evaluates contaminants with no appropriate health-based comparison values to require further evaluation. For these contaminants, ATSDR reviews relevant toxicology and epidemiology studies to put the measured levels of contamination into a public health context.

Using this approach, ATSDR identified health-based comparison values from many different sources. Though the comparison values from these sources may have been derived using different assumptions, most should be interpreted in the same fashion: environmental concentrations below the comparison values are generally considered to be safe and free from adverse health effects. In cases where chemicals have health-based comparison values for both cancer and noncancer effects, ATSDR chose the lower value for initial screening purposes, thus ensuring that the initial screening protects against both cancer and noncancer health endpoints.

For more information on health-based comparison values, refer to Appendix D for a listing of the different types of comparison values used in this PHA, as well as the assumption inherent in their derivation.

A key requirement to the public health assessment process is the level of contamination found in the environment. This section reviews what is currently known about past, current and potential future contamination levels in soils, groundwater, surface water and sediment, air and food items. This section describes ATSDR's general approach for summarizing environmental contamination data (Section V.A) and then summarizes the nature and extent of contamination at on-site (Section V.B) and off-site (Section V.C) locations. This section also reviews potential physical hazards (Section V.D) and the measures ATSDR took to ensure that the data considered in this analysis are of a known and high quality (Section V.E).

A. Overview

ATSDR's goal when preparing this PHA was to base its conclusions on the best available information on environmental contamination levels at RFETS.

The findings from the dose-reconstruction study that CDPHE administered provides major input into the analyses for this PHA. From 1990 to 1999, contractors to CDPHE thoroughly researched past operations at the Rocky Flats Plant and published a series of documents that quantified potential exposures to the site's releases. Highly qualified health physicists conducted the dose reconstruction study and a Health Advisory Panel appointed by the Governor of Colorado provided independent oversight and scientific review of the project. ATSDR scientists also carefully reviewed the dose-reconstruction study to determine if it offers a rigorous and reliable analysis of community exposures to contaminants released during operations at the Rocky Flats Plant (between 1952 and 1989). Accordingly, many results from the dose-reconstruction study are incorporated directly into this PHA.

To supplement the analyses in the dose-reconstruction study, ATSDR also obtained and reviewed rather extensive environmental sampling data that have been collected since the first phases of the dose-reconstruction study began. These data were reviewed to ensure that site conditions have not changed and that the major findings from the dose-reconstruction study continue to be valid. Given that community members expressed concern about the accuracy and completeness of data collected by DOE and DOE contractors (see Section III), ATSDR gathered data collected by many parties, including CDPHE, EPA, local municipalities, independent researchers and DOE contractors. Furthermore, only those data were considered that are known, or believed to be of a known and high quality (see Section V.E).

ATSDR organized the large volume of data from the dose-reconstruction study and from subsequent sampling studies according to the following factors:

- *On-site versus off-site data.* This section clearly separates our review of on-site levels of environmental contamination (Section V.A) from off-site contamination levels (Section V.C). ATSDR makes this distinction because local residents can only be exposed to the contamination levels found off site.

- *Data from different environmental media.* Within the summaries of on-site and off-site contamination levels, the data are organized into five environmental media: soil; groundwater; surface water, sediment and aquatic biota; air, and terrestrial biota. This organization is used to provide a clear account of the location of site-related contamination. Contamination found in surface water, sediment and aquatic biota is presented in a single section because these environmental media are clearly interrelated.

- *Measured and modeled data.* Throughout this section, ATSDR clearly differentiates measured levels of environmental contamination from contamination levels predicted by models. ATSDR makes this distinction because its preference is to base conclusions on valid sampling results; however, ATSDR will consider the predictions from scientifically defensible modeling analyses in cases in which sampling data are not available.

- *Nonradioactive and radioactive contaminants.* For each environmental medium reviewed, this section first summarizes the available sampling data for nonradioactive contaminants and then for radioactive contaminants. This distinction is made because the two types of contaminants are generally reported in different units and because the methods used to evaluate the public health implications of exposures also differs for the two classes of contaminants.

- *Time frame for which sampling results apply.* Finally, when summarizing data in this section, ATSDR differentiates environmental concentrations for the time during which Rocky Flats Plant operated from those for the years following the plant's closure. These two time periods are differentiated because the sources of environmental contamination, particularly for the air exposure pathway, changed dramatically after the plant ceased production operations in 1989.

B. Review of on-site Contamination

This section summarizes the nature and extent of environmental contamination within the RFETS property boundary. All on-site contamination is in eliminated exposure pathways, because residents do not have access to these areas. This section reviews the environmental contamination on site not because they might pose a potential public health hazard, but rather because the on-site contamination is a source for potential off-site contamination in the future. Section VI.B of this PHA presents ATSDR's public health interpretations of the on-site contamination levels.

1. On-site Soil

Some areas on the site previously contained, or still contain, surface soil with elevated levels of radioactive or nonradioactive contamination, but these areas are not publicly accessible. Areas where surface soil contamination exceeds [EPA's] action levels have already been cleaned up, transported elsewhere, or scheduled to be cleaned up or transported elsewhere by 2006.

Initial investigations at RFETS identified more than 380 areas of suspected environmental contamination and ongoing investigations have narrowed this list to 134 sites that were expected to require some cleanup (DOE 1999). Most of these sites have surface soils contaminated with metals, volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), or radionuclides. DOE is systematically investigating and remediating these areas, with oversight from EPA and CDPHE, to ensure that surface soil contamination levels do not exceed clean-up levels identified in the Rocky Flats Cleanup Agreement.

ATSDR reviewed surface-soil sampling data collected at many of the contaminated areas on the site. A complete review of these data is not presented here because no residents are being exposed to this contamination and because the contamination levels are constantly changing, as remediation efforts at the site progress. ATSDR notes that DOE contractors have already cleaned up many of the highest priority waste sites to action levels that are protective of future wildlife refuge workers.[5] The following are the action levels for radioactive contaminants in soils americium-241, 76 picocuries per gram (pCi/g); plutonium-239/240, 50 pCi/g; uranium-234, 300 pCi/g; uranium-235, 8 pCi/g; and uranium-238, 351 pCi/g (DOE 2003).

ATSDR examined surface-soil contamination from the "903 Pad Area" in greater detail, because multiple site reports indicate that off-site surface-soil contamination largely originated from this source. Surface soils in the 903 Pad Area (part of the Industrial Area OU) were originally contaminated when industrial oils containing trace amounts of plutonium leaked from steel drums stored at the site between 1958 and 1968 (Kaiser-Hill 1995). Sampling during remedial investigations of the 903 Pad Area identified plutonium and americium isotopes as the "principal radionuclide contaminants exhibiting elevated concentrations in soils" (EPA 1992). Soil-sampling studies in this area have found americium-241 and plutonium-239/240 levels as high as 97 pCi/g and 457 pCi/g, respectively (EPA 1992). Although no residents are exposed to these levels of surface soil contamination, ATSDR considered the data trends from the 903 Pad Area when evaluating off-site levels of surface soil contamination. Specifically, ATSDR ensured that its evaluations of off-site soils considered americium and plutonium isotopes—the principal radioactive contaminants of concern at the presumed source of the off-site surface-soil contamination. Section V.C.1 reviews the data ATSDR gathered on off-site surface-soils.

[5] The action levels vary with the type of contaminant. For nonradioactive contaminants, the action levels are protective of a wildlife refuge worker; for radioactive contaminants, the action levels are protective of both a wildlife refuge worker and a rural resident.

2. On-site Groundwater

Multiple groundwater contamination plumes are found at RFETS. None of the plumes extend beyond the RFETS property line and ongoing remediation efforts are removing contaminants from groundwater, tracking the migration of plumes and ensuring that the plumes do not move off site in the future.

DOE first started monitoring groundwater at the Rocky Flats Plant in 1960 and continues to do so today. The groundwater monitoring program has extensively characterized hydrogeologic conditions, identified contamination sources, tracked the migration of contaminated groundwater and assessed the impact on surface water (DOE 2002a). Currently, at least 180 wells are monitored twice per year and 16 wells are monitored quarterly, all in accordance with the Rocky Flats Cleanup Agreement (DOE 1996) and the site's Integrated Monitoring Plan (Kaiser-Hill 2000a). The groundwater monitoring wells have been placed at known contaminated areas, i.e., near surface water discharges along the boundary of the industrial area and along the eastern RFETS property line. Samples are routinely tested for a long list of potential contaminants, including volatile and semi-volatile organic compounds, metals, radionuclides and water quality indicators.

Ongoing DOE monitoring at RFETS has identified several areas with groundwater contamination that emanate primarily from locations within or near the Industrial Area. The contamination resulted from past waste discharges from various sources, such as leaking storage tanks, leachate from landfills and other past waste disposal practices. The on-site contamination is being closely monitored and, in some cases, treated or otherwise addressed. The groundwater contaminants have been found entirely in the uppermost aquifer (the UHSU) within the RFETS property line and they occur primarily in the following plumes (RMRS 2001):

- The "903 Pad/Ryan's Pit Plume" contains many contaminants, including carbon tetrachloride, methylene chloride, tetrachloroethylene (PCE), trichloroethylene (TCE) and uranium isotopes. This plume is located in the southeastern corner of the Industrial Area.

- The "Property Utilization and Disposal Yard Plume" is located immediately north of the Industrial Area. The contaminants of concern in this plume are TCE, nitrates and nitrites.

- The "East Trenches Plume" contains an area that was previously used for disposing of sanitary sewage sludge, solvents and other wastes. Although contaminated soils in the area were removed in 1996, groundwater contamination remains. Monitoring wells at this plume continue to detect carbon tetrachloride, PCE and uranium isotopes. A passive ground water collection trench and zero valence iron treatment system were constructed in 1999.

- The "881 Hillside Plume" is located on the southern edge of the Industrial Area, but north of Woman Creek. Past waste disposal practices in this area caused several contaminants to enter the groundwater. These contaminants include carbon tetrachloride, methylene chloride, PCE, TCE, selenium and uranium isotopes. Contamination in this plume is being addressed as part of OU1 CAD/ROD (EPA 1997a).

- The "Carbon Tetrachloride Plume" and the "Industrial Area VOC Plume" both extend from portions of the Industrial Area where waste solvents leaked into the soil and have since migrated into groundwater. Contaminants detected at elevated levels in at least one of the plumes include 1,1-dichloroethylene, cis-1,3-dichloropropylene, TCE, carbon tetrachloride and uranium isotopes.

- The "Solar Evaporation Ponds Plume" is located in the northeastern part of the Industrial Area. Contamination in this area originated from selected liquid wastes that the Rocky Flats Plant that were previously discharged to temporary holding ponds. The contaminants of concern for this groundwater plume include nitrates and uranium isotopes. Several treatment steps have been implemented at this plume to prevent contaminants from entering Walnut Creek.

- The "Mound Plume" is adjacent to the Solar Ponds Plume and contains many contaminants that originated from leaking drums in a waste storage area. Many VOCs have been detected in the plume, but the contaminants of greatest concern are PCE, TCE and vinyl chloride. The Mound Plume Treatment System is the prototype of the East Trenches system and was completed in July 1998.

- The "Present Sanitary Landfill Plume" is in the Buffer Zone, located north of the Industrial Area. Various sanitary wastes and some hazardous wastes were disposed of at this landfill, which is now closed. Contaminants with elevated concentrations in down-gradient wells include selected metals and uranium isotopes. The present landfill does not produce a groundwater plume. The landfill does produce some leachate, which discharges into the pond at the toe of the landfill.

The purpose of this discussion is merely to identify the contaminants detected in on-site groundwater contamination plumes. ATSDR does not present a quantitative summary of on-site groundwater contamination levels because these contaminants are in an eliminated exposure pathway: no one is exposed to the on-site groundwater contamination and therefore the levels measured in the aforementioned plumes are not a public health hazard.

ATSDR's review of off-site groundwater (V.C.2) and surface water contamination (V.C.3), however, considers whether the contaminants listed above are migrating through groundwater or surface water to off-site locations, where people might come into contact with them.

3. On-site Surface Water, Sediment and Aquatic Biota

Past operating processes at the Rocky Flats Plant discharged contaminants into the Walnut Creek and Woman Creek drainage basins and some contaminants continue to enter these basins today. The contaminants that entered the basins have since flowed off-site, evaporated, degraded, or settled into sediments. Site access restrictions prevent residents from coming into contact with contaminated surface water, sediment, or aquatic biota within the RFETS boundary.

Contaminants can enter surface water bodies at RFETS by several mechanisms. For instance, both dry and wet deposition processes can cause airborne contaminants to enter surface waters; soil contaminants can flow into surface waters through erosion; and groundwater contaminants can seep from aquifers into surface waters. The fate of contaminants in surface water depends upon their chemical and physical properties. In general terms, volatile contaminants tend to evaporate from surface water, soluble contaminants tend to remain in the water column and flow downstream and insoluble contaminants tend to settle to sediments. Sediment-bound contaminants can become resuspended and eventually flow downstream, particularly during high flow conditions. Persistent contaminants in surface water and sediments can also accumulate in aquatic plants and fish. Thus, contaminants in surface water, sediment and aquatic biota are clearly inter-related and this section examines contamination levels in all three media.

ATSDR reviewed numerous documents that report levels of site-related contaminants in the surface water and sediments in the Woman Creek and Walnut Creek drainage basins. These drainage basins include numerous creeks, ditches, holding ponds and evaporation ponds that directly or indirectly received runoff and waste from the Rocky Flats Plant between 1952 and 1989 and continue to receive runoff from RFETS today (ChemRisk 1992). A review of the contamination levels in the on-site portions of these drainage basins follows. This data review is strictly qualitative, because residents cannot access RFETS property and therefore cannot be exposed to the on-site contamination levels in surface water, sediment, or biota. The main reason for reviewing the on-site data is because the contaminants detected in on-site surface water, sediment and biota are most likely to transport downstream to off-site locations, where residents might be exposed (see Section V.C.3).

- *Surface Water*. Both DOE and CDPHE have collected large volumes of surface water monitoring data from various on-site locations in the Walnut Creek and Woman Creek drainage basins. For a qualitative sense of the nature and extent of on-site surface water contamination, ATSDR reviewed relevant data documented in site environmental reports dating back to 1970 and in remedial investigations of selected waste sites. These data sources suffice for identifying the contaminants in on-site surface waters that should be considered for the off-site evaluation.

  The aforementioned data sources report surface-water concentrations for a wide array of organic compounds, inorganic compounds and radionuclides. Though many organic compounds have been detected in on-site surface waters, ATSDR

identified the following nine compounds that have been found at levels exceeding health-based comparison values in at least one sample: 1,1-dichloroethylene, atrazine, benzo(a)pyrene, bromodichloromethane, carbon tetrachloride, chloroform, methylene chloride, PCE, TCE and vinyl chloride. The highest surface water concentrations of these contaminants were observed during the time the Rocky Flats Plant operated and at locations within or near the Industrial Area. Levels of organic compounds in on-site surface water have decreased since the Rocky Flats Plant shut down, although some contamination continues to be found. In 2002, for instance, elevated levels of four chlorinated solvents were found in pond B-2, an isolated holding pond in the Walnut Creek drainage basin; CDPHE is investigating the source of this contamination (CDPHE 2002). The volatile compounds detected in the on-site holding ponds evaporate from surface water before moving off site.

The various site reports document the presence of several inorganic compounds and elements in on-site surface waters as well. Some of the analytes detected are of natural origin (e.g., arsenic), while others clearly result from operations at the former Rocky Flats Plant (e.g., nitrates). The data ATSDR reviewed indicate that arsenic, boron, cadmium, chlorine, manganese, nickel, nitrates and sodium have been detected in at least one surface water sample at levels higher than health-based comparison values. Given this trend, ATSDR's evaluation of off-site surface water conditions (see Section V.C.3) examined readily available data on a full suite of inorganic compounds and elements.

Finally, site reports ATSDR reviewed document the presence of radioactive contamination in on-site surface waters, both during the time that Rocky Flats Plant operated and since the facility shut down. Contaminants consistently measured in on-site surface waters (primarily the holding ponds) at levels greater than background include gross alpha radiation, gross beta radiation, tritium and isotopes of americium, plutonium and uranium. ATSDR ensured that its review of off-site surface waters considered these same radioactive contaminants.

- *Sediment*. Sediments at RFETS have not been sampled as extensively as have the surface waters, largely because on-site sediment sampling is not part of CDPHE's or DOE's annual monitoring programs. However, remedial investigations conducted between 1986 and 1989 collected 25 sediment samples at on-site locations throughout the Walnut Creek and Woman Creek drainages. The samples were analyzed for VOCs, metals and ions and radioactive contaminants (DOE 1991a). Several contaminants were detected during this sampling which focused on depositional areas near the Industrial Area. Contaminants found at levels greater than ATSDR's health-based comparison values for soil ingestion include antimony, arsenic, iron, strontium and thallium. Site access prevents residents from coming into contact with these contaminants, some of which will be removed during ongoing clean-up efforts.

- *Aquatic biota.* None of the site reports ATSDR accessed present data on levels of environmental contaminants in aquatic biota from on-site surface waters. This lack of data is not a critical information gap, because site access restrictions prevent residents from ingesting fish or shellfish from areas within the RFETS boundary.

Section VI.B of this PHA reviews the public health implications of environmental contamination in on-site surface water, sediment and aquatic biota. Although on-site portions of the Walnut Creek and Woman Creek drainages have been contaminated with past discharges from the Rocky Flats Plant, site access restrictions prevent residents from contacting these contaminants at on-site locations and the contamination summarized above is in an eliminated exposure pathway. Our evaluation of off-site exposures considers the possibility of contaminants moving through the Walnut Creek and Woman Creek drainages to downstream locations.

4. On-site Air

Site-related air emissions varied from year to year. It is estimated, for example, that more than 99.9% of plutonium emissions occurred before 1970. The highest emission rates for several contaminants occurred during episodic events (e.g., fires), but emissions associated with routine processing operations occurred throughout operations at the Rocky Flats Plant. Air emissions clearly have contributed to ambient-air contamination at on-site locations, but access restrictions prevent residents from being exposed to the levels observed on the site.

Multiple site documents indicate that site-related air emissions decreased markedly in 1989, when Rocky Flats Plant ceased operating. Accordingly, this PHA evaluates air exposures for two distinct time frames, from 1953 to 1989, while Rocky Flats Plant operated; and 2) from 1989 to the present, after the facility shut down. In this section, ATSDR reviews on-site air-contamination levels for these two time frames to identify contaminants of concern for off-site exposure pathways. As Section IV.A.1 explains, ATSDR considers all on-site exposures to be an eliminated exposure pathway, because residents do not have access to RFETS property. Following is a review of key points regarding on-site air contamination levels:

- *Contamination levels between 1953 and 1989.* From 1953 to 1989, air emissions from the Rocky Flats Plant occurred both from numerous routine materials-processing operations and from episodic events, such as the 1957 and 1969 fires and releases of plutonium-contaminated dust from the 903 Pad Area (see Section II.A.1). Although many documents ATSDR identified comment on air emissions sources at Rocky Flats Plant, the dose-reconstruction study presents the most extensive and thoroughly peer-reviewed account of emissions sources (ChemRisk 1994d, Radiological Assessments Corporation. 1999b). The study presents a highly detailed inventory of measured and estimated emission rates for different contaminants, years, release points and episodic events. Phase II of the dose-reconstruction study examined potential exposures for several contaminants found

to be of greatest health concern: plutonium isotopes, carbon tetrachloride, tritium, beryllium, dioxins and uranium isotopes (Radiological Assessments Corporation. 1999a).

ATSDR refers readers to the dose-reconstruction study for detailed information on how the air emission rates were estimated. Key findings from the study for selected contaminants follow:

- Table 3 summarizes the estimated plutonium emissions data reported in Phase II of the dose-reconstruction study (Till et al. 2002). The table clearly shows that emissions from the 1957 fire and the 903 Pad Area account for more than 99% of the overall historical emissions from Rocky Flats Plant. Of particular note, nearly 99.99% of the estimated plutonium emissions occurred between 1953 and 1969, suggesting that only long-term residents of the area experienced the highest inhalation exposures. Section VI.C.4 revisits this issue.

- Estimated releases of uranium isotopes follow a similar profile to that shown in Table 3. In general, emissions during the mid-1950s accounted for the largest amount of uranium isotopes that Rocky Flats Plant released to the air (Radiological Assessments Corporation. 1999a).

- Air emissions of carbon tetrachloride exhibit a different temporal profile. Between 1953 and 1957, only modest quantities of carbon tetrachloride were used. From 1958 to 1970, however, the dose-reconstruction study estimates that Rocky Flats Plant used and emitted between 40 and 200 tons of carbon tetrachloride annually (Till et al. 2002). Usage of carbon tetrachloride gradually decreased between 1970 and 1989.

- Extensive review of beryllium emissions data has also occurred. The Phase I dose-reconstruction study indicates that Rocky Flats Plant did not use beryllium in full-scale production operations until 1958. For the remaining decades that Rocky Flats Plant operated, 72% of the estimated beryllium emissions occurred during the 1960s, 27% occurred during the 1970s and only 1% occurred during the 1980s (ChemRisk 1994d).

The previous review indicates that the overwhelming majority of emissions for most contaminants of concern, except carbon tetrachloride, occurred before 1970. By inference, on-site and off-site air quality impacts from these emissions also were greatest before 1970, as Section VI.C.4 describes further. Although DOE operated numerous sampling devices that measured emission rates from Rocky Flats Plant, less extensive ambient-air-monitoring data are available.[6] Data from

[6] It is important to distinguish emissions monitoring data from ambient- air monitoring data. Emissions data measure the rate at which contaminants are being released from a specific point, typically a duct or stack. Thus, no one is exposed to the concentrations found in emissions data. Ambient air- monitoring data measure the concentrations of contaminants in the ambient air, typically near ground level. Therefore,

DOE's recent Site Environmental Reports summarize ambient-air monitoring data for plutonium at numerous on-site locations. These data show that trace levels of plutonium have been detected throughout the operation of the monitoring network. Data that ATSDR reviewed show that the highest concentrations consistently occurred in the Industrial Area; further, airborne plutonium levels at the site boundary, on average, were approximately 80 times less than the levels observed in the Industrial Area (DOE 1983–1994). Extensive on-site air-monitoring data are not available for the other contaminants reviewed above.

- *Contamination levels between 1989 and the present.* After the Rocky Flats Plant ceased operating, total facilitywide air emissions decreased sharply. Nonetheless, air emissions still occur from various sources, such as windblown dust from contaminated surface soils, evaporation from ponds and landfills and releases from building decontamination and demolition projects. The decreased emissions were associated with decreased ambient-air concentrations, both at on-site and off-site locations.

Overall, extensive data are available on air emission rates from the former Rocky Flats Plant. Data on ambient-air concentrations of selected contaminants are also available for on-site locations, primarily in the Industrial Area. These on-site sampling results are not representative of exposure-point concentrations, because residents do not have access to the site. The highest levels of air contamination that area residents might inhale are at the RFETS site boundary and these levels are considerably lower than those observed in the Industrial Area. Section V.C.4 reviews observed and estimated ambient air concentrations at off-site locations.

5. On-site Terrestrial Biota

Multiple sampling and modeling studies have shown limited evidence of radioactive contaminants accumulating in the tissues of plants or animals within the RFETS property boundary. No one is exposed to the limited contamination in on-site terrestrial biota and studies suggest that populations of large game on the site (e.g., deer) generally do not mix with populations at off-site locations.

Studies of on-site terrestrial biota have largely addressed plant uptake of radionuclides, primarily plutonium and the extent to which these contaminants are found in large game items. None of the site reports ATSDR reviewed documents levels of nonradioactive contaminants in terrestrial biota. The lack of data for these contaminants is not a critical information gap, since the environmental media at RFETS are not heavily contaminated with highly persistent and highly bioaccumulative compounds.

The available plant uptake studies suggest minimal root uptake of plutonium, with most of the plutonium isotopes in plant tissues originating from air deposition or rain water (DOE 2002a). One study, for instance, estimated that more than 99% of the plutonium at RFETS remains in soils, with less than 0.3% of the plutonium isotopes found in various

ambient-air monitoring data are used to characterize contamination levels in the air that people breathe.

species of plants and small animals (Little, Whicker, Winsor 1980). Further, concentrations of plutonium in small animals were found to be 100 times lower than levels found in the on-site soils. These findings suggest that plants do not readily uptake plutonium from soils; therefore, the animals that consume the plants also have minimal plutonium contamination.

The documents ATSDR reviewed include a 1992 study of mule deer at RFETS (Symonds 1992). The study primarily examined deer movements and survival patterns and also measured levels of plutonium contamination in the lungs, livers and ribs from seven roadkill deer collected from the Buffer Zone. Colorado State University's Department of Radiological Health Sciences analyzed the tissue samples and all samples contained plutonium at levels below detection limits. This study also found that the adult deer population inhabiting the RFETS Buffer Zone generally remains on site all year, but yearling males appear to be more likely to move off site. Though limited in scope, the 1992 study presents the most recent account of plutonium levels in deer tissue at RFETS. ATSDR notes that the U.S. Fish and Wildlife Service recently collected samples of lung, liver, kidney, muscle and bone from 26 deer at RFETS. The samples are currently being archived and will be analyzed if the U.S. Fish and Wildlife Service allows hunting to occur on the site in the future (RFCAB 2003).

C. Review of Off-site Contamination

This section summarizes the nature and extent of off-site environmental contamination, organized by the medium in which contamination occurs. Because all off-site exposure pathways are either potential or completed, this section presents detailed, quantitative data summaries. Environmental contamination levels are compared to health-based comparison values throughout this section as an initial screen for potential toxicity. Section VI.C presents ATSDR's detailed review of the public health implications of exposures to the levels of environmental contamination described below.

1. Off-site Soil

Windblown dust has carried contaminants from the former Rocky Flats Plant to off-site surface soils. The contaminants of concern are isotopes of americium and plutonium. The highest off-site surface-soil concentrations were found in unpopulated areas immediately east of the RFETS property line. The surface soil concentrations decrease rapidly with downwind distance and approach background levels at locations 2 to 3 miles east of the facility. Surface-soil-sampling results reported by DOE, CDPHE and the Citizens' Environmental Sampling Committee are generally consistent.

ATSDR evaluated several data sources to characterize the nature and extent of off-site surface-soil contamination. These data sources primarily contain contamination levels of radionuclides. The absence of data for metals and VOCs is not viewed as a critical data gap for two reasons. First, site investigations in the Buffer Zone areas east of the Industrial Area did not find metals at concentration levels greater than background in the surface soils (EPA 1997b). Second, VOCs tend to evaporate from surface soils, so it is

unlikely that these compounds transported from the Rocky Flats Plant through the air and contaminated off-site surface soils.

ATSDR considered the following four data sources when evaluating the levels of radionuclides in off-site surface soils:

- *OU3 Remedial Investigation.* DOE considered three data sets when evaluating surface soil conditions at off-site locations. The first data set was 144 samples that DOE collected from 10-acre plots of land east of RFETS. The second data set was 47 surface soil samples collected from the "Remedy Lands" immediately east of RFETS and the third was samples collected from the Rock Creek drainage basin to characterize background levels of contamination. The highest surface soil concentrations for plutonium-239/240 (6.5 pCi/g) and americium-241 (0.52 pCi/g) were measured at locations within 1,800 feet of the east RFETS property line (EPA 1997b). No residents live in the areas where these maximum values were detected. A spatial analysis of the OU3 data, combined with surface soil sampling results from other studies, indicated that plutonium and americium concentrations in surface soils return to background levels at distances between 2 and 3 miles east of the RFETS property line (EPA 1997b).

- *DOE routine soil-sampling efforts.* Between 1984 and 1994, DOE conducted 11 surface-soil sampling studies to survey plutonium levels at 40 locations, including several locations along the RFETS property line. Each sample contained the top 2 inches of undisturbed soil from the designated sampling location and samples were analyzed in a laboratory for plutonium content, but not for americium or any other radionuclide. ATSDR reviewed the surface-soil concentrations measured as an indicator of possible off-site exposure levels and the highest plutonium-239/240 level found along the property line was 10.0 pCi/g—a level generally consistent with the highest concentrations DOE found during its remedial investigation for OU3. No residents live where this surface soil concentration was observed.

- *Citizens' Environmental Sampling Committee (CESC) study.* In 1993 and 1994, CESC, a group of interested citizens assisted by technical consultants, sampled off-site soils at 28 locations in the vicinity of RFETS. At each sampling location, field workers collected both a surface soil sample (0–1 inch below ground surface) and a subsurface sample (0–8 inches below ground surface). A data summary of this study indicates that plutonium-239/240 levels at six of the off-site sampling locations exceeded 0.084 pCi/g, an estimate of local background levels (CESC 1996). The highest plutonium-239/240 concentration measured in surface soils (4.5 pCi/g) was found approximately 1 mile east of RFETS, near the Great Western Reservoir. This maximum concentration is reasonably consistent with those cited in the previous two bulleted items.

- *CDH soil surveys.* When preparing this PHA, ATSDR received copies of CDH's monthly environmental surveillance reports from 1970 to 1991 (CDH 1970–91).

Although these reports primarily focus on air and surface water monitoring, some reports document results from soil surveys. The last survey conducted during this time frame involved surface soil sampling in numerous off-site areas. During this 1989 study, the highest plutonium-239 concentration measured along the eastern RFETS site boundary was 2.9 pCi/g (CDH 1970–91). This concentration is not directly comparable to the previous three studies, because CDH apparently conducted sector-average sampling, while the other results are from individual surface soil samples.

Overall, the four aforementioned sampling studies all indicate that off-site surface soil contamination is highest along the eastern RFETS property line and that contamination levels decrease with distance from the site. In all four studies, the highest plutonium levels were observed in unpopulated areas and the maximum concentrations from the four studies are in excellent agreement. Section VI.C.1 comments on the public health implications of coming into contact with contaminated off-site surface soils.

2. Off-site Groundwater

Sampling data are not available for the private groundwater wells located east of RFETS, but local hydrogeologic conditions and monitoring data from perimeter wells suggest that groundwater contamination plumes at RFETS remain on site and have not migrated to the private well locations. Ongoing sampling is needed because, in the last 5 years, chlorinated organic compounds have been periodically detected at trace levels in groundwater wells along the eastern RFETS property line.

ATSDR considered several data sources when characterizing the nature and extent of off-site groundwater contamination. Exposure at off-site locations could occur at private wells used for drinking water and irrigation, if site-related contaminants reach these locations. As Section II.D.2 noted, no private wells are located less than 1 mile from the eastern RFETS site boundary, but 15 private wells have been identified at distances between 1 and 2 miles from the eastern site boundary. ATSDR focuses on locations east of RFETS because groundwater beneath the site generally flows from west to east. The site reports ATSDR reviewed did not document groundwater sampling results for the private wells east of RFETS. Nonetheless, the following observations all suggest that the groundwater contamination beneath RFETS has not migrated off site:

- *Local hydrogeologic conditions.* Groundwater in the uppermost aquifer beneath RFETS moves relatively slowly. Specifically, the dose-reconstruction study estimates that it would take 30 to 300 years, if not longer, for site-related contaminants to migrate from the center of the Industrial Area to the nearest down-gradient private wells located off site (ChemRisk 1994b). This estimate suggests that contaminants released to groundwater when Rocky Flats Plant first operated in the 1950s would not have reached off-site locations before the 1980s. This is an important observation because perimeter monitoring was occurring at the site by the mid-1980s. Therefore, it is highly unlikely that any contaminants could have migrated off site before the perimeter monitoring was implemented.

- *Perimeter monitoring results.* RFETS collects samples from perimeter monitoring wells to ensure that groundwater contaminants are not migrating off site. The extent of the perimeter monitoring has changed over time. In 1986, for example, four groundwater monitoring wells were installed along Indiana Street at the eastern (i.e., down-gradient) boundary of RFETS (EG&G 1991). Since then, some wells have been added, replaced, or retired. Currently, DOE monitors six wells at the site boundary; four of these wells sample from the alluvium and two samples from bedrock. All six wells are sampled either quarterly or twice per year. Samples are analyzed for 31 inorganic contaminants (28 metals and 3 water-quality parameters), 64 organic compounds and 7 radioactive contaminants (Kaiser-Hill 2002a). It is important to note that this list of analytes includes all of the contaminants of concern in the on-site groundwater plumes.

  To characterize conditions at the site since the dose-reconstruction study was completed, ATSDR reviewed the eight most recent quarterly groundwater-monitoring data that DOE contractors prepared in fulfilling the requirements of the Rocky Flats Cleanup Agreement (Kaiser-Hill 1998, 1999b, 1999c, 2000b, 2000c, 2001a, 2001b, 2002a, 2002b). A summary of these recent sampling studies follows, organized by groups of contaminants:

  - *Organic compounds (volatile and semi-volatile).* Between 1998 and 2002, 50 groundwater samples were collected from the perimeter wells and analyzed for concentrations of VOCs and semi-volatile organic compounds. Of the 64 compounds considered, 55 were not detected in any of the samples collected from the site boundary. Table 4 summarizes the groundwater concentrations for the nine VOCs that were detected. These compounds clearly were detected infrequently (i.e., in no more than 3 out of the 50 samples collected) and at levels only marginally higher than the method detection limits. Only one compound, 1,2-dichloroethane, was detected at a level greater than health-based comparison values and this detection (0.8 µg/L) was an estimated value.

  - *Inorganic analytes (nonradioactive).* During the 1998 to 2002 sampling period, 35 samples were analyzed for metals and 46 samples were analyzed for water quality parameters (i.e., fluoride, nitrate and sulfate). This is fewer than the 50 samples analyzed for organic compounds because dry well conditions, in some cases, produced only enough water for a partial suite of analytes. Some metals (e.g., manganese and nickel) were analyzed more often than others, because the Integrated Monitoring Program (IMP) requires increased sampling frequency when metals are detected above their specific action levels.

    Of the 31 inorganic compounds that were analyzed, 8 were detected in at least one sample at levels greater than health-based comparison values. Table 5 summarizes groundwater concentrations of these 8 analytes from

1998 to 2002. ATSDR notes that many of the inorganic compounds detected in the boundary wells are naturally occurring and, therefore, are not necessarily the result of site-related contamination.

- *Radioactive contaminants.* Six radioactive contaminants were tested between 40 and 50 times during the 1998 to 2002 sampling period. Some were sampled more frequently than others because dry well conditions occasionally make it impossible to measure a full suite of analytes. Radiological sampling results are presented in Table 6. While each contaminant was detected in at least 20% of the samples analyzed, none of the detections exceeded health-based comparison values. For most of the contaminants in Table 6, the highest concentration found is more than 100 times lower than the health-based comparison values.

Overall, the previous summary shows that *site-related* contaminants—volatile organic compounds and radionuclides—are not consistently detected at elevated levels nor at levels that are higher than health-based comparison values. Inorganic analytes, on the other hand, are detected more frequently at the site boundary, but most of these are naturally occurring. Also, none of the inorganic analytes are consistently detected at levels greater than health-based comparison values. Therefore, the most recent sampling data available show no evidence of elevated groundwater contamination at the RFETS property line, although some chlorinated organic compounds are periodically detected at trace levels.

- *Data considered in the dose-reconstruction study.* Rather than relying strictly on the most recent groundwater sampling data, ATSDR also considered the review of groundwater contamination presented in the dose-reconstruction study (ChemRisk 1994b). The data reported for perimeter monitoring wells in the dose-reconstruction study—and in DOE's annual monitoring reports for 1992, 1993 and 1994—are generally consistent with the data summarized above. Specifically, certain organic compounds were detected, but sporadically and generally not at levels exceeding health-based comparison values. The final conclusion in the dose-reconstruction study was that "…it is not likely that contaminants from the Rocky Flats Plant have migrated in groundwater significantly beyond Indiana Street between 1953 and 1989 and impacted domestic wells" (ChemRisk 1994b).

In summary, ATSDR reviewed data from numerous sources to characterize the likelihood that groundwater contamination has moved off site. Specifically, ATSDR considered DOE's Rocky Flats Plant Site Environmental Reports, CDPHE's Environmental Surveillance Reports, the dose-reconstruction study prepared for CDPHE and RFCA Quarterly Groundwater Monitoring Reports prepared by DOE contractors. Combined, these reports paint a consistent picture of the nature and extent of groundwater contamination at RFETS; i.e., although several contamination plumes are located beneath RFETS, the groundwater monitoring data and the hydrogeologic conditions suggest that these plumes remain within the property lines and have not affected off-site private wells.

Section VI.C.2 reviews the public health implications of the groundwater contamination at RFETS.

3. Off-site Surface Water, Sediment and Aquatic Biota

Trace amounts of site-related contaminants have previously flowed from the Rocky Flats Plant, through the Walnut Creek and Woman Creek drainages and into the Great Western Reservoir, Mower Reservoir and Standley Lake. Past site investigations have identified radioactive and nonradioactive contaminants in surface water samples, sediment samples and fish tissue samples from these water bodies. However, none of the site-related contaminants have been consistently found at levels greater than health-based comparison values for drinking water, sediment ingestion, or fish ingestion exposure scenarios. Contamination levels in the reservoirs will probably decrease in the future, because effluents from RFETS no longer flow into these surface waters.

As Section V.B.3 indicates, Rocky Flats Plant previously discharged contaminants that eventually flowed off site and into the Walnut Creek and Woman Creek drainages. The fate of these contaminants depends largely on their chemical and physical properties. The contaminants flowing off site will evaporate, settle to sediments, remain suspended in the water column, degrade, or accumulate in biota. Once surface waters flow across the RFETS property line, there are few restrictions placed on their access. Residents can come into contact with site-related contaminants in off-site surface waters through drinking water supplies, incidental ingestion of surface waters or sediments, or by eating fish caught from Standley Lake.

ATSDR identified numerous studies that measured levels of contamination in off-site surface waters. Although limited surface water sampling data are available for the 1950s and 1960s, CDPHE, DOE, local municipalities and other parties have studied off-site surface waters extensively and routinely since 1970. As a result of concerns that contamination would enter local drinking water supplies, thousands of off-site surface water samples have been collected over the past 30 years. It is not expected that concentrations of radionuclides in surface water would have been elevated in the years prior to 1970, except as a result of above ground nuclear testing. An extremely large volume of data is available for radioactive contaminants. Though fewer sampling records are available for nonradioactive contaminants, the available sampling results are sufficient for characterizing the nature and extent of off-site contamination.

The available sampling data can be summarized many ways. In this section, ATSDR organizes the sampling data according to the four exposure pathways that they characterize:

- *Contamination in drinking water supplies.* Several municipalities near RFETS obtain, or previously obtained, their drinking water from surface waters in the Walnut Creek and Woman Creek drainages. Specifically, Broomfield's drinking water came from the Great Western Reservoir from 1955 to 1997 and the cities of

Northglenn, Thornton and Westminster continue to obtain part or all of their drinking water from Standley Lake.

ATSDR evaluated the quality of the drinking water supplies based on thousands of drinking water samples, as documented in several references. The Phase I dose reconstruction study, for instance, summarizes CDH's bimonthly drinking water sampling results collected between 1970 and 1989 from the Broomfield and Westminster municipal water supplies (ChemRisk 1994d). For insights into contamination levels after the dose reconstruction study was released, ATSDR retrieved all available annual drinking water quality reports from the Broomfield and Westminster municipal water supplies (City of Broomfield 1991–1997; City of Westminster 1994–2002).[7] ATSDR's review of the drinking water data follows:

- *Westminster water supply.* Table 7 summarizes the highest levels of radioactive contamination measured in the Westminster drinking water supply between 1970 and 1989 (ChemRisk 1994d; CDH 1970–1971). As the table shows, the maximum concentrations of radionuclides observed among hundreds of drinking water samples were all lower than their corresponding health-based comparison values. Consistent with this finding, the data ATSDR accessed on Westminster's drinking water supply show no radioactive contamination above health-based comparison values in more recent years (City of Westminster 1994–2002).

  ATSDR also evaluated sampling data for nonradioactive contaminants in Westminster's drinking water supply. According to data in the recent annual water quality reports (City of Westminster 1994–2002), the nonradioactive contaminants are all found at levels below ATSDR's corresponding health-based comparison values. Consistent with this observation, the municipal water supply has reported that "…since Westminster started managing its water supply we have never had a violation of contaminant levels or other water-quality regulations" (City of Westminster 1994–2002).

- *Broomfield water supply.* Table 8 summarizes the highest levels of radioactive contamination measured in the Broomfield water supply between 1970 and 1989 (ChemRisk 1994d; CDH 1970–1971). During this time, every concentration of americium, plutonium and uranium isotopes were lower than corresponding health-based comparison values. However, the maximum concentrations of gross alpha radiation, gross beta radiation, tritium and "natural" uranium all exceeded comparison values. The peak concentrations of these contaminants roughly correspond to the times

[7] ATSDR also obtained and reviewed drinking water sampling data from the Northglenn and Thornton water supplies. Data from these supplies are not summarized here, because many more samples were collected from the Westminster supply. Basing conclusions on the Westminster data is appropriate, because all three water supplies draw from the same source (Standley Lake).

when maximum concentrations were observed in Walnut Creek. Because the comparison values for these four contaminants are based on long-term exposure scenarios, ATSDR calculated annual average concentrations of the four radioactive contaminants in Broomfield's drinking water supply. In the years with maximum gross alpha and gross beta concentrations, the annual average levels of these indicators were 10.0 pCi/L and 9.4 pCi/L, respectively; both annual average levels are lower than the health-based comparison values for these contaminants. Further, between 1970 and 1989, the highest annual average tritium and "natural" uranium concentrations in Broomfield's drinking water were 8,555 pCi/L and 16.74 pCi/L, respectively (ChemRisk 1994d). Both of these levels are lower than the contaminants' corresponding comparison values. Since 1989, no radioactive contaminants have been found at levels higher than comparison values in Broomfield's drinking water supply.

The site documents ATSDR reviewed present limited information on non-radioactive contamination in Broomfield's drinking water supply. The most extensive information on these contaminants is presented in Broomfield's annual water quality reports from 1991 to 1997. More recent data were not reviewed, because Broomfield's water supply stopped drawing from Great Western Reservoir in 1997. With one exception, no volatile organic compounds or metals were found at levels greater than ATSDR's health-based comparison values in Broomfield's drinking water supply between 1991 and 1997. As the exception, arsenic levels were found at concentrations up to 0.005 mg/L, which is higher than ATSDR's comparison value, but lower than EPA's Maximum Contaminant Level. Broomfield's most recent annual drinking water quality report indicates that "…our system has never violated a Maximum Contaminant Level or any other regulatory requirement" (City of Broomfield 2002).

The previous data review indicates that, since 1970, no contaminants consistently exceeded levels of health concern in the drinking water supplies near RFETS. It is not expected that concentrations of radionuclides in surface water would have been elevated in the years prior to 1970, except as a result of above ground nuclear testing. Section VI.C.3 evaluates the public health implications for the few contaminants that had maximum concentrations greater than comparison values, but average concentrations below these levels.

- *Contamination in surface water that recreational users might ingest.* ATSDR gathered data to characterize potential exposures that recreational users of off-site surface waters might experience. However, direct contact with these surface waters appears to be limited. Swimming is prohibited in Standley Lake and residents were not allowed to access Great Western Reservoir in the years it provided Broomfield's drinking water supply. Although residents may access off-site portions of Walnut Creek and Woman Creek, ATSDR found no accounts of extensive recreational activity occurring in these creeks, most likely due to their

limited flow. Given these limited recreational uses of off-site surface waters, ATSDR's evaluation focused on whether surface water contamination reached levels that would pose an acute health hazard following incidental ingestion of surface waters. ATSDR reviewed an extremely large volume of surface water sampling data documented in the following references:

- Routine and periodic sampling results for Walnut Creek, Woman Creek, Standley Lake and Great Western Reservoir documented in CDH's monthly surveillance reports (CDH 1970–1991).

- Sampling results from the reservoirs during the OU3 remedial investigation (DOE 1997).

- Quarterly sampling results for Walnut Creek and Woman Creek available from CDPHE's Web site (CDPHE 2000–2003).

- Routine and periodic sampling conducted by DOE contractors, as documented in annual site environmental reports (DOE 1983–1994), the recent automated surface water monitoring report (DOE 2002b) and DOE's 5-year update for the RFETS site (DOE 2002a).

- Effluent and surface water monitoring data documented in the dose reconstruction study.

Taken together, the data in these references thoroughly characterize surface water quality for the site: samples were collected when Rocky Flats Plant operated and since the facility closed; samples were collected from all off-site surface water bodies potentially affected by site-related contamination; and samples were routinely analyzed for the contaminants believed to be of greatest concern. Not surprisingly, the data trends in the surface water are reasonably consistent with those for the drinking water supplies, summarized above. In Standley Lake and Great Western Reservoir, no contaminants were consistently found in the surface waters at levels greater than health-based comparison values derived for chronic exposure scenarios and no contaminants were ever found at levels greater than health-based comparison values for acute exposures. Furthermore, concentrations of most site-related contaminants in the off-site surface waters have decreased considerably since Rocky Flats Plant closed.

ATSDR notes that, in the early 1970s, elevated levels of radioactive contaminants were periodically detected in Walnut Creek as it flowed off site (ChemRisk 1994d). Specifically, plutonium-239/240 readings peaked at 172.3 pCi/L in 1972 and tritium concentrations reached 119,070 pCi/L in 1973. Some of these maximum levels were observed during the time when DOE contractors were reconstructing the retention ponds at Rocky Flats Plant and untreated water flowed off site (ChemRisk 1994d). Though contaminants in Walnut Creek periodically exceeded health-based comparison values, the concentrations of these

contaminants in Great Western Reservoir did not, presumably because of the dilution that occurs when Walnut Creek enters the reservoir. Section VI.C.3 reviews the public health significance of the elevated radioactive contamination that occurred in Walnut Creek in the early 1970s.

- *Contamination in sediments that recreational users might ingest.* Recreational users of off-site surface waters might come into contact with potentially contaminated sediments, particularly when lower reservoir water levels expose sediments that are typically submerged. Numerous studies have reported site-related contaminants in the sediments of the Great Western Reservoir, Mower Reservoir and Standley Lake (e.g., Battelle 1981, DOE 1991b, EPA 1997b). Focusing on sediment contamination in these reservoirs is appropriate, because sediment deposition behind their dams prevent significant contaminant migration to locations further downstream (EG&G 1991).

  Of all studies ATSDR reviewed, the remedial investigation for OU3 provides the most extensive account of sediment contamination levels in the off-site reservoirs (EPA 1997b). This study reviews results from 389 sediment samples. These include 120 surface and 155 subsurface samples collected in the early 1990s during the remedial investigation and 114 sediment samples collected from Great Western Reservoir and Standley Lake in the early 1980s. Plutonium-239/240 was the contaminant of greatest concern for the reservoir sediments and was found at levels up to 3.3 pCi/g in surface sediments and 4.3 pCi/g in subsurface sediments (EPA 1997b). These highest levels were both observed in Great Western Reservoir, with lower contamination levels found in Standley Lake and Mower Reservoir. It is important to note that the highest sediment concentrations were found to be lower than the highest surface soil concentrations at off-site locations; Section VI.C.3 draws upon this observation when interpreting the public health implications of contacting potentially contaminated reservoir sediments. Concentrations of heavy metals and other radionuclides were also reported, but ATSDR previously concluded that none of these contaminants were found at levels of health concern (ATSDR 1997).

  Although the future surface sediment concentrations in off-site reservoirs cannot be predicted, ATSDR notes that continued effluent and surface water monitoring show that off-site migration of site-related contaminants has greatly decreased since the Rocky Flats Plant ceased operating. As a result, the sediments that deposit in the reservoirs in the future will be largely uncontaminated, at least when compared to the sediments that deposited previously. Thus, it is unlikely that surface sediment concentrations in the reservoirs will increase in the future.

- *Contamination in fish that residents might ingest.* Fishing is permitted in Standley Lake and is relatively common among some area residents. Fish are stocked in the reservoir to supplement the natural supply. ATSDR identified one study that measured contamination levels in fish tissues from Standley Lake (CDPHE 1990). In the study, CDH collected fillet samples from four fish species that local fishers

are known to catch: rainbow trout, smallmouth bass, walleye and channel catfish. For each species, fillets from at least three fish were analyzed as composite samples for radionuclides, metals and organic compounds.

Table 9 summarizes the contamination levels measured during the 1989 sampling study. The table presents the highest concentrations for seven contaminants that were detected in at least one fish tissue sample. As the table shows, trace amounts of cadmium, mercury, selenium and pesticide residues (DDT, DDE, DDD and malathion) were detected in at least one sample, all at concentrations below 0.5 ppb. Of these contaminants, mercury, DDT, DDE and DDD all had at least one composite sampling result greater than health-based comparison values. Section VI.C.3 reviews the significance of these detections. The following contaminants were not detected in any of the composite samples, suggesting that fish in Standley Lake do not accumulate these contaminants in significant amounts: beryllium, chromium, lead, nickel, plutonium-239/240, cesium-137 and uranium (sum of all isotopes).

4. Off-site Air

Levels of air pollution near RFETS have varied significantly with time and location. While Rocky Flats Plant operated, the site-related contaminants of principal concern were plutonium isotopes and carbon tetrachloride. The dose reconstruction study estimated exposure concentrations for these contaminants. The study found that plutonium emissions from routine operations at Rocky Flats Plant (1953–1989) had minimal air quality impacts at off-site locations; these impacts were estimated to be comparable to the plutonium levels that have been attributed to fallout from past testing of nuclear weapons. Exposures to plutonium were clearly greatest during the 1957 fire and during the time (1964–1969) when strong winds blew plutonium-contaminated dust from the 903 Pad Area to off-site locations. Estimated plutonium exposures during these events have inherent uncertainties, but ATSDR believes the plutonium exposure estimates from the dose reconstruction study are based on the best information available and there are currently no practical opportunities for reducing this uncertainty.

In the case of carbon tetrachloride, estimated air quality impacts from site-related emissions were notably lower than the ambient-air concentrations of carbon tetrachloride typically observed in urban and suburban locations around the country today. ATSDR believes the estimated carbon tetrachloride exposure concentrations are reasonable, given that they are based on the assumption that 100% of the carbon tetrachloride used at Rocky Flats Plant evaporated into the air. Section VI.C.4 reviews the public health implications of exposure to both plutonium and carbon tetrachloride.

After Rocky Flats Plant stopped operating in 1989, site-related air emissions decreased substantially. From 1989 to the present, both CDPHE and DOE have collected thousands of air samples from the RFETS site perimeter and in neighboring communities. These samples have been analyzed for air concentrations of numerous pollutants: isotopes of plutonium, americium and uranium; beryllium; criteria pollutants; and volatile organic

compounds. Since 1989, off-site ambient-air concentrations of all site-related pollutants have been lower than corresponding health-based comparison values.

Levels of ambient-air contamination near RFETS have varied from year to year, depending on activities occurring at the site. ATSDR has defined two time frames for evaluating the air exposure pathway: the time when Rocky Flats Plant operated and the time since the facility shut down. These time frames were selected because site-related air emissions and off-site exposures to air contaminants changed considerably in 1989, when routine manufacturing operations at Rocky Flats Plant permanently ceased. ATSDR's review of ambient-air contamination at off-site locations during these two time frames follows:

- *Air contamination while Rocky Flats Plant operated (1953–1989).* Rocky Flats Plant had numerous air emissions sources, including releases that occurred from routine operations and those associated with unplanned events (e.g., fires). Air emissions from most every source at the facility first passed through pollution control devices before being vented to the atmosphere. Regardless of the source and the extent of pollution controls, air emissions from Rocky Flats Plant dispersed considerably over the 2 miles that separate the center of the Industrial Area from the site boundary. Therefore, exposures to site-related contamination in the surrounding communities were much lower than exposures that occurred within the site boundary and within the main processing buildings.

  Insights on past levels of off-site air contamination for this PHA came almost entirely from the dose reconstruction study. ATSDR relied heavily on this study because it presents the most comprehensive and most thoroughly peer reviewed account of past exposures to contaminants from the Rocky Flats Plant. As previously noted, highly experienced and qualified CDPHE contractors completed the dose reconstruction study, under the oversight of an independent expert review panel. This section reviews the dose reconstruction study's key findings regarding off-site air contamination.

  In the initial phase of the dose reconstruction study, the CDPHE contractors performed several preliminary tasks: identifying chemicals and radionuclides that were previously used at Rocky Flats Plant (ChemRisk 1991a); selecting chemicals and radionuclides of potential concern based on the quantities used, potential for exposure and relative toxicity (ChemRisk 1991b); reconstructing past operations at Rocky Flats Plant (ChemRisk 1992); and estimating air releases over the entire history of facility operations (ChemRisk 1994d). Release estimates were then used as inputs to fate and transport models, which predicted ambient-air concentrations throughout much of the Denver metropolitan area as functions of location and time. After using tracer studies to evaluate the performance of multiple air dispersion models, the principal investigators for the dose reconstruction study decided to use the RATCHET model to simulate how contaminants emitted from the Rocky Flats Plant moved through the air to off-site locations.

Following is a review of the modeling predictions both for the two contaminants identified as being of greatest potential health concern (plutonium and carbon tetrachloride) and for additional contaminants that were considered but found to contribute little to overall exposure (e.g., beryllium, dioxins and uranium). This discussion presents the estimated exposure concentrations and comments on the uncertainties associated with the estimated exposure levels. Section VI.C.4 comments on the public health implications of exposure to the ambient-air concentrations summarized in the following paragraphs:

- *Plutonium.* The dose reconstruction study estimated past ambient-air concentrations of plutonium as a result of both routine operations and episodic releases. Air quality impacts from *routine operations* were found to generally follow the trends in emissions data (see the first two rows of Table 3): estimated annual average ambient-air concentrations between 1953 and 1969 tended to be at least an order of magnitude greater than those that occurred between 1970 and 1989.

  Specifically, the highest estimated annual average concentrations of plutonium at off-site locations resulting from *routine operations* ranged from 0.00000005 pCi/m^3 (in 1978) to 0.0001 pCi/m^3 (in 1957) (Radiological Assessments Corporation. 1999a). These exposure levels were predicted to occur immediately east of Rocky Flats Plant, in an unpopulated area along Indiana Avenue. The estimated annual average plutonium levels from Rocky Flats Plant's *routine operations* were slightly lower than plutonium levels that have been attributed to fallout from past testing of nuclear weapons (Radiological Assessments Corporation. 1999a). This finding suggests that emissions from the *routine operations* had air quality impacts at off-site locations that were essentially comparable to "background" plutonium levels.

  To assess the accuracy of the modeling predictions, the authors of the dose reconstruction study compared the estimated plutonium concentrations from *routine operations* to measured plutonium levels in the vicinity of the Rocky Flats Plant. This comparison found reasonable agreement between measured and estimated air concentrations between 1970 and 1989; comparisons were not made for earlier years due to the lack of quality plutonium ambient-air-monitoring data prior to 1970. Given the general consistency between the measured and estimated airborne plutonium levels, ATSDR has confidence that the air modeling approach for evaluating Rocky Flats Plant's *routine operations* is defensible and free of significant bias.

  The dose reconstruction study also predicted air quality impacts from three *episodic releases*: the 1957 fire, the 1969 fire and emissions from the 903 Pad Area between 1964 and 1969. Table 10 summarizes the results of

these predictions. Estimated exposure concentrations for the two fires were notably higher than the air quality impacts resulting from routine operations. ATSDR notes, however, that residential exposures to plutonium-contaminated smoke were of short duration (i.e., less than 1 day). Inhalation exposures to smoke from the 1957 fire, for instance, are expected to be limited, given that the fire occurred in the middle of the night, when most residents are indoors.

The accuracy of the air modeling predictions for the 1957 and 1969 fires cannot be easily assessed, because no valid ambient-air samples were collected during these events. Even though the principal investigators of the dose reconstruction study invested considerable effort to characterize air emissions from the fires accurately, emissions from such discrete events are inherently difficult to quantify. The dose reconstruction study accounted for uncertainty by using Monte Carlo simulation techniques to predict ranges of output concentrations from estimated ranges of inputs (e.g., emission rates). Nonetheless, the estimated air quality impacts from these fires are somewhat uncertain and they might overstate or understate the actual air quality impacts that occurred. ATSDR bases its conclusions for this PHA on the findings of the dose reconstruction study because it offers the most comprehensive and extensively peer-reviewed evaluation of air quality impacts; however, we acknowledge that other parties (e.g., Johnson 1981) have previously suggested that the fires released larger quantities of plutonium than the amounts listed in Table 3.

Finally, the dose reconstruction study estimated air quality impacts resulting from windblown dust from the 903 Pad Area. The dispersion modeling analysis considered emissions from 1964 (when leakage from drums at the storage area was first identified as a major issue) to 1969 (when the entire area was paved to prevent further air emissions from occurring). Although the dose reconstruction study considered the possibility of windblown dust occurring on a daily basis, the modeling analysis found that air emissions on 6 high-wind days in 1968 and 1969 accounted for more than 90% of the total plutonium releases from the 903 Pad Area (Radiological Assessments Corporation. 1999a). Table 10 presents estimated air concentrations resulting from plutonium emissions at the 903 Pad Area. The estimated air quality impacts from this source are believed to be reasonably accurate, given that the spatial variations in predicted airborne concentrations closely resemble spatial patterns in off-site surface soil contamination and that the magnitude of surface soil contamination compares well to levels predicted by the fate and transport models used in the dose reconstruction study (Radiological Assessments Corporation. 1999a).

- *Carbon tetrachloride.* Estimated ambient-air concentrations of carbon tetrachloride are more easily summarized, because air emissions resulted

primarily from routine operations, with relatively minor losses attributed to unplanned events. The dose reconstruction study assumed that 100% of the carbon tetrachloride used at Rocky Flats Plant was released to the air and became available for off-site transport. Based on this assumption and the estimated quantities of carbon tetrachloride used on site between 1952 and 1989, the dose reconstruction study estimates that the highest annual average air concentration of carbon tetrachloride at off-site locations in 1988 was 0.19 $\mu g/m^3$, which was predicted to occur along the eastern boundary of the former Rocky Flats Plant (Radiological Assessments Corporation. 1999a). The highest exposure concentration between 1958 and 1970 was estimated to be approximately twice as high as the 1989 levels.

The estimated carbon tetrachloride exposure levels are greater than ATSDR's corresponding health-based comparison value (0.07 $\mu g/m^3$, a Cancer Risk Evaluation Guide). Therefore, exposures to this chemical are evaluated further in Section VI.C.4. It is important to note, however, that the estimated exposure level is notably lower than the carbon tetrachloride levels (0.57 $\mu g/m^3$) that are routinely measured using EPA-approved sampling and analytical methods in suburban and urban locations around the United States today (ERG 1998). ATSDR acknowledges, however, that various reports document a fairly broad range of "background" carbon tetrachloride levels (ATSDR 1994; Radiological Assessments Corporation. 1999a).

Regardless of actual "background" carbon tetrachloride levels, ATSDR is reasonably confident that the predicted site-related carbon tetrachloride concentrations do not systematically understate actual air quality impacts. This confidence stems from the fact that the dose reconstruction study assumes that 100% of the carbon tetrachloride used at Rocky Flats Plant was emitted to the air, even though some quantities of spent solvent were collected and shipped off site or otherwise handled as waste.

- *Other contaminants.* Though the final dose reconstruction study clearly identifies plutonium and carbon tetrachloride as the principal contaminants of concern, the study also examines air quality impacts from other chemicals and radionuclides that Rocky Flats Plant previously released. These other contaminants, however, were found to have minimal air quality impacts. The highest off-site annual average air concentration of beryllium, for instance, was estimated to be 0.000014 $\mu g/m^3$ (Radiological Assessments Corporation. 1999a), which is more than 20 times lower than the lowest health-based comparison value (0.0004 $\mu g/m^3$, an ATSDR cancer risk evaluation guide). Similarly, the dose reconstruction study examined the amounts of dioxins that incinerators at Rocky Flats Plant emitted and found that the median estimated cancer risk was more than 100 times lower than the range of cancer risks that typically trigger EPA

actions (Radiological Assessments Corporation. 1999a). Finally, the dose reconstruction study concluded that uranium emissions from the Rocky Flats Plant were of limited radiological significance when compared to the plutonium emissions (Radiological Assessments Corporation. 1999a). For the reasons stated here, this PHA does not consider air emissions of beryllium, dioxins, or uranium isotopes any further. Readers are referred to the dose reconstruction study for additional information on these and other contaminants that were found to contribute little to overall exposures and potential health risks.

- *Air contamination since Rocky Flats Plant shut down (1989–present).* The time frame 1989 to the present for this site differs from 1952–1989 in at least three important regards:1) since 1989, Rocky Flats Plant was no longer operating, so air emissions from manufacturing processes no longer occurred; 2) since 1989, several site-remediation and building-decontamination efforts commenced, which present an air emissions source that had not been evaluated in the dose-reconstruction study; and 3) from 1989 to the present, both CDPHE and DOE operated extensive environmental surveillance networks to measure air concentrations of several contaminants of potential concern. This section reviews the ambient-air-monitoring data collected since 1989 to characterize exposures to contaminants released during ongoing site clean-up activities. The dose-reconstruction study could not be used for this evaluation, because that study only considered exposures that occurred during the time that Rocky Flats Plant operated.

  Since 1989, CDPHE and DOE have collected thousands of air samples in the vicinity of RFETS. CDPHE's current monitoring network was initiated in July 1992 and expanded in January 1995; today, this network includes five monitoring stations along the perimeter of RFETS. CDPHE monitors air concentrations of particulate matter, nitrogen oxides, ozone, VOCs, beryllium and selected radionuclides (isotopes of plutonium, americium and uranium). ATSDR reviewed all of CDPHE sampling data that have been posted to the its Web site (CDPHE 1999; 2000–2003).

  DOE has also routinely monitored the air at and near RFETS. The extent and operation of DOE's monitoring network has changed over the years, but the network has typically included 14 monitoring stations along the site perimeter and 14 monitoring stations in surrounding communities. These stations (plus more than 20 on-site monitoring stations) collect composite samples that are analyzed for plutonium contamination. Additionally, DOE has monitored levels of several nonradioactive contaminants, including particulate matter and ozone, at a sampling location near the eastern entrance to RFETS. ATSDR reviewed several reports that document DOE's ambient-air-monitoring results since 1989 (DOE 1983–1994; DOE 2000–2002; DOE 2002c).

The following paragraphs review results from routine ambient-air-monitoring at or near RFETS since 1989. These paragraphs review trends among the sampling data, while Section VI.C.4 comments on the public health implications of the measured concentrations. ATSDR notes that focused monitoring also occurred during specific demolition and remediation activities and those monitoring data are generally consistent with the findings from the routine sampling.

- *Radionuclides.* Both CDPHE and DOE have been routinely measuring airborne levels of plutonium, americium and uranium isotopes around the perimeter of RFETS since Rocky Flats Plant shut down. Table 11 shows the highest quarterly or annual average ambient-air concentrations that have been reported for these radionuclides. For each radionuclide, the highest concentration is considerably lower than its corresponding health-based comparison value.

  Three other trends among the sampling data deserve mention. First, concentrations reported by CDPHE are reasonably consistent (i.e., on the same order of magnitude) with those reported by DOE for the same time frame, thus suggesting that neither data set is significantly biased. Second, every chemical's annual-average concentration reported in the site environmental reports was at least 100 times lower than the corresponding health-based comparison values which indicates that long-term exposures are well below levels of health concern. Third, ratios of the uranium isotope concentrations strongly suggest that the majority of uranium detected in the surveillance networks are naturally occurring—an important observation considering that uranium accounts for most of the annual effective dose equivalent from exposure to radionuclides (see Section VI.C.4).

- *Beryllium.* Several site documents report measured and estimated levels of beryllium near RFETS since 1989. CDPHE, for instance, routinely analyzes its air samples for beryllium content but has yet to find beryllium at levels greater than the detection limit (CDPHE 2000–2002; DOE 2002a); however, the detection limit for this sampling (0.0011 $\mu g/m^3$) is greater than the comparison value for cancer health endpoints (0.0004 $\mu g/m^3$). Nonetheless, other environmental measurements confirm that RFETS releases minimal amounts of beryllium. Stack tests have shown, for instance, that RFETS typically vented less than 10 grams of beryllium *per year* to the atmosphere (DOE 1983–1994). For reference, EPA's National Emission Standard for Hazardous Air Pollutants allows emissions of up to 10 grams of beryllium *per day* (DOE 2002a). Thus, beryllium emissions from RFETS clearly fall within federal health-based regulatory limits.

- *Other pollutants.* Since 1989, CDPHE and DOE have collected ambient-air monitoring data for two additional classes of pollutants: criteria

pollutants and VOCs. The following paragraphs review the available sampling data.

Criteria pollutants are general indicators of air quality that EPA and states routinely monitor. The criteria pollutants recently monitored near RFETS are particulate matter, nitrogen dioxide, sulfur dioxide and ozone. With one exception, the air concentrations of these pollutants are well within EPA's health-based National Ambient Air Quality Standards. In the case of particulate matter, for example, CDPHE's and DOE's monitoring data from throughout the 1990s have shown that concentrations of total suspended particulates (TSP) and particulate matter smaller than 10 microns (PM10) are consistently lower than EPA's current and former air quality standards for these pollutants. Similarly, limited monitoring of nitrogen dioxide and sulfur dioxide found air concentrations to be considerably lower than EPA's health-based standards.

On the other hand, concentrations of ozone near RFETS and throughout the Denver area have exceeded EPA's National Ambient Air Quality Standards numerous times over the last 30 years. Local and state environmental agencies continue to implement air pollution control measures to help improve air quality in the Denver area, but some elevated ozone levels continue to be observed, typically in the summer months. ATSDR notes that the past and ongoing ozone problems in the Denver area are a regional environmental issue and air emissions from RFETS contributes little to the elevated ozone levels periodically observed throughout the Denver metropolitan area. Therefore, this PHA does not address the public health implications of ozone any further. Readers interested in learning more about ozone concerns in the Denver area are encouraged to contact CDPHE's Air Quality Control Division (303-692-3100) or to visit CDPHE's Web site (http://www.cdphe.state.co.us).

CDPHE has also conducted routine air sampling for 30 VOCs at five locations around the perimeter of RFETS. Several of these compounds were routinely detected in the ambient air, as is common for suburban locations across the country (ERG 1998). The compounds detected most frequently include refrigerants, chemicals typically found in motor vehicle exhaust (e.g., xylene isomers, benzene, toluene and ethylbenzene) and industrial solvents. The concentrations measured are all below threshold limit values (CDPHE 1999) and do not exhibit spatial variations that would suggest that RFETS is the primary emissions source.

The previous discussion describes the estimated and observed levels of air contamination near the former Rocky Flats Plant and near RFETS today. Section VI.C.4 presents ATSDR's findings regarding the public health implications of inhaling the levels of contamination summarized above.

5. Off-site Terrestrial Biota

ATSDR did not locate any studies that measured environmental contamination levels in terrestrial biota at off-site locations near RFETS. However, off-site biota (e.g., deer) is not contaminated at levels greater than what has been found on site. The dose reconstruction study used standard uptake equations to estimate contamination levels in homegrown vegetables, locally raised beef and milk products.

Some residents in the vicinity of RFETS consume various forms of terrestrial biota, including deer, vegetables, grains and dairy products. However, none of the reports that ATSDR reviewed for RFETS present sampling data for any type of terrestrial biota at off-site locations. ATSDR used the following two approaches to estimate exposure concentrations in off-site terrestrial biota:

- *Mule deer.* As Section V.B.5 notes, tissues were collected and analyzed from seven mule deer from on-site locations. Plutonium isotopes were not detected in any of the samples. Because the mule deer from this study lived and foraged in on-site areas with surface soil contamination levels higher than those that have been observed off site, ATSDR assumes that plutonium levels in mule deer at off-site locations are not higher than the levels found on site. In other words, trends among the surface soil sampling data and the mule deer sampling data strongly suggest that off-site mule deer have nondetectable amounts of plutonium in their tissues.

- *Homegrown vegetables, locally raised beef and milk products.* Though no studies have measured site-related contamination in off-site terrestrial biota, the dose reconstruction study estimated contamination levels in homegrown vegetables, locally raised beef and milk products. These estimates were calculated from standard exposure assessment equations and documented contamination levels in soil and air (ChemRisk 1994a). Contamination levels in beef, for instance, were based on amounts of soil and pasture that cattle typically ingest and the volumes of air that cattle inhale. ATSDR used the estimated exposure point concentrations for these food items when evaluating the implications of ingesting terrestrial biota.

In Section VI.C.5, ATSDR presents public health interpretations of potential exposures at off-site locations to site-related contaminants found in mule deer, homegrown vegetables, locally raised beef and milk products.

D. Physical and Other Hazards

ATSDR did not find any physical hazards that need to be evaluated or mitigated. As noted previously, public access to RFETS is restricted. Fences, gated entrances and security personnel ensure that community members do not enter the site. Therefore, residents cannot access any physical hazards that might exist on the property. On-site remediation workers at RFETS are also not expected to encounter physical hazards,

assuming they follow the procedures outlined in the Health and Safety Plans for the specific remediation projects.

E. Quality Assurance and Quality Control

In preparing this public health assessment, ATSDR reviewed and evaluated information provided in the referenced documents (see Section XI). Documents prepared for the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA) programs must meet specific standards for adequate quality assurance and control measures for chain-of-custody procedures, laboratory procedures and data reporting. The environmental data presented in this PHA have already been documented in various reports prepared by DOE, CDPHE, ChemRisk and other parties and those original reports note the limitations of the sampling data. After evaluating the data, ATSDR determined that the quality of environmental data available in site-related documents for RFETS is adequate to make public health decisions.

Knowing that some community members are concerned about the accuracy and quality of sampling data collected by DOE and its contractors (see Section III), ATSDR reviewed results from DOE's sampling programs carefully before using these data in this PHA. Moreover, in cases where data collected by DOE are used in our analyses, we also attempted to locate relevant sampling data collected by parties other than DOE for purposes of comparison. Our evaluation of environmental contamination throughout this section clearly indicates the source of the sampling data and our conclusions are ultimately based on data of known and high quality that were reported by multiple parties.

VI. Public Health Implications

This section presents ATSDR's interpretations of the public health implications of exposure to contaminants at and near RFETS. These evaluations help ATSDR determine whether public health actions are needed to prevent exposure and whether site-related exposures are expected to cause adverse health effects. The contents of this section include: a summary of the approach taken to assess exposures; public health implications of contacting on-site contamination and off-site contamination; a review of health outcome data and related studies; and consideration of children's exposure issues. The findings presented in this section form the basis for the conclusions and recommendations for this PHA.

A. Overview

ATSDR followed well-established procedures (ATSDR 1992) to assess the public health implications of exposure to environmental contaminants at RFETS. Three general approaches are presented here. First, ATSDR evaluated exposures and compared the amounts of contaminants that residents might contact to exposure levels that toxicological and epidemiological studies have shown to be associated with adverse health effects. Quantitative exposure estimates are presented for the completed exposure pathways. These analyses are presented in Sections VI.B and VI.C for on-site and off-site contamination, respectively. Second, for added insights on health implications of exposure, ATSDR reviewed health outcome data and related studies that characterize exposures and diseases among residents who live near RFETS. Section VI.D presents this review, which evaluates findings from selected epidemiological studies and exposure investigations. Finally, ATSDR assessed children's health issues in Section VI.E.

In short, ATSDR's approach brings together information on environmental contamination, exposure assessment, toxicological data and epidemiological data to address community concerns. Using data from these multiple disciplines helps account for the inherent limitations in any one field of study.

B. Evaluation of On-site Contamination

As Section IV.A.1 explains, ATSDR considers all on-site contamination to be an eliminated exposure pathway, because gates, fences and other security measures prevented residents from accessing Rocky Flats Plant property and continue to prevent access to RFETS today. The on-site contamination at RFETS is therefore no public health hazard to the community, because no exposure occurs. Furthermore, on-site contamination levels will not be a public health hazard in the future, so long as site access is restricted. Any future plans to allow public access to RFETS property must be carefully reviewed, considering the amounts of environmental contaminants that remain on the site after DOE's completes its clean-up projects.

ATSDR recognizes that several fate and transport mechanisms have previously carried on-site contamination to off-site locations and this transport continues to occur today. The next section addresses the public health implications of off-site contamination levels. In addition, ATSDR realizes that some residents have concerns about past occupational exposures experienced by workers at the former Rocky Flats Plant. ATSDR does not address occupational health concerns in this PHA, because occupational health evaluations do not fall under ATSDR's mandate. However, being sensitive to this community concern, ATSDR includes a brief review of selected occupational epidemiology studies in Section VI.D and provides contact information for NIOSH for those residents who seek additional insights on occupational health issues for former workers.

C. Evaluation of Off-site Contamination

The following sections describe the public health implications of coming into contact with off-site contamination levels at RFETS. Five environmental media were examined: soil, groundwater, surface water (including sediment, aquatic biota and drinking water), air and terrestrial biota. Data on the nature and extent of environmental contamination (see Section V.C) were the main input to these environmental health evaluations.

ATSDR uses a components-based approach which focuses on mixture components that are present at toxicologically significant exposure levels, based on estimated exposures and relevant health guideline values. Synergistic models {Linked physiologically-based pharmacokinetic/pharmacodynamic (PBPK/PD)} for two or more components, if available, may be used to predict the potential for interactions, or possibly for noncancer or cancer health effects from the mixture. The hazard index method is used to screen for noncancer health hazards from potential additivity of the components. Cancer risks for the components are summed to screen for health hazards from potential additivity of carcinogenic effects. A weight-of-evidence method is used to evaluate the potential impact of interactions on noncancer and cancer health effects (ATSDR 2004).

1. Off-site Surface Soil

Surface soils immediately east of RFETS contain elevated levels of americium and plutonium isotopes. No one currently lives where the highest contamination levels occur, but residents may access this area. Exposures calculated for both recreational and residential scenarios are well below levels that would cause adverse health effects. Therefore, no past, current, or future public health hazard exists from exposure to off-site surface soils, even at the most contaminated locations.

As Section V.C.1 notes, the contaminants of concern in off-site surface soils are isotopes of americium and plutonium, both of which are found at elevated levels in surface soils east of RFETS. The highest off-site concentrations observed during the OU3 remedial investigation were 0.52 pCi/g for americium-241 and 6.5 pCi/g for plutonium-239/240 (EPA 1997b). No one lives at the locations where these contamination levels were found.

Plutonium contamination levels observed during the remedial investigation are consistent with those reported by other investigators.

DOE examined the health implications for OU3 by calculating the radiation exposure dose that a hypothetical resident living at the point with the highest surface soil contamination would experience. The calculation includes contributions from soil ingestion, inhalation, external radiation and ingestion of vegetables, milk and meat that were raised or grown on the property. Even in this scenario that clearly overstates actual exposures, the total effective dose equivalent for the resident was estimated to be 0.12 millirem/year (mrem/yr)(EPA 1997b). This exposure level is not only far lower than ATSDR's Minimal Risk Level for ionizing radiation exposure (100 mrem/yr), but is also far lower than the average exposure to ionizing radiation experienced by United States residents (360 mrem/yr) (ATSDR 1999). Similarly, exposure calculations revealed incremental cancer risks well within levels EPA considers protective of human health (EPA 1997b). Based on these evaluations, CDPHE, DOE and EPA concurred that the off-site surface soil contamination does not need to be cleaned up to be protective of human health.

In 1997, ATSDR reviewed and commented on the human health risk assessment that reached the aforementioned conclusions (ATSDR 1997). ATSDR concurred with the risk assessment's findings, supported the approach used to select contaminants of concern, indicated that off-site contamination of heavy metals is at levels below health concern and concluded that no additional activities are needed to ensure the public's health. ATSDR continues to support this conclusion, because our review of environmental data collected since the remedial investigation provides no evidence of significant migration of contaminants from RFETS to off-site surface soils.

2. Off-site Groundwater

Though several contaminated groundwater plumes are found on site, sampling data from perimeter monitoring wells and review of local hydrogeologic conditions suggest that the plumes at RFETS are not migrating beyond the site boundary. Use of groundwater drawn from off-site private and municipal wells is therefore not a public health hazard, because no exposure to site-related contaminants occurs. Ongoing monitoring of perimeter wells should help ensure that no public health hazards occur in the future. To verify this conclusion and as a prudent public health measure, ATSDR recommends that CDPHE offer to sample groundwater from private wells located within 2 miles beyond the eastern RFETS property line.

ATSDR evaluated several data sources to determine whether groundwater contamination from RFETS has migrated to off-site areas. Though these data sources present extensive information on on-site groundwater contamination, they present no data on groundwater contamination at off-site locations. As far as ATSDR can tell, the 15 private wells located less than 2 miles of the eastern RFETS property line have not been sampled. While private well monitoring data are not available, ATSDR was able to assess potential

exposures to off-site groundwater contamination by considering two data sources, as described below:

- *Perimeter monitoring wells.* Groundwater from RFETS must first pass through the site perimeter before reaching the off-site private wells and municipal supply wells. As a result, data from the perimeter monitoring wells are reasonable indicators of potential off-site contamination. Section V.C.2 reviews data published in several sources on groundwater contamination levels at the RFETS perimeter wells. Both the dose reconstruction study (ChemRisk 1994b) and the recent RFCA quarterly monitoring reports reveal common data trends.

  According to these data sources, no site-related contaminants have been detected at levels or frequencies that would suggest on-site groundwater plumes are flowing past the RFETS property line, but some chlorinated organic compounds have been occasionally detected at trace levels in the perimeter wells. The one organic compound (1,2-dichloroethane) found at concentrations greater than health-based comparison values is not of public health concern, because the single detection—an estimated value—is only marginally higher than a comparison value derived for lifetime exposures, which clearly do not occur. Similarly, the radioactive contaminants were found at levels considerably lower than health-based comparison values. The inorganic compounds and metals found in the groundwater at the site boundary appear to be of natural origin, as most have been detected at comparable levels at up-gradient locations.

- *Hydrogeologic conditions.* ATSDR also reviewed data on local hydrogeologic conditions to assess the mobility of groundwater beneath RFETS. As noted previously, groundwater beneath RFETS moves slowly. The dose reconstruction study, for instance, indicates that it would take between 30 and 300 years for groundwater beneath the Industrial Area at RFETS to move to the off-site private wells. Therefore, any site-related contaminants being detected at the RFETS property line most likely were released to groundwater decades ago. Furthermore, it is highly unlikely that a site-related groundwater contamination plume passed through the site boundary before perimeter monitoring began in the 1980s.

Overall, the infrequent detections of site-related contaminants in perimeter monitoring wells, combined with the slow groundwater velocity, suggest that contaminated groundwater plumes are not migrating beyond the RFETS property line. As a result, off-site private wells and municipal wells have not been affected by site-related contamination and past and current use of water from these wells presents no public health hazard.

Whether groundwater contamination plumes reach off-site locations in the future cannot be predicted. However, with the ongoing remediation and monitoring efforts, it is highly unlikely that plumes would extend off site undetected. To ensure that the on-site plumes do not affect off-site water sources in the future, ATSDR recommends that DOE continue to monitor its perimeter groundwater wells. In addition, ATSDR recommends that

CDPHE offer to sample any operating drinking water supply well (private or municipal) that is located less than 2 miles from the eastern RFETS property line and that provides drinking water. This latter recommendation is made as a prudent public health measure to verify the findings presented above. Such sampling will help conclusively address any concerns regarding groundwater contamination, with relatively minor costs.

3. Off-site Surface Water, Sediment and Aquatic Biota

Site-related contaminants have been found in off-site sediment and surface water, including in reservoirs that provide drinking water to local communities. Extensive surface water, drinking water and sediment sampling data have been collected from 1970 to the present from through the Walnut Creek and Woman Creek drainages, including from two reservoirs previously or currently used as drinking water supplies. This large volume of sampling data indicates that local residents were exposed to trace amounts of site-related contaminants, but not at levels associated with adverse health effects. The drinking water supplies that still draw from Standley Lake should continue to be monitored regularly for radioactive contamination to verify that the plutonium deposits in the reservoir's sediments do not enter the water supply. Only limited sampling data are available on contamination in fish, but these data found no detectable amounts of radioactive contamination in species frequently caught from Standley Lake. Based on these analyses, ATSDR concludes that all exposure pathways associated with off-site surface waters are no apparent public health hazard.

In Section V.C.3, ATSDR summarizes sampling data from numerous off-site locations in the Walnut Creek and Woman Creek drainages. CDH, DOE, local municipalities and other parties collected thousands of samples from these waters and most sampling events occurred between 1970 and the present. This section draws from the sampling results to comment on the public health implications of exposure to contaminants found in four exposure pathways associated with surface waters:

- *Contamination in drinking water supplies*. Contaminants in discharges from Rocky Flats plant previously flowed into reservoirs that provided drinking water to the cities of Broomfield, Northglenn, Thornton and Westminster. These municipalities and CDH both tested the drinking water frequently and, with one exception, site-related contamination was never found at levels exceeding health-based drinking water standards. As the exception, the Broomfield water supply contained elevated concentrations of uranium and plutonium, which were detected in isolated sampling events from the early 1970s. However, the annual average concentrations of these contaminants, which better indicate long-term exposure levels, were safely below health-based drinking water standards. Therefore, ATSDR concludes that, from 1970 to the present, the municipal supplies of Broomfield, Northglenn, Thornton and Westminster provided water that was safe to drink. It is not expected that concentrations of radionuclides in surface water would have been elevated in the years prior to 1970, except as a result of above ground nuclear testing, but no data are available. Oxides of plutonium are extremely insoluble in water and would not have been a hazard from ingestion.

- ATSDR also considered potential future exposures to contaminants in drinking water. Broomfield no longer receives drinking water from the Great Western Reservoir; therefore, no public health actions are needed to ensure that site-related contaminants enter Broomfield's water supply in the future. Northglenn, Thornton and Westminster still receive drinking water from Standley Lake. Future levels of contamination in the lake are expected to be low, largely because surface water runoff from RFETS is diverted away from the reservoir. Though it is possible that trace amounts of plutonium might migrate from the Standley Lake sediments into the drinking water, the extent to which this occurs will be minimal, especially as the plutonium-contaminated sediments continue to be covered with freshly deposited, uncontaminated material. Nonetheless, as a prudent public health measure, ATSDR recommends that the drinking water drawn from Standley Lake continue to be sampled routinely for plutonium and indicators of radioactive contamination.

- *Contamination in surface water that recreational users might ingest.* When evaluating sites with surface water contamination, ATSDR typically considers the possibility that residents might incidentally ingest water during recreational activities. In this case, residents do not routinely come into direct contact with off-site surface waters at RFETS: swimming is not allowed at Standley Lake; the Great Western Reservoir is inaccessible to the public; and ATSDR found no accounts of residents swimming in or otherwise accessing the portions of Walnut Creek and Woman Creek located immediately east of RFETS. Thus, incidental ingestion of surface waters during recreational activities seems highly unlikely. Given that water from off-site reservoirs is safe to drink from *on a daily basis*, it is extremely unlikely that any incidental ingestion of off-site surface water would lead to exposures at levels of health concern. ATSDR therefore concludes that such incidental exposures, if they occur, present no apparent public health hazard.

- *Contamination in sediments that recreational users might ingest*. As Section V.C.3 notes, contaminated sediments have been detected in Great Western Reservoir, Mower Reservoir and Great Standley Lake, where plutonium is the primary contaminant of concern (EPA 1997b). Residents are expected to contact these sediments infrequently, given that swimming is not permitted in these reservoirs. Nonetheless, recreational users of the reservoirs may incidentally ingest sediments, especially when low water levels expose sediments that are typically submerged.

  The remedial investigation for OU3 examined the health risks associated with contacting sediments (EPA 1997b). The exposure scenario for that risk assessment assumed that the Great Western Reservoir was drained and subsequently developed for residential land uses. This scenario, though somewhat unrealistic, is informative because it provides an upper bound estimate of potential exposures. Even in this scenario, the estimated total effective radiation dose was only 0.0065 mrem/yr (EPA 1997b)—a level more than 15,000 times

lower than ATSDR's Minimal Risk Level for ionizing radiation (100 mrem/yr) (ATSDR 1999).

In 1997, ATSDR reviewed the findings from the OU3 remedial investigation and concluded that the plutonium and metals contamination in the off-site sediments were present at levels below health concern (ATSDR 1997). ATSDR continues to conclude that the sediment contamination does not present a public health hazard.

- *Contamination in fish that residents might ingest*. In 1990, CDH collected fish samples from Standley Lake, the largest off-site surface water body near RFETS where recreational fishing is permitted. Plutonium was not detected in any of the fish fillet samples that were analyzed (CDPHE 1990). This finding is consistent with the scientific literature on plutonium bioaccumulation in fish which suggests that 1) the extent of bioaccumulation decreases for species higher in the aquatic food chain (i.e., the species that people would most likely ingest) and 2) that the overwhelming majority of plutonium that does accumulate in fish tends to concentrate in bones (ATSDR 1990). Using the detection limit of plutonium as the estimated contamination level, CDH calculated that the radiation dose for a recreational fisher would be 0.06 mrem/year (CDPHE 1990),[8] a level more than 1,500 times lower than ATSDR's Minimal Risk Level. Based on these findings, ATSDR concludes that radioactive contamination in the fish tissues that people would most likely ingest is minimal and not at levels of health concern.

  As Table 9 indicates, CDH's sampling study measured four nonradioactive contaminants (mercury, DDT, DDE and DDD) in fish tissues at levels greater than health-based comparison values. The origin of these contaminants was not assessed in CDH's study; however, ATSDR notes that mercury is a relatively common contaminant in fish tissues and the other three contaminants are typically found in areas where DDT has been used previously. CDH evaluated the public health implications of consuming fish that contain these four contaminants. Using the maximum concentrations detected and the assumption that recreational fishers consume one 4-ounce serving per week of fish caught from Standley Lake for 70 years), CDH concluded that consumption of a reasonable quantity of fish from Standley Lake does not present an appreciable risk to the public health (CDPHE 1990). ATSDR has reviewed CDH's calculations and confirmed that the fish ingestion scenario evaluated indeed presents no appreciable health risks, both for cancer and noncancer outcomes.

4. Off-site Air

Both site-related air emissions and inhalation exposures experienced by community members varied considerably from one year to the next. While Rocky Flats Plant operated (1953–1989), the air contaminants of primary concern were plutonium and

[8] CDH actually computed radiation doses on the basis of the detection limits for 21 radionuclides, none of which were detected in the fish-tissue samples. The radiation dose noted (0.06 mrem per year) is the sum of the contributions from these 21 radionuclides.

carbon tetrachloride. Plutonium emissions between 1970 and 1989 posed virtually no health risk to off-site residents, according to the dose-reconstruction study. In earlier years, plutonium emissions posed a very small, theoretical cancer risk to residents who lived southeast of the facility at the time of the 1957 fire. This theoretical risk is impossible to detect with epidemiological studies (it might be zero) and it is substantially smaller than the theoretical cancer risks associated with inhalation exposures to current levels of carcinogenic compounds in urban air pollution. In the case of carbon tetrachloride, estimated off-site air concentrations resulting from Rocky Flats Plant's emissions are lower than the carbon tetrachloride levels routinely measured at suburban and urban locations throughout the United States today. Air-quality impacts from all other contaminants are also believed to be lower than levels of health concern. Therefore, the best available information suggests that past exposures to contaminants emitted from Rocky Flats Plant are of minimal public health significance. These findings are made on the basis of the best available and most thoroughly peer-reviewed information. Though estimates of past exposures have inherent uncertainties, there are no practical opportunities for reducing the uncertainties in the evaluation of past exposures.

Since Rocky Flats Plant shut down in 1989, air emissions sources have been limited to releases from building decontamination and site-remediation efforts. Both CDPHE and DOE have collected thousands of off-site air samples between 1989 and the present to characterize potential air quality impacts from air emissions sources at RFETS. These sampling results found no site-related contaminants at concentrations associated with adverse health effects. In fact, the radioactive contaminants of greatest concern are consistently found at concentrations more than 100 times lower than levels that would trigger emissions control measures.

The site-related contaminants disperse greatly between their source (typically the Industrial Area of the facility) and the nearest off-site residential receptor. Though residents have been exposed to trace levels of site-related contaminants in the past and continue to be exposed today, the estimated and measured exposure levels are lower than those associated with adverse health effects. The appropriate ATSDR conclusion category used for such scenarios is "no apparent public health hazard" (see Appendix C for more information on conclusion categories). To ensure that potential air quality impacts from RFETS do not increase in the future, ATSDR recommends that CDPHE and DOE continue to operate their environmental surveillance networks until site clean-up activities are completed.

As Section V.C.4 indicates off-site ambient-air-contamination levels during the time the Rocky Flats Plant operated (1953–1989) were distinctly different from air contamination levels in the years since the plant shut down (1989–present). Accordingly, inhalation exposures that community members experienced also differed considerably for these two time frames. The following are ATSDR's interpretations of the public health implications of exposures to air contaminants released previously from Rocky Flats Plant and those released currently from RFETS:

- *Air contamination during time Rocky Flats Plant operated (1953–1989).* As noted previously, ATSDR bases its conclusions about past exposures to air emissions from Rocky Flats Plant almost entirely on the dose-reconstruction study. ATSDR carefully reviewed the air exposure pathway, because the dose-reconstruction study indicates that "the most important pathway of exposure was inhalation" (Till et al. 2002) and that "atmospheric transport was the primary pathway by which people were exposed" (ChemRisk 1994a). The dose-construction study also reports that potential health risks associated with exposures vary significantly with location, time and pollutant. ATSDR presents its conclusions for the following contaminants of concern identified in the dose-reconstruction study.

    - *Plutonium.* As Section V.C.4 indicates, residents who lived in the vicinity of Rocky Flats Plant were exposed to airborne plutonium emitted from the facility during both routine operations and episodic events. The main health concern associated with plutonium exposure is the potential for developing cancer. ATSDR notes, for instance, that the International Agency for Research on Cancer has concluded that plutonium-239 is carcinogenic to humans. Whether a person who was exposed to plutonium has an increased risk of developing cancer depends upon total radiation dose.

      The dose-reconstruction study used standard risk-assessment techniques to estimate the likelihood that persons who lived, worked, or went to school near Rocky Flats Plant would develop cancer as a result of their inhalation exposures to plutonium. Cancer risk coefficients were developed on the basis of findings from epidemiological studies of workers exposed to plutonium in Russia and the findings of various other studies of populations exposed to radionuclides that emit alpha radiation. Readers are referred to the dose-reconstruction study for further information about how these risk coefficients were derived (Radiological Assessments Corporation. 2000).

      In summary, an individual's potential health risk associated with inhaling airborne plutonium from Rocky Flats Plant depends on the location of the individual's residence and the time period during which the person lived there. Plutonium emissions from Rocky Flats Plant caused virtually no cancer risk to persons who lived in the area after 1970. A very small, theoretical cancer risk existed for residents who lived southeast of the facility and were exposed to emissions from the 1957 fire; however, epidemiological studies would not be able to detect this risk. The highest theoretical cancer risk predicted for the site is more than 25 times lower than the theoretical cancer risk Denver-area residents currently receive from inhaling airborne carcinogenic compounds that are ubiquitous to urban environments.

- *Carbon tetrachloride.* According to studies in laboratory animals, inhalation exposure to carbon tetrachloride can cause a variety of adverse health effects, including various noncancer and cancer effects. ATSDR evaluated the toxicological and epidemiological literature on carbon tetrachloride to comment on the likelihood that either type of effects occurred among residents during the operation of Rocky Flats Plant.

  For noncancer effects, ATSDR has derived a Minimal Risk Level for repeated exposures of 50 parts per billion (ppb), which is equivalent to 315 micrograms per meter^3 (µg/m^3) The ATSDR Minimal Risk Level represents an exposure concentration that is to be without an appreciable risk of noncancer adverse health effects. In other words, persons who inhale carbon tetrachloride at concentrations lower than the Minimal Risk Level will not experience noncancer health effects. The estimated carbon tetrachloride exposure levels when the Rocky Flats Plant operated were more than 500 times lower than the Minimal Risk Level; therefore, ATSDR concludes that persons residing near Rocky Flats Plant were not exposed to carbon tetrachloride at levels that would cause noncancer effects.

  For potential cancer effects, ATSDR reviewed the scientific literature on the carcinogenicity of carbon tetrachloride and evaluated findings in the dose-reconstruction study. Multiple studies have established that oral exposure to carbon tetrachloride causes liver cancer in laboratory animals (ATSDR 1994). However, limited information is available to prove whether carbon tetrachloride causes cancer in humans. Specifically, ATSDR located only two case reports that suggest inhalation of carbon tetrachloride might have caused liver cancer in two individuals. On the basis of this information, both the International Agency for Research on Cancer and EPA have concluded that "there is sufficient evidence that carbon tetrachloride is carcinogenic in experimental animals and that it is possibly or probably carcinogenic in humans" (ATSDR 1994).

  For perspective on the carbon tetrachloride exposures, ATSDR compared the estimated air-quality impacts from Rocky Flats Plant to the airborne levels of carbon tetrachloride typically observed in urban and suburban settings. According to the dose reconstruction study, emissions from Rocky Flats Plant caused carbon tetrachloride concentrations at the most affected off-site location to increase by 0.35 µg/m^3 (or 0.06 ppb) over the site history (computed from data presented in Radiological Assessments Corporation. 1999a). For comparison, the EPA Urban Air Toxics Monitoring Program consistently shows that average concentrations of carbon tetrachloride in ambient air is 0.57 µg/m^3 (or 0.09 ppb) in urban and suburban locations throughout the United States (ERG 1998). This comparison indicates that any health risks associated with normal "background" levels of carbon tetrachloride clearly outweigh the very

small risks that were associated with air emissions from the Rocky Flats Plant.

- *Other contaminants.* As Section V.C.4 notes, the dose reconstruction study considered numerous other contaminants than plutonium and carbon tetrachloride that Rocky Flats Plant probably released. Best estimates of past exposure concentrations for beryllium, dioxins and uranium are all considerably lower than levels associated with adverse health effects (Radiological Assessments Corporation. 1999a). Although Rocky Flats Plant emitted numerous other contaminants (e.g., metals, solvents, gases), the dose reconstruction study found that past air-quality impacts of those contaminants were minimal, given that the two contaminants of primary concern (i.e., plutonium and carbon tetrachloride) had air-quality impacts below levels of public health concern. ATSDR concurs with this finding.

In summary, Rocky Flats Plant released numerous contaminants into the air between 1953 and 1989. Inhalation exposures to site-related contaminants by area residents were determined by the location of their residence, the length of time lived there and the time period in which they lived there. Residents who lived east and southeast of Rocky Flats Plant between 1953 and 1970 were the most highly exposed populations. ATSDR concludes that residents who lived near Rocky Flats Plant were exposed to site-related air contaminants, but these exposure levels did not cause adverse health effects. According to ATSDR's internal guidance (ATSDR 1992), such an exposure scenario is categorized as *no apparent public health hazard*.

- *Air contamination since Rocky Flats Plant shut down (1989–present).* The primary contaminants of concern since Rocky Flats Plant ceased operating are those associated with building decontamination and site-remediation efforts. Since the plant ceased production in 1989, CDPHE and DOE have collected and analyzed thousands of air samples to assess the potential air-quality impacts of these clean-up efforts. ATSDR reviewed the large volume of sampling data collected at the site boundary, the area that would be expected to have the highest site-related impacts, to characterize current exposures to emissions from RFETS. ATSDR's conclusions regarding the public health implications of exposure to post-1989 levels of air pollution near RFETS include the following:

  - *Radionuclides.* Extensive ambient-air monitoring data have been collected around the RFETS perimeter for isotopes of americium, plutonium and uranium. Section V.C.4 summarizes these data, as does Table 11. Since 1989, all three radionuclides have never been measured at concentrations greater than their health-based comparison values. In fact, americium, plutonium and uranium concentrations have consistently been several orders of magnitude below levels of health concern. Furthermore, 3 years of recent sampling data show that the highest annual-effective-radiation-dose equivalent associated with these three radionuclides at off-site locations was 0.14 millirems per year (mrem/yr), with naturally occurring

uranium accounting for the majority of this exposure (DOE 2002c). This exposure level is more than 500 times lower than ATSDR's Minimal Risk Level for ionizing-radiation exposure (100 mrem/yr). Therefore, the air surrounding RFETS clearly does not contain radionuclides at levels of health concern.

- *Beryllium.* Measurements of both air contamination and air emissions from RFETS have characterized potential inhalation exposures to beryllium at RFETS. As Section V.C.4 indicates, CDPHE's ambient-air monitoring program has never detected beryllium along the RFETS perimeter and DOE's previous stack testing at RFETS has demonstrated that air emissions are well within federal health-based limits. On the basis on these observations, ATSDR concludes that beryllium levels in the air near RFETS are not at levels of health concern.

- *Other pollutants.* Since the Rocky Flats plant ceased production in 1989, both CDPHE and DOE have conducted routine monitoring of ambient air for selected criteria pollutants and VOCs. The site-related air contaminants have consistently been found at levels lower than their corresponding health-based comparison values. On the other hand, airborne ozone concentrations near RFETS and throughout the Denver metropolitan area, periodically reach levels that might cause health problems (e.g., cough, wheeze, difficulty breathing), particularly among children, the elderly and those with preexisting respiratory conditions. The periodic elevated levels of ozone result from numerous sources of air emissions, including motor vehicles and industrial sources. Because ozone pollution is a regional problem and not one that can be attributed to RFETS, this PHA does not address this matter further. For readers who would like to learn more about ozone levels in the Denver area, ATSDR notes that CDPHE's Air Quality Division (303-692-3100) and the agency's Web site (http://www.cdphe.state.co.us) have extensive information on this issue.

Overall, ambient-air monitoring data collected since 1989 quite clearly indicate that the air near RFETS has been safe to breathe. Although site-related contaminants continue to be released into the air, none of these contaminants are found at levels of health concern at off-site locations. ATSDR recognizes, however, that ongoing building decontamination and site-remediation efforts are potential sources of future air emissions. Continued implementation of DOE and CDPHE environmental surveillance networks is needed to ensure that such future air emissions do not cause off-site air contamination to reach unhealthy levels.

5. Off-site Terrestrial Biota

Contamination levels have not been measured in terrestrial biota from off-site locations at RFETS. To evaluate potential exposures for this pathway, ATSDR considered on-site sampling results for mule deer and estimated contamination levels in locally raised beef,

dairy products and homegrown vegetables. These data suggest that contamination levels in food items present no apparent public health hazard, even for residents who daily consume food items from local sources.

As noted previously, some residents living in the vicinity of RFETS consume various forms of terrestrial biota from off-site locations. These food items include deer meat, homegrown vegetables, products from dairy farms and locally raised beef. Although none of the studies ATSDR reviewed present direct measurements of contamination levels in terrestrial biota from off-site locations, several observations provide insight into the potential for site-related contaminants to accumulate in food items:

- *Deer meat.* One study examined site-related contamination in tissues of mule deer, but did not detect plutonium in any of the tissues sampled from seven carcasses collected within the RFETS site boundary (Symonds 1992). Although this study had a limited sample size, its findings are consistent with data collected in laboratory animal studies that have studied the absorption and distribution of ingested plutonium. According to these studies, only a small fraction of plutonium that animals ingest are absorbed into their systems and most of the amounts absorbed deposit in the bones and, to a lesser extent, in organs (e.g., liver, kidney) (ATSDR 1990). Therefore, if any plutonium is found in deer meat, it tends to accumulate in body parts that people typically do not consume. Given the low amounts of plutonium, if any, expected to be found in deer meat, ATSDR views human exposures to plutonium through this pathway to be insignificant.

- *Vegetables, grains, beef and dairy products.* Both the OU3 remedial investigation and the dose reconstruction study estimated potential health risks associated with consuming other forms of terrestrial biota from off-site locations. ATSDR's review of these studies follows.

  In the OU3 remedial investigation, DOE evaluated health risks associated with the contaminated soils east of the RFETS property line. This evaluation not only considered direct ingestion of soil, but also considered potential health risks associated with ingestion of vegetables, milk and meat grown or raised on contaminated property. Even considering the upper-bound exposure scenario of a resident living immediately east of RFETS and consuming large quantities of locally grown food items, this evaluation, which was reviewed and approved by CDPHE and EPA, found excess lifetime cancer risks and radiation exposures to be lower than the levels that require clean-up of soils (EPA 1997b). ATSDR has already concurred with these findings (ATSDR 1997). Specifically, ATSDR concluded that ingestion of potentially contaminated food items is not a major pathway of exposure because plutonium and americium isotopes in the surface soils at RFETS are not bioconcentrated to any degree in biota.

  The dose reconstruction study also examined potential exposures that result from ingesting locally grown or raised vegetables, wheat, dairy and beef. However, this study is much broader in scope, because it considers potential exposures over the

entire history of operations at Rocky Flats Plant and examines exposures to the 12 contaminants of greatest concern (ChemRisk 1994a). Key assumptions that factored into the exposure assessment include daily ingestion rates for selected food items. For instance, the exposure scenario in the study assumes that a resident ingests (on average) the following food items: 10 gallons of milk per year from a dairy farm in the contaminated areas, 15 pounds per year of beef from cattle locally grown, 6 pounds per year of homegrown vegetables and 6 pounds per year of flour made from locally grown wheat (ChemRisk 1994a).[9] For this scenario, the dose reconstruction study presents the relative contributions of existing exposure pathways to the total exposure dose, taking into consideration that these contributions vary by year, location and contaminant. In all cases examined by ATSDR, the combined doses for food-ingestion pathways accounted for a small fraction of the total exposure dose. For instance, at locations immediately east of RFETS, the estimated food-ingestion doses for plutonium isotopes were more than 50 times lower than the total estimated exposure dose for every year evaluated (ChemRisk 1994a). Therefore, the dose reconstruction study also suggests that ingestion of locally grown food items contributes little to total environmental exposures to contaminants from RFETS.

Taken together, the deer meat studies, the OU3 remedial investigation and the dose reconstruction study all suggest that contamination levels in food items raised or grown at off-site locations are not a public health hazard for past or current exposures and probably will not be a public health hazard in the future.

D. Evaluation of Health Outcome Data and Exposure Investigations

Several epidemiology studies have tried to identify relationships between proximity to Rocky Flats Plant and cancer incidence, but the studies have provided no clear evidence of cancers in the community being associated with environmental contamination. The studies' failure to identify increased cancer rates is consistent with ATSDR's review of the public health implications of environmental contamination levels as well as the results of multiple exposure investigations that found that residents in the immediate vicinity of RFETS do not have unusually high levels of plutonium in their bodies. Multiple parties have concluded that further epidemiological studies of communities neighboring RFETS are not warranted; ATSDR concurs with this finding.

Many parties have studied whether local residents and former employees at Rocky Flats Plant show signs of exposure to, or illness resulting from, site-related contaminants. These studies include epidemiology studies, compilations of health-outcome data and exposure investigations. Although ATSDR's review of environmental sampling data indicate that past and current exposures are not at levels of health concern, ATSDR reviewed relevant information on health-outcome data and

[9] The dose reconstruction study acknowledges that residents typically consume greater amounts of the food items than are listed in this section. The values listed in this section are the estimated amounts of food items that are raised or grown in contaminated areas east of RFETS. Food items that originate from other areas are assumed to be uncontaminated.

exposure investigations as a supplementary evaluation of environmental health conditions near RFETS. The remainder of this section presents ATSDR's interpretations of three types of studies: 1) epidemiology studies of occupational cohorts, 2) epidemiology studies of residential cohorts (including reviews of cancer-registry data) and 3) exposure investigations. The section concludes by briefly summarizing the implications of all of these studies.

- *Epidemiological studies of occupational cohorts.* As stated previously, this PHA does not address occupational health issues for former workers of Rocky Flats Plant because such issues do not fall under ATSDR's Congressional mandate. When gathering information about this site, however, ATSDR learned that many former workers are concerned about their past occupational exposures. To be responsive to this concern, ATSDR notes that NIOSH has recently completed one of the most extensive epidemiology studies to date of former Rocky Flats Plant workers. The study considered more than 16,000 former employees who worked at Rocky Flats Plant for at least 6 months between 1952 and 1989.

  Two types of evaluations were conducted in this study, 1) a cohort mortality study that compared the number of workers who died from certain diseases to the expected number of cases and 2) a case-control study for lung cancer. The cohort mortality studied found a statistically significant elevation among the workers in unspecified tumors of the nervous system. Increased mortality was also observed for cancers of the stomach, rectum, brain and other sites in the central nervous system, but the increases for these diseases were not statistically significant (NIOSH 2003). The case-control study found strong associations between smoking frequency and lung cancer, but the links between plutonium exposure and lung cancer were less clear. Specifically, a statistically significant correlation was found between lung cancer and radiation dose in a group of workers with moderate plutonium exposures, but not in the group of workers with the highest plutonium exposures (NIOSH 2003). Information on these findings and other aspects of the study can be found in NIOSH's summary report *(Epidemiologic Evaluation of Cancer and Occupational Exposures at the Rocky Flats Environmental Technology Site)*, which is available at the DOE Reading Room at Front Range Community College in Westminster, Colorado. Further information on this study and other occupational health issues can be obtained by contacting NIOSH (513-841-4400) or by visiting the agency's Web site for DOE-related issues (http://www.cdc.gov/niosh/2001-133.html).

  This discussion on occupational exposures is intended to inform former workers where they can obtain additional information on this topic. ATSDR emphasizes that findings from this and other occupational studies do not necessarily apply to residential populations near RFETS. The level and duration of exposure largely determine whether diseases will occur and occupational exposures at the former Rocky Flats Plant were considerably different from the exposures that residents experienced. The remainder of this section reviews the studies that are directly relevant to residential exposures.

In addition, DOE provides an easily accessible a public-use repository of data (without personal identifiers) collected during occupational and environmental health studies of workers at DOE facilities and nearby community residents. This large resource, called the Comprehensive Epidemiologic Data Resource (CEDR), organizes the electronic files of data and documentation collected during these studies and makes them accessible on the Internet at http://cedr.lbl.gov. Most of CEDR's large data collection pertains to about 50 epidemiologic studies of workers at various DOE sites. But of particular interest to Colorado residents is an additional component of CEDR (at http://cedr.lbl.gov/DR/drrf.html), where additional information about the Rocky Flats Historical Public Exposures Studies is easily accessible. It includes all of the Studies' technical and summary reports, as well as a special feature that sets up geographical displays of time-integrated-concentrations of airborne plutonium estimated to have been released from Rocky Flats during its operation.

- *Exposure Investigations.* Exposure investigations are studies that evaluate, often through biological sampling, the extent to which populations have been exposed to certain contaminants. ATSDR reviewed three studies that used biological sampling for plutonium to identify populations potentially exposed to plutonium released from Rocky Flats Plant:

  - A 1982 EPA summary report documents the findings of an exposure investigation that examined plutonium levels in human tissues at autopsy (EPA 1982). Between 1978 and 1979, more than 500 samples, mostly of lung and liver tissue, were collected. Samples were split into three groups: those from residents who lived within approximately 15 miles of Rocky Flats Plant; those who lived between 15 and 30 miles from the facility; and those who lived at least 30 miles away. The study found that plutonium levels in these tissues were strongly associated with age and smoking history. Plutonium levels in soft tissues, on average, were higher for the groups who lived closer to Rocky Flats Plant, but the precise role of releases from Rocky Flats Plant was difficult to assess. The authors concluded that past plutonium releases from the facility "contributed only a small amount to plutonium burdens in humans east and southeast of the site"; however, the burdens detected were similar to those reported among persons in several other parts of the country (EPA 1982).

  - In 1999, researchers from Colorado State University published a study of plutonium-239 concentrations in urine of 64 residents (Ibrahim et al. 1999). The study population consisted of long-term residents of areas immediately east of RFETS; the comparison population consisted of residents who always lived at least 10 miles from the facility. Former employees of Rocky Flats Plant were excluded from this study. The mean plutonium-239 concentrations in urine among the study population and the comparison population were 16.2 attocuries per liter (aCi/L) and 14.8 aCi/L {1 picocurie = 1,000,000

attocuries}, respectively; the difference between these average concentrations was not statistically significant. The authors concluded that the study population was exposed to plutonium at very low doses and that the daily urinary excretion rate of plutonium among the study population was within the range of measured and estimated excretion rates reported in the literature for the general U.S. population (Ibrahim et al. 1999).

- In 2002, researchers from Colorado State University published a paper reporting plutonium-239 concentrations detected in human bone samples (collected during autopsies conducted between 1975 and 1979) from 55 residents who did not work at Rocky Flats Plant (Ibrahim et al. 2002). The study population included 12 area residents who lived within 15 miles of Rocky Flats Plant, 16 residents who lived between 15 and 30 miles from the site and 27 residents who lived further away. Median plutonium-239 burdens in bone samples were greatest for the residents who lived closest to Rocky Flats Plant {3.97 picocuries (pCi)} and lowest for those who lived furthest (1.92 pCi), but the concentration difference between these groups was not statistically significant. The authors examined correlations between bone-sampling results and several factors (e.g., distance from Rocky Flats Plant, age, smoking history), but none of the factors were significantly correlated with the observed plutonium levels. The absence of statistically significant findings reflects the variability in the measured concentrations and the limited sample size of the study. Though a larger study might establish spatial variations in plutonium bone concentrations that are statistically significant, this study suggests that the highly exposed populations do not have considerably greater plutonium body burdens than the general population.

Taken together, these exposure investigations provide limited, but not statistically significant, evidence that residents who live near RFETS have higher levels of plutonium in their bones, urine and selected soft tissues than do residents who live further from the facility. However, the difference in body burdens between these groups is relatively small and suggests that residents in the immediate proximity of RFETS did not experience unusually high exposures to plutonium, when compared to the general population.

- *Epidemiological studies of local residents.* Over the last 25 years, several researchers have published epidemiology studies to assess whether exposures to contaminants from Rocky Flats Plant are associated with various diseases. The following paragraphs review findings of four individual epidemiology studies that focused specifically on cancer in communities surrounding the Rocky Flats Plant. ATSDR's interpretation of the studies, taken as a whole, is provided after the following review of the individual publications.

  - *Johnson 1981.* This study investigated trends among the number of cancer diagnoses between 1969 and 1971 in four areas in the vicinity of Rocky Flats Plant (Johnson 1981). The four areas were classified according to levels of

plutonium contamination in surface soils. The study found that overall cancer incidence in the area with the highest environmental contamination was higher than expected for both males (24% increase) and females (10% increase) and these increases were at a statistically significant level. The increases in total cancers resulted largely from greater-than-expected cases of leukemia, lymphoma and lung cancer. These findings, according to the study author, support "the hypothesis that exposure of the general public to low concentrations of plutonium in the environment may have an effect on cancer incidence" (Johnson 1981). As noted below, other researchers have disputed this finding.

- *Selvin et al. 1987.* This study examined spatial variations among the same set of lung cancer and leukemia diagnoses considered in the Johnson study, summarized above. The study assessed whether cancer diagnoses stratified by age and sex exhibited any meaningful relationship with distance from Rocky Flats Plant. Spatial variations were examined for 20 different scenarios. For 19 of these 20 scenarios, no pattern among spatial variations could be discerned. The data suggested that increased incidence of acute granulocytic leukemia among older males might have been associated with distance from Rocky Flats Plant; however, the authors could not rule out the possibility that this one apparent increase out of 20 evaluations resulted from chance alone. Overall, the authors concluded that no association appears to exist between incidence of lung cancer and leukemia between 1969 and 1971 and distance from the Rocky Flats Plant (Selvin et al. 1987). Though the absence of a discernable spatial trend might have simply reflected limited statistical power to detect an effect, the authors noted that the types of cancers considered likely had more than enough cases for conducting rigorous spatial analyses. In short, both this study and the 1981 study considered the same underlying data set of cancer diagnoses but reached different conclusions.

- *Crump et al. 1987.* This study examined spatial variations in cancer incidence for two time frames: 1969–1971 (the same time frame considered in the two studies reviewed above) and 1979–1981. Therefore, the study re-analyzed earlier findings and considered more recent statistics to assess cancers with longer latency periods. The study authors first replicated the findings from Johnson's study and confirmed that total cancer and certain specific cancers were elevated between 1969 and 1971 in certain areas southeast from Rocky Flats Plant. Crump notes, however, that the diagnoses from this time frame did not show increased incidence for the cancer types typically observed in studies of experimental animals (e.g., liver cancer, bone cancer). These general trends were also observed for the 1979–1981 time frame; however, the areas with the highest cancer incidence during the more recent period were different (and further from Rocky Flats Plant) from those observed previously.

  After verifying these general trends, the study authors examined further how cancer diagnoses varied with location and found that distance from the

downtown area of Denver (specifically, the State Capitol) was strongly correlated with cancer incidence (Crump et al. 1987). In fact, the authors found that the increased cancer rates previously reported for the 1969 to 1971 time frame vanish when analyses are controlled for urbanization. Based on this observation, the authors conclude that Johnson's previous findings were based largely on cancer cases among populations located closer to downtown Denver and not in the immediate vicinity of Rocky Flats Plant. More simply stated, the authors suggested that previous findings of elevated cancer rates were likely caused by a confounding factor or urbanization.

- *Colorado Central Cancer Registry (CCCR) 1998.* In 1998, CCCR analyzed whether cancer incidence is related to distance from the former Rocky Flats Plant (CCCR 1998). The study considered incidence data from 1980 to 1989 for total cancer and for ten individual cancers (esophagus, stomach, colon and rectum, liver, lung, prostate, bone, leukemias, lymphomas and brain and central nervous system). For the analysis, CCCR compared age- and sex-specific cancer incidence for ten "regional statistical areas" in the immediate vicinity of RFETS to cancer incidence for the rest of the Denver metropolitan area.

  CCCR reported multiple findings in its summary report (CCCR 1998). For instance, the incidence of total cancers and the incidence of the ten individual cancers for the ten regional statistical areas nearest RFETS were not higher than expected when compared to the remainder of the Denver metropolitan area. CCCR also examined cancer incidence for the individual regional statistical area. Out of nearly 200 evaluations of cancer incidences among the 10 areas, only 4 cancer ratios showed higher than expected levels when compared to the urban area. The authors noted that these isolated increases in cancer incidence could result from chance alone. Overall, CCCR concluded that its data "show that communities in the general vicinity of Rocky Flats had cancer incidence during 1980–1989 that was comparable to the remainder of the Denver Metro area" (CCCR 1998).

Overall, the epidemiological studies provide no consistent evidence of cancer incidence being higher in areas nearest RFETS as compared to rates for the Denver metropolitan area. There are two possible explanations for the studies not finding increased cancer rates: either the cancer rates truly do not vary with distance from RFETS, or such spatial patterns in cancer rates exist, but they could not be detected because the trends are too subtle or due to other limitations in study design (e.g., lack of control for confounding factors, particularly smoking; failure to incorporate exposure data; inadequate statistical power).

ATSDR's review of the environmental data strongly suggests that the epidemiological studies failed to detect increased cancer incidence primarily because the estimated increased theoretical cancer risk is extremely low (see Section VI.C.4). Other scientists have agreed with this evaluation, noting that the

limited cancer risks associated with Rocky Flats Plant are much lower than risks that can be attributed to radiation exposures from global fallout (Dreyer et al. 1982). More recently, the authors of the dose reconstruction study also concluded that further epidemiological study of the areas surrounding RFETS is not warranted, due to the low estimated exposures to site-related contaminants, changes in demographics since the time Rocky Flats Plant operated and the fact that no disease can be attributed solely to plutonium exposures. The belief that future epidemiological studies would generate inconclusive results is generally consistent with the findings of the exposure investigations, which suggest that residents near RFETS do not have unusually high levels of plutonium in their bodies.

In summary, the epidemiological studies conducted on populations near RFETS have provided no definitive evidence linking adverse health effects to contaminants released from Rocky Flats Plant. Though it is possible that a more robust study (e.g., a case-control study involving rigorous exposure estimates) might be capable of detecting effects that the previous studies failed to identify, detailed review of the environmental data suggest that cancer risks attributed to past releases from Rocky Flats Plant are far too low to detect.

E. Child Health Considerations

ATSDR's review of environmental contamination at RFETS identified no exposure scenarios that pose unique health hazards to children. The levels of environmental contamination that remain at the site are below levels of health concern for all residents, including children.

Because children often are at greater risk than adults from being exposed to toxic chemicals and because more than 10,000 children (age 6 and under) live within 5 miles of RFETS, ATSDR considered children's health issues when evaluating exposures and their public health implications. In general, children are more likely than adults to experience adverse health effects due to environmental exposure for several reasons, such as:

- Children drink more fluids, eat more food and breathe more air per kilogram of body weight than do adults. As a result, children receive greater doses to environmental contaminants (on a pound of contaminant per pound of body weight basis) than do adults.

- Children crawl on floors, put things in their mouths, play close to the ground and spend more time outdoors. These behaviors may result in longer exposure durations and higher intake rates.

- Children's developing bodies can be particularly sensitive to toxic exposures during certain critical growth stages, especially when children are exposed to chemicals known to cause developmental effects.

For these reasons, ATSDR specifically considered children's health issues during the public health assessment process for RFETS. For instance, during site visits, ATSDR identified locations nearest RFETS that children access. Though children tend to explore their surroundings, sometimes in areas where access is not permitted, ATSDR found no evidence that children access the RFETS property, most likely due to the extensive security measures at RFETS. Further, ATSDR did not identify any parks, playgrounds, or schools immediately adjacent to RFETS. The nearest school and park are 2.7 miles and 1.0 mile, respectively, from the site boundary.

ATSDR also considered children's health issues when evaluating exposures and their public health implications. For instance, when comparing levels of environmental contamination to health-based comparison values, ATSDR used comparison values that are protective of children's exposures and health conditions more common in children (e.g., asthma), to the extent that these comparison values are available. For instance, ATSDR used EPA's drinking water standards and National Ambient Air Quality Standards when evaluating contamination levels in surface water, groundwater and air. These standards were all developed to protect the health of sensitive populations, including children. Moreover, several conclusions in this PHA are based largely on the dose reconstruction study, which examines children's exposure scenarios, including that of an infant born in 1953 and exposed to releases from Rocky Flats Plant and students who attended local schools while Rocky Flats Plant operated (Till et al. 2002).

Although the available environmental sampling data and exposure studies indicate that children near RFETS may be exposed to trace levels of site-related environmental contaminants, particularly in air and soil, these exposures appear to be much lower than levels associated with adverse health effects (see Section VI.C). ATSDR concludes, therefore, that exposure to site contamination at RFETS does not pose unique health hazards for children. This PHA includes several recommendations, particularly for ongoing sampling, to ensure that residents—including children—are not exposed to unhealthy levels of environmental contamination in the future.

VII. Conclusions

In this PHA, ATSDR evaluates the past, present and future public health implications of community members coming into contact with environmental contamination at and near the RFETS site near Denver, Colorado. The conclusions for past exposures are based largely on the extensive dose reconstruction study conducted by expert scientists and critically reviewed by CDPHE and an independent health advisory panel. The conclusions for current and future exposures are based largely on ATSDR's interpretation of sampling data recently collected by multiple parties. This PHA focuses entirely on environmental health concerns, because occupational safety and health concerns are not part of ATSDR's mandate.

Overall, ATSDR did not identify any environmental exposures at levels of public health concern for past and current exposures and we propose several actions to ensure that environmental contamination at RFETS does not present a health hazard in the future (see Section VIII). ATSDR's specific conclusions for the RFETS site follow:

- *On-site contamination in all media.* All on-site contamination at RFETS poses no general public health hazard and was not a public health hazard in the past, because multiple security measures continue to prevent visitors from coming into contact with on-site contamination levels. The on-site contamination levels will continue to pose no public health hazard to residents in the future, so long as site access is restricted. Any future changes to site access must be carefully reviewed (see Section VIII), based on the contamination levels that remain at RFETS after remediation is completed and the proposed land uses.

- *Off-site surface soil contamination.* Past releases from the Rocky Flats Plant contaminated off-site surface soils, primarily with americium and plutonium isotopes. The highest off-site contamination levels occur immediately east of RFETS, in an area where no one lives, but contamination above background levels is believed to extend up to 3 miles from the site boundary. Though off-site surface soil contamination clearly exists, estimated total exposures to radiation from the soil are far lower than levels associated with adverse health effects and are 3,000 times lower than the average exposure to ionizing radiation experienced by United States residents. Therefore, the levels of off-site surface soil contamination are no apparent public health hazard for past, current and future exposures.

- *Off-site groundwater contamination.* Although groundwater at several areas beneath RFETS is contaminated, monitoring data from wells along the RFETS property line suggest that the groundwater contamination plumes remain on site. Therefore, past and current use of water obtained from off-site private and municipal wells presents no public health hazard. Recognizing that some of the groundwater contaminants found on site are highly mobile and that chlorinated organic compounds are already detected at the site boundary, albeit infrequently

- and at trace levels, ongoing monitoring is needed to ensure that groundwater contamination at RFETS is not a public health hazard in the future (see Section VIII).

- *Off-site contamination in surface water, sediment and aquatic biota.* Discharges and runoff from Rocky Flats Plant caused site-related contaminants to flow off site in Walnut Creek and Woman Creek and eventually into three local reservoirs. These reservoirs supplied, or continue to supply, drinking water to the cities of Broomfield, Northglenn, Thornton and Westminster. Thousands of drinking water samples have been collected from these municipal supplies since 1970. Although the sampling data indicate that drinking water has contained trace amounts of site-related contamination, average contamination levels in these municipal supplies have never exceeded drinking water standards or relevant health guidelines, even for plutonium. It is not expected that concentrations of radionuclides in surface water would have been elevated in the years prior to 1970, except as a result of above ground nuclear testing, but no data are available. Oxides of plutonium are extremely insoluble in water and would not have been a hazard from ingestion. As a result, past and current exposures via the drinking water pathway pose no apparent public health hazard. Ongoing monitoring is needed to ensure that plutonium does not migrate from the sediments into the drinking water supplies in the future (see Section VIII), even though plutonium's chemical and physical properties suggest that such migration is unlikely.

  Residents who use the off-site surface waters for recreational purposes might incidentally ingest sediment and water that contains, or previously contained, site-related contaminants. Data collected from several extensive site investigations demonstrate that incidental contact with the surface water or sediment is not expected to be detrimental to one's health. Therefore, contamination in surface water and sediment that residents and recreational users might ingest are no apparent public health hazard for past and present exposures. Further monitoring of surface waters (see Section VII) is needed to ensure that ongoing clean-up efforts at RFETS continue to be conducted in a manner that does not lead to elevated exposures to off-site populations.

  Fish tissue sampling from Standley Lake found no evidence of radioactive contaminants in the fillets of channel catfish, rainbow trout, smallmouth bass and walleye. Trace amounts of mercury and pesticide residues in the fish tissues likely originated from sources other than RFETS. Regardless of their source, these contamination levels pose no apparent public health hazard to people who consume up to one meal containing fish from Standley Lake per week.

- *Off-site air contamination.* Because site-related air emissions varied considerably from one year to the next, ATSDR evaluated inhalation exposures for two distinct time frames:

  - *While Rocky Flats Plant operated (1952–1989).* Of all exposure pathways considered, the air exposure pathway accounted for the majority of exposures to site-related contaminants at off-site locations. The primary contaminants of concern were plutonium and carbon tetrachloride. The dose reconstruction study concluded that nearly 99.99% of Rocky Flats Plant's estimated plutonium emissions occurred between 1953 and 1969. Residents who lived east and southeast of the facility during that time might have experienced a very small, theoretical increased risk for cancer from inhaling airborne plutonium. This cancer risk has not been detected by epidemiological studies and might, in fact, be zero. Moreover, this theoretical cancer risk is more than 25 times smaller than that associated with airborne carcinogenic compounds that motor vehicles and other sources typically emit. Although Rocky Flats Plant emitted carbon tetrachloride into the air, the estimated air quality impacts from the facility's emissions are approximately half of the ambient-air concentrations of carbon tetrachloride typically observed in suburban and urban locations across the county. Potential exposures to other contaminants released by Rocky Flats Plant are less significant from a public health perspective.

    Based on these observations, ATSDR concludes that residents who lived near Rocky Flats Plant were exposed to site-related contaminants, but not at levels associated with adverse health effects. This conclusion is based largely on the modeling analyses reported in the dose reconstruction study. Though these analyses have inherent uncertainties, ATSDR believes the data from the dose reconstruction study are the best available information for evaluating past exposures and there are no clear opportunities for reducing uncertainties associated with past exposures to air contaminants.

  - *Since Rocky Flats Plant shut down (1989–present).* Extensive sampling data collected since 1989 show that the air near RFETS is safe to breathe. Ambient air concentrations of americium, beryllium, plutonium, uranium and several site-related contaminants have consistently been well below levels of potential health concern.

  Overall, ATSDR finds past and current inhalation exposures to site-related air emissions to be no apparent public health hazard. Ongoing operation of DOE and CDPHE's environmental surveillance networks should help ensure that ongoing exposures associated with site cleanup efforts do not present a health hazard in the future.

- *Off-site contamination in terrestrial biota.* No sampling studies have measured levels of site-related contamination in food items raised or harvested from off-site locations, such as vegetables, meat and dairy products and deer meat. However, on-site deer meat sampling studies, human health risk assessments prepared for site clean-up projects and the dose reconstruction study all suggest that eating these food items contributes little to total exposures of site-related contaminants. Therefore, ingestion of food items from off-site locations at RFETS is no apparent public health hazard for past, current and future exposures.

VIII. Recommendations

As Section VII explains, ATSDR concludes that environmental contamination at RFETS poses no apparent public health hazard, but will reevaluate risks in the future as new data become available. ATSDR makes the following recommendations to ensure that this site's contamination does not pose a health hazard in the future:

- ATSDR recommends that DOE continue the site remediation and building decommissioning efforts, under EPA and CDPHE oversight, as outlined in the Rocky Flats Cleanup Agreement. Until the remediation is complete, DOE should continue to restrict access to RFETS and ensure that remediation workers are adequately protected from site-related contaminants.

- ATSDR recommends that DOE continue to monitor water quality in wells along the eastern boundary of RFETS to ensure that groundwater contaminants are not migrating offsite. ATSDR also recommends, as a prudent public health measure, that Boulder and Jefferson Counties offer to sample any private drinking water wells located within 2 miles of RFETS eastern boundary to verify the conclusion that site-related contaminants have not migrated off site.

- ATSDR recommends that CDPHE and DOE continue to monitor the surface water (Walnut Creek, Woman Creek and Mower Ditch) at locations along the eastern site boundary. This monitoring will ensure that site-related contaminants do not flow off-site as a result of ongoing remediation projects. Further, ATSDR recommends that the municipal drinking water supplies that draw from Standley Lake monitor the drinking water for plutonium contamination indefinitely, given that trace amounts of plutonium remain in this reservoir's sediments.

- ATSDR recommends that CDPHE and DOE continue to operate their ambient-air-monitoring stations around the perimeter of RFETS. Monitoring for plutonium and other site-related contaminants should continue for the duration of site remediation and building decontamination efforts.

IX. Public Health Action Plan

The public health action plan for RFETS describes actions taken at the site and those recommended to be taken after ATSDR completes this PHA. The purpose of the public health action plan is to ensure that this PHA not only identifies potential and ongoing public health hazards, but also provides a plan of action designed to mitigate and prevent adverse human health effects from occurring in the future. The following public health actions at RFETS are completed, ongoing, planned, or recommended:

A. Completed Actions

DOE has identified areas of environmental contamination at RFETS, characterized the nature and extent of contamination in these areas and implemented several projects under EPA and CDPHE oversight to reduce, remove, or monitor this contamination.

Contractors to CDPHE completed an extensive dose reconstruction study that estimated the extent to which residents were exposed to contaminants released from the Rocky Flats Plant between 1952 and 1989.

CDPHE, DOE and numerous other parties have sampled the soil, air, groundwater, surface water and biota around RFETS.

B. Ongoing Actions

DOE continues to implement remediation projects and to decommission and demolish buildings where the Rocky Flats Plant's manufacturing operations previously occurred. These activities are being conducted under CDPHE and EPA oversight.

DOE and CDPHE continue to operate environmental surveillance networks to detect potential migration of site-related contaminants.

C. Planned Actions

DOE plans to complete its remediation projects and building decommissioning projects by 2006.

DOE has developed a Comprehensive Risk Assessment (CRA) Work Plan and Methodology outlining the approach to be used in performing a CRA at the site. This methodology was prepared with input from CDPHE, EPA and FWS, and was approved by CDPHE and EPA in September 2004. The CRA will evaluate and quantify risks to human and ecological receptors posed by residual contamination at RFETS. The CRA will address all areas within the RFETS boundary, based on the anticipated future use of RFETS as a wildlife refuge as designated by the Rocky Flats National Wildlife Refuge Act of 2001.

D. Recommended Actions

Until the site cleanup work is completed, DOE should continue to restrict access to RFETS and ensure that remediation workers are adequately protected from site-related contaminants.

DOE should continue to monitor levels of groundwater contamination in the wells along the eastern RFETS property line.

CDPHE should offer to sample any private drinking water wells located within 2 miles of RFETS eastern boundary to verify the conclusion that site-related contaminants have not migrated off site.

Municipalities that draw drinking water from Standley Lake should routinely monitor the water for plutonium contamination. This routine monitoring should occur indefinitely as a precautionary measure, given the presence of trace amounts of plutonium in Standley Lake sediments. This recommendation currently affects the municipalities of Northglenn, Thornton and Westminster.

DOE, EPA, CDPHE and other parties should carefully review any future plan that allows residents to access RFETS property. The parties should consider requiring an additional round of confirmatory sampling before lifting RFETS site access restrictions.

X. Preparers of Report

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XII. Appendices

Appendix A. Figures

Figure 1. General Vicinity Map

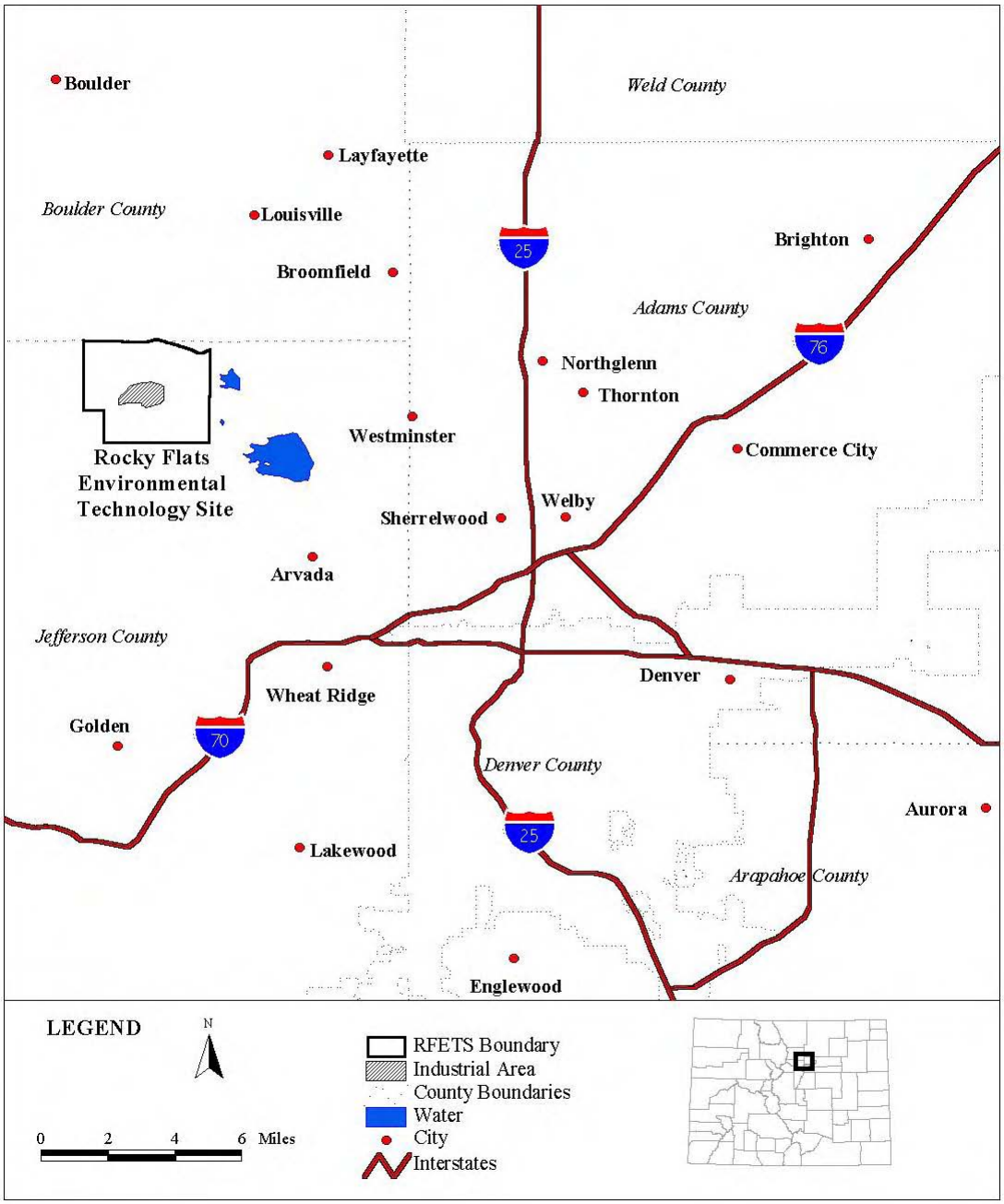


Figure 2. Demographics of RFETS Vicinity

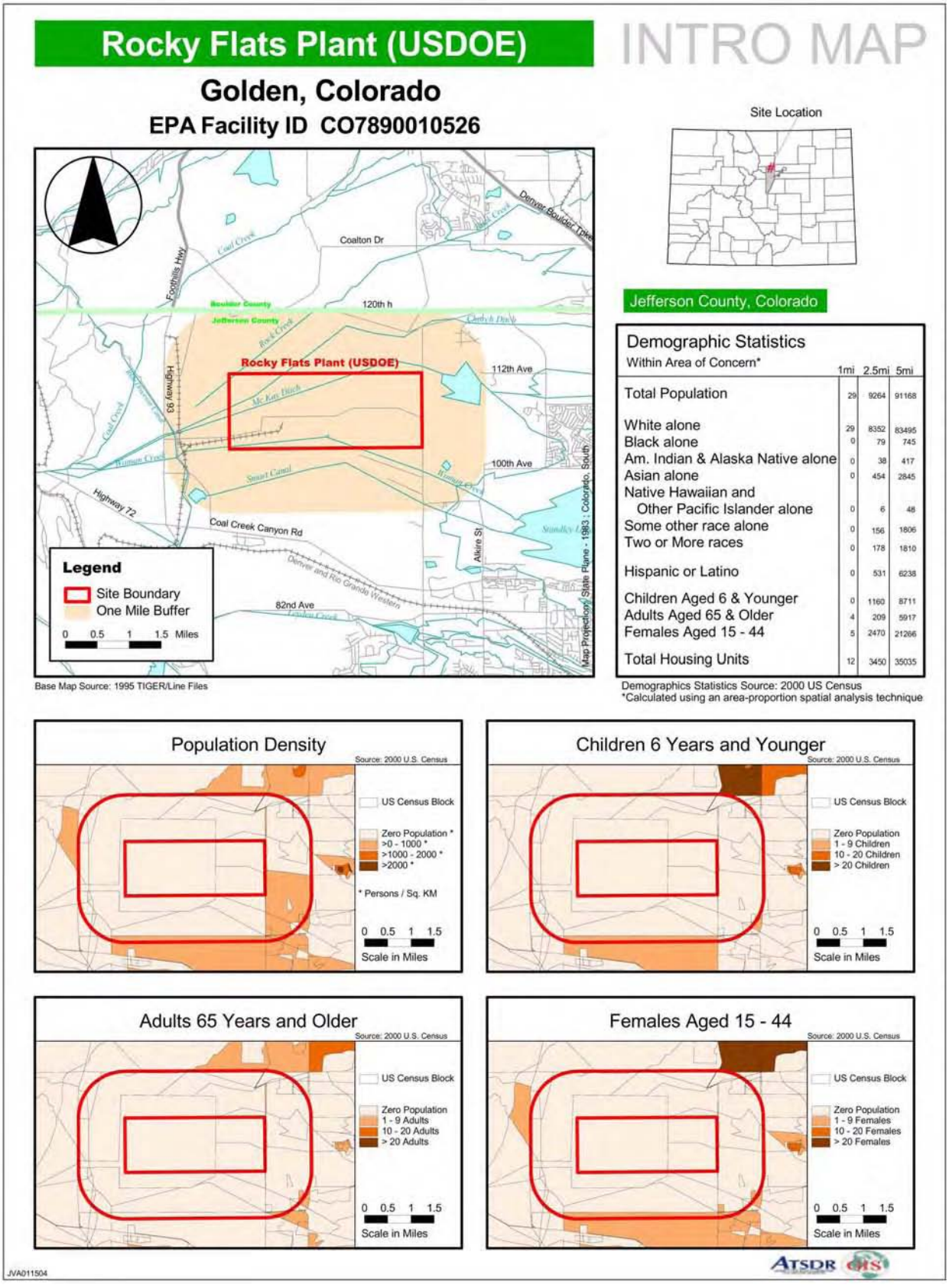
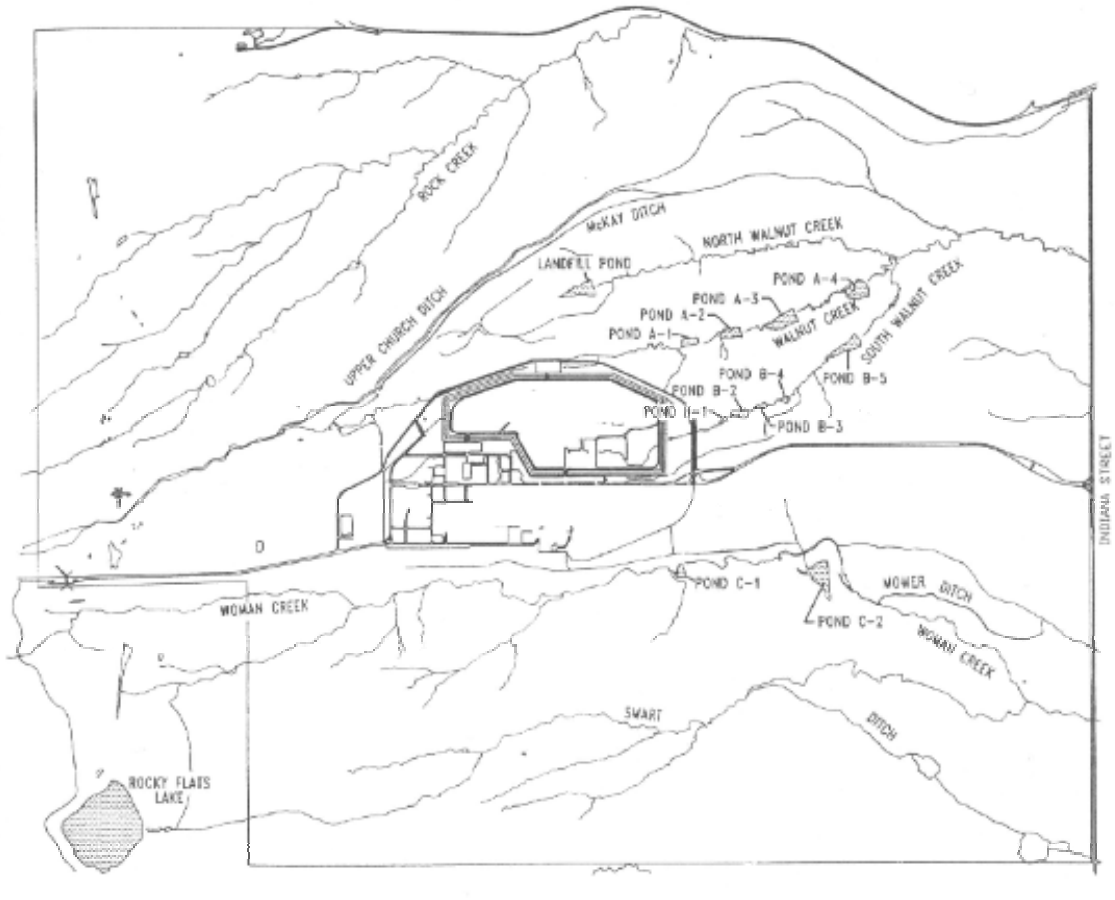


Figure 3. Facility Boundary and Industrial Area



Source: EG&G Rocky Flats, Inc. 1991.

Figure 4. Land Use in the RFETS Vicinity

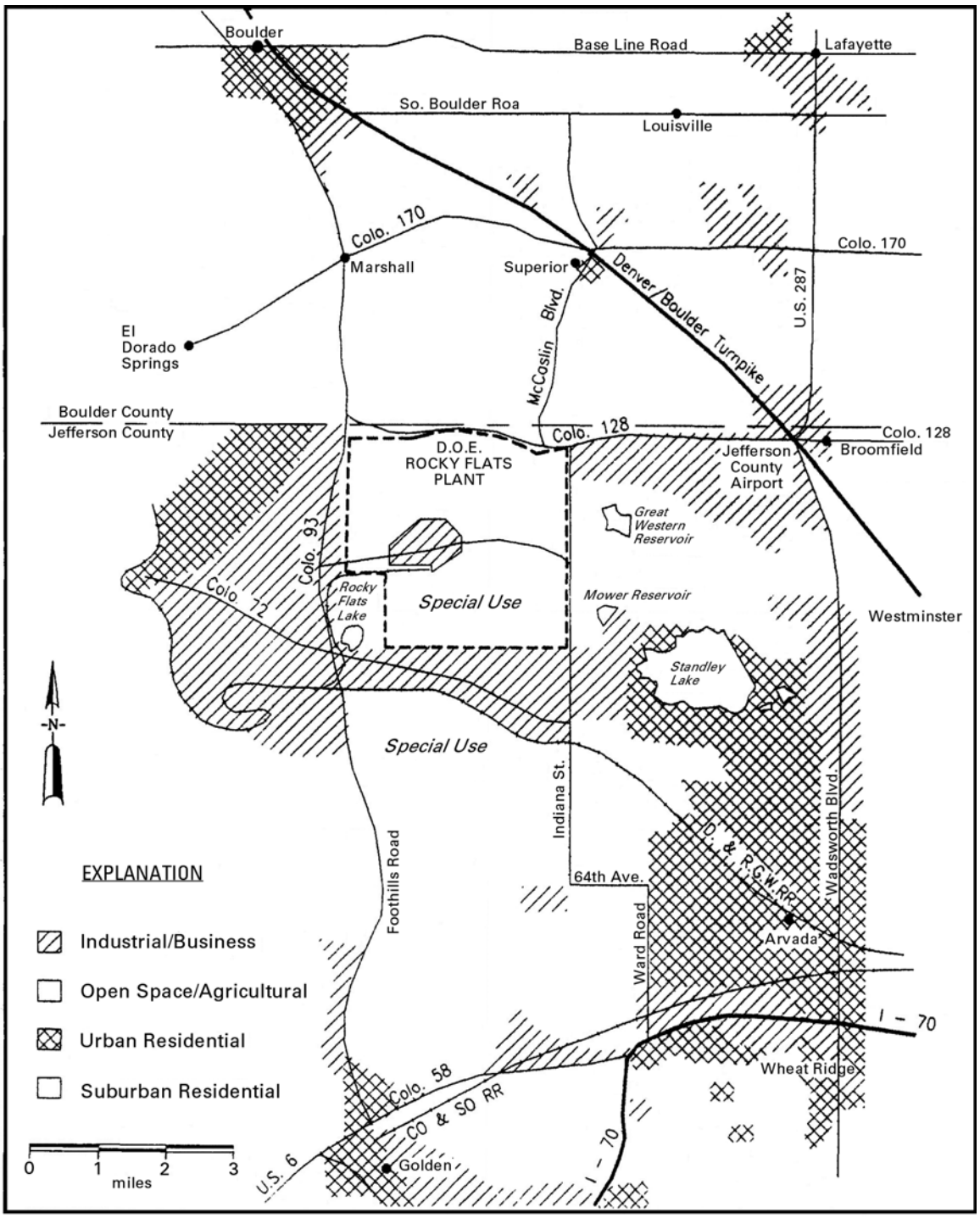
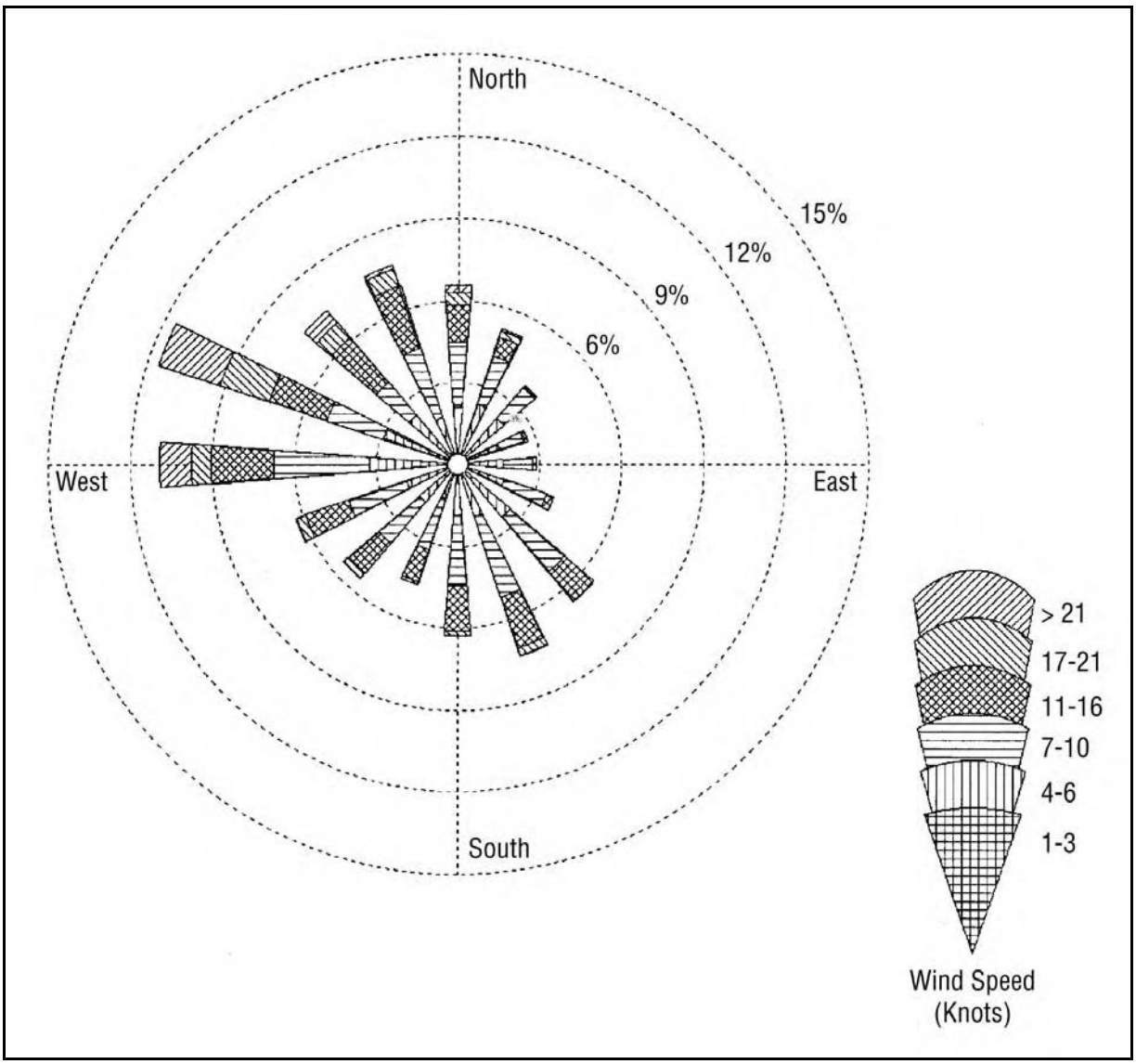
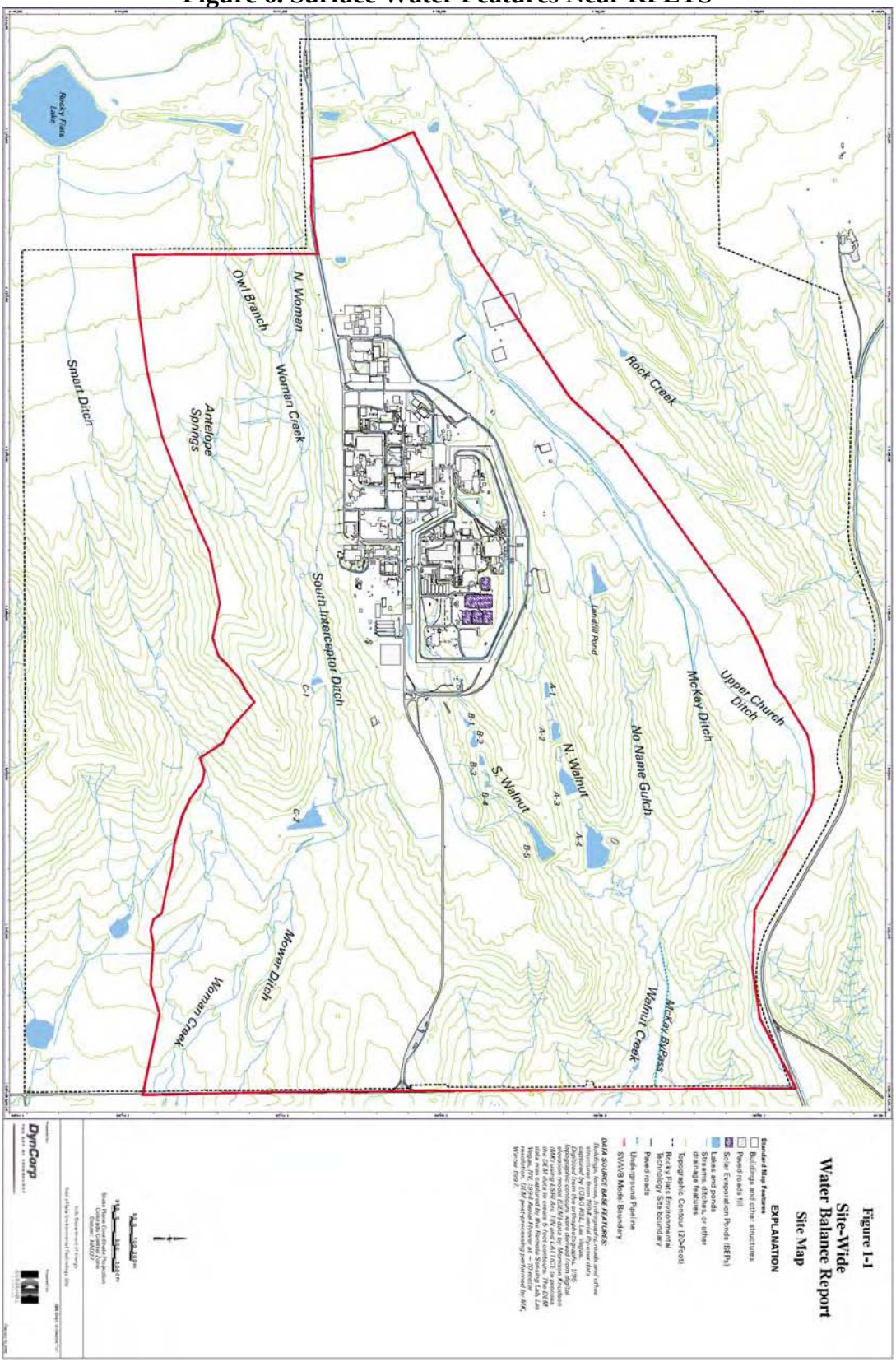


Figure 5. Wind Rose (1999) for RFETS



Notes: The bars in the wind rose indicate the directions *from which* winds blow.
The wind rose is based on meteorological data collected in 1999 at RFETS by CDPHE.
Source of information: CDPHE 1999.

Figure 6. Surface Water Features Near RFETS



Appendix B. Tables

Table 1. Summary of the Current Operable Units (OU) at RFETS

OU Number	Waste Sites at OU	Description of OU
OU1	Hillside 881	OU1 originally contained 11 hazardous substance sites that were located south and east of Building 881 and north of Woman Creek. A groundwater plume is found at this site and the contaminants of concern are various chlorinated solvents (e.g., carbon tetrachloride, 1,1-dichloroethylene, TCA, TCE, PCE) and selenium. Contamination in this area has been addressed by removing contaminated soils and continues to be addressed by pumping and treating contaminated groundwater. Long term groundwater monitoring will continue in this area, even after official site closure (DOE 2002a), as a precautionary measure.
OU3	Off-site Areas	Of the seven OUs listed in this table, OU3 is the only one that extends beyond the RFETS property line. Over the years, contaminants in surface soils and sediments at RFETS gradually transported, through air and surface water, to the off-site locations within OU3. This OU includes two general areas: off-site areas with surface soil contamination and the sediments of Great Western Reservoir, Standley Lake and Mower Reservoir. In 1997, EPA issued a "No Action" record of decision for OU3, based largely on findings of a risk assessment that found no unacceptable human health risks for selected residential and recreational scenarios (EPA 1997b). ATSDR previously reviewed this risk assessment and concurred that no further remedial activities were needed to protect public health (ATSDR 1997).
OU5	Woman Creek Priority Drainage	OU5 includes several waste sites along the Woman Creek drainage. These sites include numerous ash pits and an incinerator that previously operated near the creek. They also include retention Ponds C-1 and C-2. The retention ponds continue to receive runoff from the southern portion of the Industrial Area and previously received sanitary sewage discharge. A series of construction projects at RFETS between 1973 and 1995 removed some contamination from the pond areas and permanently diverted the surface water flow in this drainage away from Standley Lake to ensure that site-related contaminants could no longer enter drinking water supplies. The Rocky Flats Cleanup Agreement requires that DOE conduct extensive surface water monitoring along this drainage to track potential sources of contamination (DOE 1996).
OU6	Walnut Creek Priority Drainage	OU6 includes several waste sites along the Walnut Creek drainage. These sites include multiple trenches and former spray areas, as well as Ponds A-1 through A-5 and Ponds B-1 through B-5. These retention ponds continue to receive runoff from the northern portion of the Industrial Area and previously received wastewater effluent, treated sanitary effluent and process waste. RFETS conducted a series of construction projects to divert the surface water in this drainage away from downstream drinking water reservoirs. This diversion was completed in 1989. The Rocky Flats Cleanup Agreement requires that DOE conduct extensive surface water monitoring along this drainage to track contamination level in the future (DOE 1996).

Table 1 (Continued). Summary of the Current Operable Units (OU) at RFETS

OU Number	Waste Sites at OU	Description of OU
OU7	Landfill	OU7 is located in the Buffer Zone and includes a 27-acre landfill, an inactive waste storage area, a pond and the areas that were previously used for spray evaporation of wastes. The Phase I and Phase II investigations for the OU identified contaminants at elevated levels in groundwater, including chlorinated solvents, tritium and selected metals. Several measures have been implemented to prevent contaminants from migrating away from the site. For instance, a leachate collection system and groundwater diversion system were installed in the area, but these proved to be only partially effective at preventing contamination from migrating. Since 1995, two projects were implemented to prevent contaminants from flowing into Walnut Creek from this OU and these measures have proven to be effective at protecting the local surface waters from elevated levels of site-related contaminants (DOE 2002a).
Industrial Area OU	Industrial Area	The Industrial Area includes all waste sites located within the roughly 350 acres at the center of RFETS (see Figures 3 and 6). A large number of hazardous waste sites are located within the Industrial Area. These sites originally included solar ponds, process waste lines, locations of spills and leaks, waste storage areas, underground storage tanks and numerous former processing buildings that are being decommissioned. Contamination levels in this area have been extensively characterized: the 2000 site characterization effort, for example, has a database of more than 700,000 records. A variety of clean-up strategies are being pursued to address residual contamination in surface soil, sub-surface soil, surface water and groundwater. CDPHE is responsible for overseeing all clean-up activities in the Industrial Area.
Buffer Zone OU	Buffer Zone	The Buffer Zone OU includes several hazardous waste sites located in the southeastern corner of the Industrial Area. The most notable waste site is the 903 Drum Storage Area, where drums containing liquid wastes were temporarily stored between 1958 and 1967. Leaking drums released volatile organic compounds and radionuclides to the surface soil. Some of this contamination has since migrated into the groundwater and some has been carried to off-site surface soils by strong winds. Contaminants of concern in this area include: americium, plutonium and uranium isotopes; poly-chlorinated biphenyls; and selected chlorinated solvents (e.g., chloroform, methylene chloride, PCE, TCE). Multiple remediation activities, all under EPA oversight, are being conducted to address the Buffer Zone OU.

Note: The number and organization of OUs at RFETS has changed over the years. In 1991, the original Interagency Agreement between DOE, EPA and CDH organized the 177 individual hazardous substance sites into 16 OUs. In 1996, these agencies entered into another agreement—the Rocky Flats Cleanup Agreement—that further reorganized the site into 7 OUs. This table describes these OUs and reviews their current cleanup status.

Table 2. Summary of Exposure Pathways

Pathway Name	Exposure Pathway Elements					Time of Exposure	Comments
	Source of Contamination	Environmental Medium	Point of Exposure	Route of Exposure	Exposed Population		
On-site Exposure Pathways (see Sections IV.A, V.B, VI.B)							
Coming into contact with contaminants in any medium (soil, groundwater, surface water, sediment and biota)	Past disposal practices, leaks, spills, effluents, discharges at the hazardous waste site.	Soil Groundwater Surface water Sediment Biota	None: access to RFETS is restricted to unauthorized persons	None	No one	Past Present Future	As Section II.A.2 indicates, access to RFETS is restricted. Gates, fences and 24-hour security prevent residents from accessing RFETS property. Because residents cannot access the site, all on-site exposure pathways are **eliminated exposure pathways**.
Off-site Exposure Pathways (see Sections IV.A, V.C, VI.C)							
Contacting off-site surface soils	Wind-blown dust from RFETS	Surface soils	Locations within OU3, primarily east and southeast of RFETS	Incidental ingestion	Residents and recreational users of lands	Past Present Future	Surface soil contamination has been detected in publicly accessible areas extending up to approximately 1 mile east of the RFETS property line. Thus, this is a **completed exposure pathway**. See Sections V.C.1 and VI.C.1 for further information.
Contacting off-site groundwater	Groundwater plumes at RFETS resulting from previous releases at Rocky Flats Plant	Groundwater	Private wells and municipal water supply wells	Ingestion of drinking water	Users of private wells at locations down-gradient (i.e., east) of RFETS	Future	The available data suggest that groundwater plumes at RFETS have not moved off site. The groundwater in this area flows east and it is possible that trace levels of contaminants might migrate off site in the future. As a result, ATSDR considers contacting off-site groundwater to be a **potential exposure pathway**. Sections V.C.2 and VI.C.2 further discuss this pathway.

Table 2 (Continued). Summary of Exposure Pathways

Pathway Name	Exposure Pathway Elements					Time of Exposure	Comments
	Source of Contamination	Environmental Medium	Point of Exposure	Route of Exposure	Exposed Population		
Contacting off-site surface water, sediment, aquatic biota	Contaminants previously discharged to on-site retention ponds	Local surface water bodies (see Section II.D.3) and the sediments and biota within them	Walnut Creek, Woman Creek, Great Western Reservoir, Standley Lake and Mower Reservoir	Dermal contact and ingestion	Residents whose drinking water comes from the reservoirs and recreational users of the surface water	Past Present Future	Some contaminants in the liquid wastes that were previously discharged to the on-site retention ponds have moved off site through Walnut Creek and the Woman Creek drainage basins into reservoirs that have been used for drinking water supply and recreational purposes. Because residents have come into contact with these contaminants and may continue to do so in the future, ATSDR considers the surface water (including sediment and aquatic biota) to be a **completed exposure pathway**, which Sections V.C.3 and VI.C.3 discuss in detail.
Contacting off-site air	Emissions from Rocky Flats Plant occurred from routine operations and episodic events. Emissions now are limited to dusts and cleanup-related releases	Ambient air	Off-site locations downwind from RFETS	Inhalation	Residents who reside downwind from RFETS	Past Present Future	Air emissions from Rocky Flats Plant occurred from 1952 and 1989. Since 1989, emissions decreased considerably, but still occur. Contaminants have and continue to blow off site, albeit in trace amounts. Inhaling air is a **completed exposure pathway**, which is reviewed in Sections V.C.4 and VI.C.4.
Contacting off-site terrestrial biota	Contaminants released to surface soils that can accumulate in the food chain	Vegetables, fruits, crops, dairy products and locally hunted game	Off-site locations in the immediate vicinity of RFETS	Ingestion	Residents who consume food items grown in or harvested from areas near RFETS	Past Present Future	The exact levels of contaminants in terrestrial biota near RFETS are not known. Because trace amounts of persistent contaminants might be found in biota, ATSDR considers ingesting local food items to be a **potential exposure pathway** (see Sections V.C.5 and VI.C.5).

Table 3. Estimated Plutonium Emissions from the Rocky Flats Plant (1953–1989)

Release Event	Estimated Release Quantity (Ci*)	Percent of Total Releases
Routine operations: 1953–1969	0.116	0.48%
Routine operations: 1970–1989	0.0043	0.018%
1957 Fire	21.1	87.1%
1969 Fire	0.038	0.16%
Releases from 903 Pad Area: prior to 1969	2.97	12.3%
Total (1953–1989)	24.21	100%

Data Source: Till et al. 2002 (Phase II dose reconstruction study data).

*Ci = curies. The estimated release quantities are in units of curies (1Ci = 14 grams).

Notes:

The percentages in the table do not add up to 100% due to rounding errors.
Release data presented in the table are the estimated median amounts (or 50th percentile amounts) of plutonium emitted to the air. The dose reconstruction study also estimates 5th and 95th percentiles for these releases.

Table 4. Organic Compounds Detected in Boundary Monitoring Wells (1998–2002)

Chemical	Frequency of Detection (%)	Maximum Concentration (µg/L*)	Health-Based Comparison Value (CV†) (µg/L)	CV Source	Number of Concentrations Greater Than CV (% of samples above)
Carbon tetrachloride	4 %	0.3 J	0.3	CREG	0
Dichlorodifluoromethane	2 %	1	1,000	LTHA	0
1,2-Dichloroethane	2 %	0.8 J	0.4	CREG	1 (2%)
1,1-Dichloroethylene	2 %	1	90	Chronic EMEG	0
Methylene chloride	6 %	2	5	CREG	0
Naphthalene	6 %	0.22 J	100	LTHA	0
Styrene	2 %	0.1 J	100	LTHA	0
1,2,3-Trichlorobenzene	4 %	0.18 J	40	LTHA	0
1,2,4-Trichlorobenzene	2 %	0.1 J	70	LTHA	0

* µg/L = micrograms per liter.

Data Sources: Kaiser-Hill 1998, 1999c, 1999b, 2000b, 2000c, 2001a, 2001b, 2002a, 2002b.

Note: Each sample was analyzed for 64 organic compounds. The 9 compounds shown in this table were detected in at least one sample. The remaining 55 organic compounds were not detected in all 50 samples collected. In this tabulation, J-qualified results were considered valid measurements. B-qualified results were not considered valid detections, since the contaminant was also detected in blank samples analyzed by the laboratory.

Abbreviations for CVs (see Appendix D):

CREG = ATSDR Cancer Risk Evaluation Guide
LTHA = EPA Lifetime Health Advisory for Drinking Water
EMEG = ATSDR Environmental Media Evaluation Guide, chronic children's exposure

Table 5. Inorganic Analytes Detected Above Comparison Values in Boundary Monitoring Wells (1998–2002)

Contaminant	Frequency of Detection (%)	Maximum Concentration (µg/L*)	Health-Based Comparison Value (CV) (µg/L)	CV Source	Number of Concentrations Greater Than CV (% of samples above)
Arsenic	23%	3.49 B	0.02	CREG	8 (23%)
Chromium	91%	59.1	30	RMEG-c	7 (20%)
Manganese	97%	1,570	500	RMEG-c	11 (31%)
Nickel	95%	394 B	100	LTHA	8 (23%)
Sodium	100%	420,390	20,000	EPA DWA	35 (100%)
Sulfate	100%	830	250	Secondary MCL	15 (33%)
Thallium	14%	2.2 B	0.5	LTHA	3 (9%)
Uranium (Total)	63%	72.6 B	30	MCL	3 (9%)

* µg/L = micrograms/liter.

Data Sources: Kaiser-Hill 1998, 1999c, 1999b, 2000b, 2000c, 2001a, 2001b, 2002a, 2002b.

Notes: Each sample was analyzed for 31 inorganic analytes. The 8 compounds shown in this table were detected above comparison value in at least one sample. The remaining 23 inorganic compounds were not detected above CV in any of the 35 samples collected. The laboratory that analyzed these samples used a B qualifier to denote results that were detected at levels less than the contract required detection limit. These results are considered valid detections in this summary table.

The detection limits for arsenic and thallium are both greater than the lowest comparison value. Therefore, ATSDR cannot state definitively how many samples actually had contamination levels greater than comparison values. The number of concentrations greater than the comparison values is equal to the number of samples in which arsenic or thallium was detected. None of the arsenic concentrations and only one of the thallium concentrations was greater than EPA's corresponding Maximum Contaminant Levels.

Abbreviations for CVs (see Appendix D):

CREG = ATSDR Cancer Risk Evaluation Guide
RMEG = ATSDR Reference Dose Media Evaluation Guide (for children's exposure)
LTHA = EPA Lifetime Health Advisory for Drinking Water
EPA DWA = EPA Drinking Water Advisory
Secondary MCL = EPA Secondary Maximum Contaminant Level for drinking water
MCL = EPA Maximum Contaminant Level for drinking water

Table 6. Maximum Concentrations of Radionuclides in Boundary Monitoring Wells (1998–2002)

Contaminant	Frequency of Detection (%)	Maximum Concentration (pCi/L*)	Health-Based Comparison Value (CV) (pCi/L)	CV Source	Number of Concentrations Greater Than CV
Americium-241	46%	0.062 (±0.0043)	20	NRC	0
Plutonium-239/240	28%	0.035127 (±0.010576)	20	NRC	0
Strontium-90	29%	0.43 J (±0.25)	500	NRC	0
Tritium	23%	504.7 (±268.9)	20,000	MCL	0
Uranium-233/234	100%	40.5 (±6.4)	300	NRC	0
Uranium-235	73%	1.84 (±0.39)	300	NRC	0
Uranium-238	98%	29.6 (±5.72)	300	NRC	0

* pCi/L = picocuries per liter.

Data Sources: Kaiser-Hill 1998, 1999c, 1999b, 2000b, 2000c, 2001a, 2001b, 2002a, 2002b.

Note: Each sample was analyzed for seven radionuclides. The laboratory that analyzed these samples used a J qualifier to denote results that were estimated quantities. These results are considered valid detections in this summary table.

Abbreviations for CVs are (see Appendix D):

NRC = These values are taken from the Nuclear Regulatory Commission's table of annual intake levels found in 10 CFR 20, Appendix B. The concentrations shown are those that would produce a total effective dose equivalent of 50 millirem if someone drank water from this source and only this source, for an entire year.
MCL = EPA Maximum Contaminant Level for drinking water

Table 7. Radioactive Contamination in the Westminster Drinking Water Supply (1970–1989)

Contaminant	Maximum Concentration (pCi/L*)	Year in which Maximum Concentration Occurred	Health-based Comparison Value (pCi/L)	CV Source
Gross alpha	7	1986	15	MCL
Gross beta	20	1991	50	EPA SL
Americium-241	0.066	1989	20	NRC
Plutonium-238	0.62	1973	20	NRC
Plutonium-239/240	0.75	1972	20	NRC
Tritium	3,450	1975	20,000	MCL
Uranium (natural)	29.15	1974	300	NRC
Uranium-234	1.9	1987	300	NRC
Uranium-238	0.42	1991	300	NRC

*. **pCi/L = picocuries per liter.**

Data sources: ChemRisk 1994d; CDH 1970–1971.

Note: The number of samples analyzed varies by contaminant; for reference, between 100 and 280 samples were analyzed for the different radionuclides over the 1970–1989 time frame.

Abbreviations for CVs are (see Appendix D):

MCL = EPA Maximum Contaminant Level for drinking water
EPA SL = EPA screening level for beta-emitting radionuclides. Drinking water concentrations containing 50 pCi/L of gross beta require testing of individual isotope levels.
NRC = These values are taken from the Nuclear Regulatory Commission's table of annual intake levels found in 10 CFR 20, Appendix B. The concentrations shown are those that would produce a total effective dose equivalent of 50 millirem if someone drank water from this source and only this source, for an entire year.

Table 8. Radioactive Contamination in the Broomfield Drinking Water Supply (1970–1989)

Contaminant	Maximum Concentration (pCi/L*)	Year in which Maximum Concentration Occurred	Health-Based Comparison Value (pCi/L)	CV Source
Gross alpha	71.8	1974	15	MCL
Gross beta	72	1986	50	EPA SL
Americium-241	0.1	1983	20	NRC
Plutonium-238	0.16	1974	20	NRC
Plutonium-239/240	4.52	1973	20	NRC
Tritium	23,293	1973	20,000	MCL
Uranium (natural)	346.4	1976	300	NRC
Uranium-234	3	1983	300	NRC
Uranium-238	0.59	1990	300	NRC

*. **pCi/L = picocuries per liter**

Data sources: ChemRisk 1994d; CDH 1970–1971.

Note: The number of samples analyzed varies by contaminant; for reference, between 253 and 854 samples were analyzed for the different radionuclides over the 1970–1989 time frame.

Abbreviations for CVs are (see Appendix D):

MCL = EPA Maximum Contaminant Level for drinking water
EPA SL = EPA screening level for beta-emitting radionuclides. Drinking water concentrations containing 50 pCi/L of gross beta require testing of individual isotope levels.
NRC = These values are taken from the Nuclear Regulatory Commission's table of annual intake levels found in 10 CFR 20, Appendix B. The concentrations shown are those that would produce a total effective dose equivalent of 50 millirem if someone drank water from this source and only this source, for an entire year.

Table 9. Maximum Concentrations of Contaminants Detected in Standley Lake Fish

Contaminant	Maximum Concentration (µg/g*), on a wet-weight basis)	Species in which Maximum Was Observed	Health-based Comparison Value (µg/g)	CV Source
Metals				
Cadmium	0.48	Rainbow trout	1.4	RBC-n
Mercury	0.21	Smallmouth bass	0.14	RBC-n
Selenium	0.02	Smallmouth bass	6.8	RBC-n
Organic Chemicals				
DDT	0.03	Channel catfish	0.0093	RBC-c
DDE	0.02	Channel catfish	0.0093	RBC-c
DDD	0.02	Channel catfish	0.013	RBC-c
Malathion	0.04	Smallmouth bass	27	RBC-n

* µg/g = micrograms per gram.

Data Source: CDPHE 1990 (Standley Lake Fish Toxics Monitoring Report).

Notes: Samples were also analyzed for plutonium-239/240, cesium-137, total uranium, beryllium, chromium, lead and nickel. None of these analytes were detected in the samples.

Abbreviations for CVs are (see Appendix D):

RBC-n = Risk Based Concentration (for noncancer endpoints)
RBC-c = Risk Based Concentration (for cancer endpoints)
The mercury comparison value is based on exposure to methylmercury.

Table 10. Estimated Ambient-Air Concentrations of Plutonium Resulting from Unplanned Releases

Event	Maximum Ambient Air Concentration of Plutonium	Location of Maximum Air Quality Impact	Notes
1957 Fire	< 0.005 pCi-y/m^3* (This cumulative exposure concentration corresponds to a 9-hour average plutonium concentration of 4.9 pCi/m^3.)	The maximum impacts were predicted to occur at locations roughly 1 mile southeast of Rocky Flats Plant.	The modeling analysis examined air quality impacts for a 9-hour period (10:00 PM on September 11, 1957, to 7:00 AM on September 12, 1957). Fire-related exposures outside of this time frame were negligible.
1969 Fire	0.67 pCi/m^3 † (This is the highest 15-minute average concentration predicted to occur during the fire.)	The maximum impacts were predicted to occur at the west entrance to Rocky Flats Plant.	The modeling analysis examined air quality impacts for a 15-hour period (2:00 PM on May 11, 1969, to 5:00 AM on May 12, 1969). Fire-related exposures outside of this time frame were negligible.
903 Pad Area	< 0.005 pCi-y/m^3 (This cumulative exposure concentration reflects all emissions that occurred from the 903 Pad Area between 1964 and 1969.)	The maximum impacts were predicted to occur immediately east of the Rocky Flats Plant, along Indiana Street.	The modeling analysis examined air quality impacts that occurred between 1964 and 1969. Emissions from 6 high-wind days accounted for more than 90% of the total releases.

* pCi-y/m^3 = picocurie-years per cubic meter.
† pCi/m^3 = picocuries per cubic meter.

Data source: Radiological Assessments Corporation. 1999.

Note: The dose reconstruction study uses different conventions when reporting the maximum ambient-air concentrations of plutonium. *Cumulative exposure concentrations* (in units of concentration x year) at the 50th percentile are reported for the 1957 fire and releases from the 903 Pad Area and the *highest 15-minute average ambient-air concentration* at the 95th percentile is reported for the 1969 fire.

Table 11. Highest Ambient Air Concentrations of Radionuclides at Perimeter Monitoring Locations (1989–Present)

Analyte	Highest Long-term-average Ambient-Air Concentration	Location and Year of Maximum Concentration	Health-based Comparison Value
Americium-241	0.000011 pCi/m^{3*} (quarterly average)	Eastern boundary of RFETS, 4th quarter of 2001	0.0019 pCi/m^3
Plutonium-239/240	0.000017 pCi/m^3 (annual average)	Eastern boundary of RFETS, 1990	0.002 pCi/m^3
Uranium-233/234	0.000599 pCi/m^3 (quarterly average)	Western boundary of RFETS, 3rd quarter of 1999	0.0071 pCi/m^3
Uranium-235	0.000034 pCi/m^3 (quarterly average)	Eastern boundary of RFETS, 3rd quarter of 1999	0.0071 pCi/m^3
Uranium-238	0.000585 pCi/m^3 (quarterly average)	Western boundary of RFETS, 3rd quarter of 1999	0.0083 pCi/m^3

*pCi/m^3 = **picocuries per cubic meter.**

Data source: DOE site environmental monitoring reports (1989–1994); DOE Actinide Migration report (includes sampling data from 1997–1999); DOE environmental surveillance (2000–2002); and CDPHE environmental monitoring reports (1999–2002).

Notes: The data sources use different conventions to report ambient-air concentrations. Some reports indicate quarterly average concentrations and others report annual average concentrations. This table presents the highest off-site ambient-air concentration found in the data sources, regardless of the averaging time.

The time frames over which sampling occurred varied from one contaminant to the next. For instance, routine monitoring for plutonium-239/240 has occurred continuously since 1989. Although *ambient-air* monitoring for americium-241 and the uranium isotopes did not occur as frequently, *emissions* monitoring for these radionuclides has consistently shown that air releases from buildings at RFETS fall well within EPA's health-based National Emissions Standard for Hazardous Air Pollutants.

The table shows only the highest *detected* concentrations of radionuclides. Sampling results that reported non-detectable amounts of radionuclides were not considered in this summary, even though some of these samples had detection limits higher than the maximum concentrations shown.

The health-based comparison values shown in this table are "Concentration Levels for Environmental Compliance with the National Emission Standards for Hazardous Air Pollutants (NESHAP)" (40 CFR 61, Appendix E, Table 2). Inhalation exposure to these contamination levels would lead to an increased annual effective dose equivalent of 10 millirem.

Appendix C. ATSDR Glossary of Environmental Health Terms

The Agency for Toxic Substances and Disease Registry (ATSDR) is a federal public health agency with headquarters in Atlanta, Georgia and 10 regional offices in the United States. ATSDR's mission is to serve the public by using the best science, taking responsive public health actions and providing trusted health information to prevent harmful exposures and diseases related to toxic substances. ATSDR is not a regulatory agency, unlike the U.S. Environmental Protection Agency (EPA), which is the federal agency that develops and enforces environmental laws to protect the environment and human health.

This glossary defines words used by ATSDR in communications with the public. It is not a complete dictionary of environmental health terms. If you have questions or comments, call ATSDR's toll-free telephone number, 1-888-42-ATSDR (1-888-422-8737).

Acute
Occurring over a short time [compare with **chronic**].

Acute exposure
Contact with a substance that occurs once or for only a short time (up to 14 days) [compare with **intermediate duration exposure** and **chronic exposure]**.

Adverse health effect
A change in body function or cell structure that might lead to disease or health problems.

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

Analyte
A substance measured in the laboratory. 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.

Background level
An average or expected amount of a substance or radioactive material in a specific environment, or typical amounts of substances that occur naturally in an environment.

Biota
Plants and animals in an environment. Some of these plants and animals might be sources of food, clothing, or medicines for people.

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

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

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

CERCLA [see **Comprehensive Environmental Response, Compensation and Liability Act of 1980**]

Chronic
Occurring over a long time (more than 1 year) [compare with **acute**].

Comparison value (CV)
Calculated concentration of a substance in air, water, food, or soil that is unlikely to cause harmful (adverse) health effects in exposed people. The CV is used as a screening level during the public health assessment process. Substances found in amounts greater than their CVs might be selected for further evaluation in the public health assessment process.

Completed exposure pathway [see **exposure pathway**].

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. ATSDR, which was created by CERCLA, is responsible for assessing health issues and supporting public health activities related to hazardous waste sites or other environmental releases of hazardous substances.

Concentration
The amount of a substance present in a certain amount of soil, water, air, food, blood, hair, urine, breath, or any other media.

Contaminant
A substance that is either present in an environment where it does not belong or is present at levels that might cause harmful (adverse) health effects.

Curie
A measure of radioactive activity. A curie is the amount of a radioactive substance that will have 37,000,000,000 radioactive decays in one second. One gram of radium-226 is one curie.

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

Dermal contact
Contact with (touching) the skin [see **route of exposure**].

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

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

DOE
United States Department of Energy.

Dose (for chemicals that are not radioactive)
The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An "exposure dose" is how much of a substance is encountered in the environment. An "absorbed dose" is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.

Dose (for radioactive chemicals)
The radiation dose is the amount of energy from radiation that is actually absorbed by the body. This is not the same as measurements of the amount of radiation in the environment.

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

Environmental media and transport mechanism
Environmental media include water, air, soil and **biota** (plants and animals). Transport mechanisms move contaminants from the source to points where human exposure can occur. The **environmental media and transport mechanism** is the second part of an **exposure pathway**.

EPA
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 substance by swallowing, breathing, or touching the skin or eyes. Exposure may be short-term [**acute exposure**], of intermediate duration, or long-term [**chronic exposure**].

Exposure pathway
The route a substance takes from its source (where it began) to its end point (where it ends) and how people can come into contact with (or get exposed to) it. An exposure pathway has five parts: a **source of contamination** (such as an abandoned business); an **environmental media and transport mechanism** (such as movement through groundwater); a **point of exposure** (such as a private well); a **route of exposure** (eating, drinking, breathing, or touching) and a **receptor population** (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a **completed exposure pathway**.

Feasibility study
A study by EPA to determine the best way to clean up environmental contamination. A number of factors are considered, including health risk, costs and what methods will work well.

Groundwater
Water beneath the earth's surface in the spaces between soil particles and between rock surfaces [compare with **surface water**].

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

Hazardous waste
Potentially harmful substances that have been released or discarded into the environment.

Health consultation
A review of available information or collection of new data to respond to a specific health question or request for information about a potential environmental hazard. Health consultations are focused on a specific exposure issue. Health consultations are therefore more limited than a public health assessment, which reviews the exposure potential of each pathway and chemical [compare with **public health assessment**].

Indeterminate public health hazard
The category used in ATSDR's public health assessment documents when a professional judgment about the level of health hazard cannot be made because information critical to such a decision is lacking.

Incidence
The number of new cases of disease in a defined population over a specific time period [contrast with **prevalence**].

Ingestion
The act of swallowing something through eating, drinking, or mouthing objects. A hazardous substance can enter the body this way [see **route of exposure**].

Inhalation
The act of breathing. A hazardous substance can enter the body this way [see **route of exposure**].

Intermediate duration exposure
Contact with a substance that occurs for more than 14 days and less than a year [compare with **acute exposure** and **chronic exposure**].

mg/kg
Milligram per kilogram.

mg/m^3
Milligram per cubic meter; a measure of the concentration of a chemical in a known volume (a cubic meter) of air, soil, or water.

Migration
Moving from one location to another.

Mortality
Death. Usually the cause (a specific disease, condition, or injury) is stated.

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 Emission Standards for Hazardous Air Pollutants or NESHAPs
40 CFR Part 61
Subpart H - National Emission Standards for Emissions of Radionuclides Other Than Radon From Department of Energy Facilities Source: [54 FR 51695, Dec. 15, 1989] § 61.92 Standard.
Emissions of radionuclides to the ambient air from Department of Energy facilities shall not exceed those amounts that would cause any member of the public to receive in any year an effective dose equivalent of 10 mrem/yr.

No apparent public health hazard
A category used in ATSDR's public health assessments for sites where human exposure to contaminated media might be occurring, might have occurred in the past, or might occur in the future, but where the exposure is not expected to cause any harmful health effects.

No public health hazard
A category used in ATSDR's public health assessment documents for sites where people have never and will never come into contact with harmful amounts of site-related substances.

NPL [see **National Priorities List for Uncontrolled Hazardous Waste Sites]**

Plume
A volume of a substance that moves 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 a substance moving with groundwater.

Point of exposure
The place where someone can come into contact with a substance present in the environment [see **exposure pathway**].

Population
A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).

Prevalence
The number of existing disease cases in a defined population during a specific time period [contrast with **incidence**].

Public health action
A list of steps to protect public health.

Public health advisory
A statement made by ATSDR to EPA or a state regulatory agency that a release of hazardous substances poses an immediate threat to human health. The advisory includes recommended measures to reduce exposure and reduce the threat to human health.

Public health assessment (PHA)
An ATSDR document that examines hazardous substances, health outcomes and community concerns at a hazardous waste site to determine whether people could be harmed from coming into contact with those substances. The PHA also lists actions that need to be taken to protect public health [compare with **health consultation**].

Public health hazard
A category used in ATSDR's public health assessments for sites that pose a public health hazard because of long-term exposures (greater than 1 year) to sufficiently high levels of hazardous substances or **radionuclides** that could result in harmful health effects.

Public health hazard categories
Public health hazard categories are statements about whether people could be harmed by conditions present at the site in the past, present, or future. One or more hazard categories might be appropriate for each site. The five public health hazard categories are **no public health hazard, no apparent public health hazard**, **indeterminate public health hazard**, **public health hazard** and **urgent public health hazard**.

Radioisotope
An unstable or radioactive isotope (form) of an element that can change into another element by giving off radiation.

Radionuclide
Any radioactive isotope (form) of any element.

RCRA [See **Resource Conservation and Recovery Act (1976, 1984)**]

Registry
A systematic collection of information on persons exposed to a specific substance or having specific diseases [see **disease registry**].

Remedial Investigation
The CERCLA process of determining the type and extent of hazardous material contamination at a site.

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.

RFA
RCRA Facility Assessment. An assessment required by RCRA to identify potential and actual releases of hazardous chemicals.

Risk
The probability that something will cause injury or harm.

Route of exposure
The way people come into contact with a hazardous substance. Three routes of exposure are breathing [**inhalation**], eating or drinking [**ingestion**], or contact with the skin [**dermal contact**].

Safety factor
Mathematical adjustments for reasons of safety when knowledge is incomplete. For example, factors used in the calculation of doses that are not harmful (adverse) to people. These factors are applied to the lowest-observed-adverse-effect-level (LOAEL) or the no-observed-adverse-effect-level (NOAEL) to derive a minimal risk level (MRL). Uncertainty factors are used to account for variations in people's sensitivity, for

differences between animals and humans and for differences between a LOAEL and a NOAEL. Scientists use uncertainty factors when they have some, but not all, the information from animal or human studies to decide whether an exposure will cause harm to people [also sometimes called an uncertainty factor].

SARA [see **Superfund Amendments and Reauthorization Act**]

Sample
A portion or piece of a whole. A selected subset of a population or subset of whatever is being studied. For example, in a study of people the sample is a number of people chosen from a larger population [see **population**]. An environmental sample (for example, a small amount of soil or water) might be collected to measure contamination in the environment at a specific location.

Solvent
A liquid capable of dissolving or dispersing another substance (for example, acetone or mineral spirits).

Source of contamination
The place where a hazardous substance comes from, such as a landfill, waste pond, incinerator, storage tank, or drum. A source of contamination is the first part of an **exposure pathway**.

Statistics
A branch of mathematics that deals with collecting, reviewing, summarizing and interpreting data or information. Statistics are used to determine whether differences between study groups are meaningful.

Substance
A chemical.

Superfund Amendments and Reauthorization Act (SARA)
In 1986, SARA amended CERCLA and expanded the health-related responsibilities of ATSDR. CERCLA and SARA direct ATSDR to look into the health effects from substance exposures at hazardous waste sites and to perform activities including health education, health studies, surveillance, health consultations and toxicological profiles.

Surface water
Water on the surface of the earth, such as in lakes, rivers, streams, ponds and springs [compare with **groundwater**].

Survey
A systematic collection of information or data. A survey can be conducted to collect information from a group of people or from the environment. Surveys of a group of people can be conducted by telephone, by mail, or in person. Some surveys are done by interviewing a group of people.

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

Toxicological profile
An ATSDR document that examines, summarizes and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.

Urgent public health hazard
A category used in ATSDR's public health assessments for sites where short-term exposures (less than 1 year) to hazardous substances or conditions could result in harmful health effects that require rapid intervention.

Volatile organic compounds
Organic compounds evaporate readily into the air. VOCs include substances such as benzene, toluene, methylene chloride and methyl chloroform.

Other glossaries and dictionaries:
Environmental Protection Agency
http://www.epa.gov/OCEPAterms/

National Center for Environmental Health (CDC)
http://www.cdc.gov/nceh/dls/report/glossary.htm

National Library of Medicine
http://www.nlm.nih.gov/medlineplus/dictionaries.html

Appendix D. Comparison Values

Following are definitions of the various health-based comparison values that ATSDR used in this PHA to put the measured and modeled levels of environmental contamination into perspective:

CREG: **C**ancer **R**isk **E**valuation **G**uide, a highly conservative value that would be expected to cause no more than one excess cancer in a million persons exposed over time.

EMEG: **E**nvironmental **M**edia **E**valuation **G**uide, a media-specific comparison value that is used to select contaminants of concern. Levels below the EMEG are not expected to cause adverse non-carcinogenic health effects. These comparison values have been developed for acute exposure scenarios (EMEG-a), intermediate exposure scenarios (EMEG-i) and chronic exposure scenarios (EMEG-c).

LTHA: **L**ife**t**ime **H**ealth **A**dvisory for drinking water, a contaminant concentration that EPA has reported as being protective of public health for a lifetime (70 years) of exposure assuming a daily drinking water ingestion rate of 2 liters per day. Unlike primary MCLs (see below), LTHAs are not enforceable standards.

MCL: **M**aximum **C**ontaminant **L**evel, a health-based standard that applies to drinking water supplies. Primary standards (listed in this PHA simply as MCLs) help protect the public from being exposed to contaminants that can adversely affect their health; the primary standards are legally enforceable. Secondary standards (listed in this PHA as secondary MCLs) are not health-based, but rather protect against things people value other than their health, such as the taste, odor and other aesthetic qualities of drinking water.

MRL: **M**inimal **R**isk **L**evel, an ATSDR estimate of daily human exposure to a hazardous substance below which that substance is unlikely to pose a measurable risk of harmful, non-cancerous effects. MRLs are calculated for a route of exposure (inhalation or oral) over a specified time period (acute, intermediate, or chronic).

NAAQS: **N**ational **A**mbient **A**ir **Q**uality **S**tandard, an ambient-air concentration that EPA has established to identify areas with potentially unhealthy levels of air pollution. The standards are health-based and were designed to be protective of many sensitive populations, such as people with asthma and children. The standards have been developed only for a small subset of pollutants and the averaging time and statistical interpretations of the standards vary among the regulated pollutants.

NRC: ATSDR used several health-based comparison values developed by the **N**uclear **R**egulatory **C**ommission (NRC) to identify contaminants of concern for drinking water exposures. The NRC comparison values come from the agency's table of annual intake levels (see 10 CFR 20, Appendix B) that would produce a total effective dose equivalent of 50 millirem if one would drink water from a single source for an entire year.

RBC: **R**isk-**b**ased **C**oncentration, a contaminant concentration that is not expected to cause adverse health effects over long-term exposure. Scientists from EPA Region 3 drew from a variety of data sources to develop these RBCs for both cancer outcomes (RBC-c) and noncancer outcomes (RBC-n).

REL: **R**ecommended **E**xposure **L**evel, an air concentration that the National Institute for Occupational Safety and Health (NIOSH) recommends should not be exceeded. RELs are designed primarily for occupational settings and exposures. The RELs used in this PHA are all based on 8-hour time weighted average exposures.

RfC: **Ref**erence **C**oncentration, an ambient-air concentration developed by EPA that people, including sensitive subpopulations, can be exposed to continuously over a lifetime without developing adverse noncancer health effects. RfCs typically have uncertainty factors built into them to account for any perceived limitations in the data on which they are based.

RMEG: **R**eference Dose **M**edia **E**valuation **G**uide, the concentration of a contaminant in soil or water that corresponds to EPA's Reference Dose for that contaminant when default values for body weight and intake rates are taken into account. These have been developed for exposure scenarios specific to adults (RMEG-a) and children (RMEG-c).

Appendix E. Radiation and Radioactive Material

What is radioactivity?

Radioactivity is the spontaneous emission of radiation from the nucleus of an unstable atom. Atoms are the smallest units of an element that have the same properties as the element. All matter is made up of atoms, and atoms are made up of protons and neutrons (found in the nucleus of the atom) and electrons. The number of protons in an atom of a particular element is always the same, but the number of neutrons can vary. Whether an atom is unstable, or *radioactive*, is determined by the ratio of neutrons to protons. *Isotopes* are forms of the same element with different numbers of neutrons. The number of protons and neutrons in the atom are added to name the isotope. For example, an atom of cobalt that has 27 protons and 33 neutrons is called cobalt-60. Cobalt-60 is radioactive and is therefore called a radioisotope or a *radionuclide*.

Where does radioactivity come from?

All elements heavier than lead (which contains 82 protons) are naturally radioactive. Atoms, such as hydrogen-3 (tritium) and carbon-14, can also become radioactive through natural processes in the environment. Everyone is exposed to naturally occurring radiation from space and from radioactive materials in the ground. Humans can also create radioactive atoms of most elements. For example, humans create radioactive atoms to use as tracers to help measure the flow of materials in the environment. Radioactive material can travel through the air as particles or gases and can also enter soil, water, plants, and animals. The greatest dose from environmental radiation is from radon and its progeny. Radon is an alpha emitter that results from decaying radium-226, which comes from the radioactive decay of natural uranium-238.

What is radiation?

Radiation is the emission of waves or particles from an unstable atom undergoing a transformation to stabilize the number of protons compared to the number of neutrons in its nucleus. This transformation changes the radioactive atom into a stable atom. For example, a proton in a cobalt-60 atom might change into a neutron, emit radiation, and become a nickel-60 atom.

What radioactive materials were used at Rocky Flats Environmental Technology Site (RFETS)?

DOE used highly enriched uranium and plutonium at the RFETS, which is composed of three different radioisotopes: uranium-234, uranium-235, and uranium-238. Plutonium used on site was mostly plutonium-239 with some plutonium-241. Plutonium-241 decays to americium-241(ATSDR, 1999).

What are alpha particles, beta particles, and gamma radiation?

Alpha particles can be emitted by atoms that are more massive than lead, such as radium. Alpha particles are comprised of two protons and two neutrons and have a large charge, which can pull electrons off neighboring atoms (or cause them to ionize). Alpha particles cannot penetrate the skin, but can be taken into the human body if they are contained in the air people breathe, or the food or drink people consume. If they enter the human body, alpha particles can be absorbed in the blood, incorporated into molecules in the body, and deposited in living tissue.

Beta particles are electrons that result from a neutron changing into a proton. Some beta particles have very little energy and cannot pass through the dead outer layer of a person's skin, but most can do so and expose the living tissue underneath the outer layer of skin to radiation. Beta particles cannot travel all the way through the human body, however. Exposure to beta radiation can also result from inhaling air or ingesting food or liquids containing radioactive elements that give off beta particles.

Gamma rays result from the release of excess energy when an atom gives off an alpha or beta particle. Gamma rays consist of moving energy and have no mass or charge. They can travel long distances and move through the air, body tissue, or other materials. A gamma ray can pass through the body without hitting anything inside of it, or it can hit atoms in its path and cause them to ionize. Gamma rays are the primary type of radiation that can harm people when they are exposed to it externally.

Source: ATSDR. 1999. Agency for Toxic Substances and Disease Registry. Toxicological profile for Ionizing Radiation. September 1999.

Appendix F. Public Comments

#	Comment	Agency Response
1	The Public Health Assessment for RFETS uses several units of radioactivity (µBq, mBq, GBq, and pCi) and these are used alone or per g, per L, or per m3. Some definitions and conversions should be supplied somewhere such as the glossary. It would be desirable to use either the modern SI units or the traditional English units throughout, or to give quantities in both sets of units.	Converted all units to Curies.
2	pp vii-viii Bq , µBq, and GBq should be added (See, e.g., Table 3; p. 70 uses µBq/L; p. 71 has mBq)	Changed all units to traditional Curies
3	P.1 :This evaluation depends on a recently completed dose reconstruction study". Now that buildings are decommissioned with a great deal of contamination left in the walls and basements underground, how do you know what people will be exposed to when burrowing animals or rains will bring up contaminants?	The walls and building foundations, that are buried, have fixed contamination which is not removable.
4	P1. The PHA states that people have been exposed to "trace amounts" of contaminants. This sounds like radioisotopes used for analyses. Reading rad release data from the 1957 fire at RF shows otherwise. P.3 examines past contaminant exposure. If CERCLA mandates a PHA health assessment, this study needs to address future hazards.	Release quantities are from the point of release and are not what people would be exposed to. The contaminant concentrations at a receptor point would have been many orders of magnitude lower than at the release point, due to atmospheric dispersion.
5	Section A.3. last paragraph on page 8: Remediation activities include pumping ground water encountered during excavation and sending it to a site water treatment plant but there are no pump and treat systems. Action levels established for remediation activities are based on risk to a Wildlife Refuge Worker (WRW), or risk to ecological receptors.	Changed text as suggested.
6	Section A, page 4: EG&G was the contractor at Rocky Flats from 1990-1995. Kaiser-Hill has been the contractor from 1995-present.	Changed text as suggested.
7	Page 4. Tritium was not used in bomb manufacture. It was part of materials to be reprocessed for Pu.	Tritium does not contain plutonium. Tritium was used in the fabrication of triggers.

#	Comment	Agency Response
8	Page 4. Access. There is no evaluation for trespassing on the site. If, as planned, there will be a DOE maintained part for the most contaminated section of the site which is surrounded by the wildlife refuge, then trespassing must be addressed.	The site was evaluated as a wildlife refuge with possible hunting.
9	Is this PHA attempting to establish what the present situation is, or, as it should, determine what the problems will be after closure in 2005 or 2006? Also, if the Health Advisory Panel's findings on page 8 are the basis of this study, you are completely out of date. P8. You state that the "Mission is possible economic development of the site". The Rocky Flats National Wildlife Refuge Act of 2001 precludes this. On the same page "The waste sites are...cleaned to either commercial or industrial standards for land use". Be advised that no way could any industrial or commercial establishment get away with leaving this amount of contamination on a site.	Wording has been revised to state that ATSDR evaluated current conditions and future use as a wildlife refuge.
10	Footnote 2 on page 8: There is no further mission at Rocky Flats. All buildings, including water treatment facilities, are to be demolished. In fact, the wastewater treatment plant is slated for demolition this fall.	Changed footnote as suggested.
11	Section C, page 9, first bullet, first paragraph: The Site property was approximately 2500 acres in size until the mid-1970s (and not one square mile as stated in the draft document), of which the Industrial Area occupied approximately 400 acres. Additional property acquisitions increased the size of the federal property to over 6500 acres.	Corrected.
12	p 10 paragraph beginning “Figure 4…”, line 9: change “radiation levels” to “radioactive material concentrations”. Strictly speaking, it is amounts of radioactive materials in pCi/g that are of concern, not radiation levels in microrems per hour (µrem/hour), that are of concern.	Changed “radiation levels” to “radioactive material concentrations”, as suggested.
13	Section C, page 10, first bullet, second paragraph: There will be no future industrial uses on the Rocky Flats property. The center of the site will be retained by DOE to manage the remedy, and the remainder will be transferred to US Fish and Wildlife Service to become the Rocky Flats National Wildlife Refuge.	Changed to suggested wording.

#	Comment	Agency Response
14	P10. Possible Jefferson County land uses adjacent to RF. Please look into the adjacent large Vauxmont development which will comprise both residential and office space.	This type use is already covered.
15	Section D.2, page 12, first bullet: It is important to note that the shallow upper hydrostatic unit present in the Industrial Area daylights on the slopes of the incised valleys of Walnut and Woman Creeks. Any contaminated groundwater in this unit then becomes a potential surface water problem. Ground water also flows in the weathered claystone at a much slower rate but still must be considered for contaminant transport on site. The Lower Hydrostratigraphic Unit is omitted in this discussion of the site hydrogeology, however it is an important factor in the protection from contaminant migration off site.	Added clarification to first paragraph, using suggested wording. The footnote states that the upper and lower hydrostratigraphic units are considered one.
16	Page 12, footnote 3: The reference cited, CDPHE 2000b, is not listed in the reference section of this document. The understanding of the alluvial and weathered bedrock hydraulic connection is not recent. The most complete discussion of site hydrogeology is not listed as a reference to this report, the April 1995 "Hydrogeologic Characterization Report for the Rocky Flats Environmental Technology Site" by EG&G, Rocky Flats.	References have been revised.
17	P12. DOE publicly stated in the past that the groundwater under RF is one of the most contaminated of all of its sites. You state that there are 15 wells located 2 miles of the boundary. In this case it behooves this PHA to do a proper review of the planned groundwater monitoring after closure. Irrigation water, if contaminated, can be a source of air dispersion of radioactive pollutants.	ATSDR has reviewed the groundwater monitoring plan, and is satisfied with the stipulations of the RODs.
18	Page 12, last paragraph: Attached to these comments is a CDPHE memo provided to DOE, Kaiser Hill and EPA documenting an analysis of the hydrogeologic conditions of the off site private wells and evaluating the need to sample the offsite wells. It does not consider volatile organics because of the lack of a continuous hydrogeologic pathway from RFETS plumes, which are reasonably well defined.	No changes made.

#	Comment	Agency Response
19	The entire hydrology changed with the demolition of the buildings and roads. Surface water runoff patterns will change. Many miles of contaminated process waste lines, walls and tunnels, and two unlined dumps (each about 20 Acres, 40' deep) are left on the site. These contain rads, beryllium, asbestos & VOC-s. We do not know how many groundwater monitoring wells will be left.	The underlying hydrology has not been changed by the surficial grading and fill.
20	A passage on p. 13 refers to discharges from the industrial area since 1941; the facility began operation in 1952.	Changed 1941 to 1952.
21	Section D.3, page 13, second paragraph: The paragraph, as written, is confusing and has one incomplete sentence. The four drainages that cross the Rocky Flats property are Rock Creek, North Walnut Creek, South Walnut Creek, and Woman Creek. These streams are tributaries of Big Dry Creek. Waters coming from the Industrial Area feed into North and South Walnut Creeks and Woman Creek, but not Rock Creek.	Corrected incomplete sentences and attempted to make wording more clear.
22	On page 14 the PHA again states that the site will not be accessible to the public. Please update yourself on the FWS plans for the site.	Removed all mention of *inaccessible to the public* on pages 13, 14.
23	p.15: The Woman Creek Reservoir discussed in the second full paragraph is not shown (or at least not labeled) on Figure 6 or any of the Figures.	Replaced Figure 6 with more detailed map.
24	P15 "Hunting... .does not appear very likely". It is part of the FWS preferred alternative in their CCP.	The text states that *due to the encroachment of development, it does not appear to be likely.*
25	p. 15, p. 22: The report should address the extent to which large game (deer, elk), waterfowl, raptors and other birds, rabbits, foxes, coyotes, and even fish, etc. can go on and off site. To what extent is it possible for an animal to live on the RFETS site, and then move to public lands where it might be "harvested?" This is a potential exposure pathway that, although examined somewhat on pp.34-35, pp.44-45, & p.67, isn't clearly followed through for the future. Will fences be maintained around the buffer zone to prevent game migration?	On page 15 added: "It is clear that no hunting occurs on RFETS property currently, but this may change in the future. The site boundary does not prevent movement of most wildlife." On page 22 added: "The area also includes dairy farms and areas where residents might hunt deer and other game that have foraged on-site."
26	Section E, page 16, second paragraph: The paragraph starting with "In 1987" should be indented with a bullet in accord with the following bulleted items.	Changes made as suggested.

#	Comment	Agency Response
27	ATSDR assumes no future consumption of locally grown food at Rocky Flats (p. 16). However, two previous scientific studies have acknowledged that this assumption is not scientifically defensible.	ATSDR is not familiar with the studies you mention.
28	P 16&17. Please provide information on the ATSDR meetings with citizens in 2002. Very few, if any, people attend the Rocky Flats Citizens Advisory Board (RFCAB) meetings. I have been a member of this board and did not meet any ATSDR representatives. I have spoken to previous board members who were also unable to recall any such meeting. If ATSDR is planning to evaluate public health implications of potential exposure it needs to take into consideration the present and future configuration and planned use of this site, not the past.	Michael Brooks, CHP (Senior Health Physicist) and Glenn Tucker (Senior Regional Rep.) of ATSDR attended August 2002 RFCAB meeting at the Jefferson Co. Airport and in September 2004 at the Community College in Westminster.
29	The direct external irradiation pathway is not mentioned, and it should be included for completeness. (Direct irradiation is an exposure pathway unique to radioactive materials and radiation-generating machines. There is no analog for chemicals.) Given the radionuclides at RFETS, namely U, Pu, Am, [90Sr?], and 3H, one does not expect any significant external irradiation to occur. However, persons not familiar with irradiation scenarios may wonder whether radiation emitted from radioactive materials on-site reaches off-site receptors.	On page 22 added: "*Direct irradiation* is an exposure pathway unique to radioactive materials and radiation-generating machines. There is no analog for chemicals. Given the radionuclides at RFETS, namely uranium, plutonium, americium, and tritium, one does not expect any significant external irradiation to occur. uranium, plutonium, and americium emit very weak gamma radiation that would not reach off-site receptors; therefore ATSDR classifies Direct Radiation as an **incomplete exposure pathway**."
30	P 22-23. Assessment methodology. Why does this risk based assessment state "When contaminant levels are greater.. .adverse effects will not necessarily occur?"	Screening values are concentrations below which we are certain that there are no adverse effects. Above screening values, site specific exposure evaluations are necessary to determine at what level people are actually exposed. Screening values allow ATSDR to triage the massive databases of environmental data.

#	Comment	Agency Response
31	The essence of ATSDR's approach is its method of "comparing the environmental concentrations of site-related contaminants to health-based comparison values, which are derived from the scientific literature concerning exposure and health effects" (p. 23). This quote sounds like a reasonable statement, but it expresses a bias and introduces untruth into ATSDR's purportedly scientific process: "Most of the comparison values used have large "uncertainty" factors built into them so that...environmental concentrations of a contaminant that are lower than their corresponding comparison values are generally considered to be safe and not expected to cause harmful health effects." Unfortunately, that is a total misrepresentation of the truth. (p. 23)	Disagree.
32	The ATSDR report never addresses the topic of synergistic effects of exposure to several contaminants, though a member of the public asked that they do so (p. 24).	Added to Section C. Evaluation of Off-Site Contamination, discussing synergistic effects.
33	Page 25, Last Paragraph, Lines 2 and 3: "Section V.B" should read "Section V.C".	Corrected to read V.C
34	Page 25 The PHA is relying on 5 yr. old data from the HAP for a site which had major changes since that time. Some exposure pathways closed and others opened. "Data were reviewed to ensure that site conditions have not changed." They did change.	ATSDR has updated much of the data it reviewed to 2004 datasets.
35	Page 26, first bullet: Six (not five) environmental media types are listed in this section.	Corrected to read: *Within the summaries of on-site and off-site contamination levels, the data are organized into five environmental media: soil; groundwater; surface water, sediment and aquatic biota; air and terrestrial biota.*

#	Comment	Agency Response
36	Page 26B. Review of on site contamination. This paragraph is based on the wrong premise. On reviewing action levels this PHA is unaware of underground contamination in excess of the action levels. For instance while rad action levels are at 50 pCi/g of soil down to the 3' level, they are 7000 pCi/g between 3'--6', and there are no limits under 6'. As mentioned before, walls of contaminated concrete buildings will have as much as a billion times the soil action levels. PHA explanation of why there is no surface water problem omits the presence of suspended colloidal particles. It is known that colloidal PU02 is dispersed in water. Then you repeat that residents cannot access RFETS property, without consideration of the refuge bill.	Contamination in concrete structures is what is called “Fixed Contamination”, because it is not mobile.
37	Page 27, 1. On-site Soil, Paragraph 4, Line 1: When referring to "903 Pad Area," the OU within which it is located should be noted, especially when first introduced.	Noted that it was part of the Industrial Area OU.
38	Section B.2, page 28: The third bullet discussing the East Trenches plume omits the passive ground water collection trench and zero valent iron treatment system constructed in 1999. The fourth bullet should reference the OUI CAD/ROD.	Added suggested language. (EPA 1997a)
39	Section B.2, page 29: The fourth bullet on this page should include the Mound Plume Treatment System, the prototype of the East Trenches system completed in July 1998.	Added suggested language.
40	Section B.2, page 29: The last bullet pertains to a Present Landfill Pond groundwater plume. The Present Landfill does not produce a groundwater plume. The landfill does produce some leachate, which discharges into the pond at the toe of the landfill. Distal groundwater from the Property Utilization and Disposal Yard plume may be diverted around the Present Landfill through a groundwater interception system that has been installed around the perimeter of the landfill. As a precaution, the interception system piping will be connected to the leachate treatment system as part of the landfill closure. Downgradient concentrations of metals are within the range of background, the uranium isotopes	Added: “*The Present Landfill does not produce a groundwater plume. The landfill does produce some leachate, which discharges into the pond at the toe of the landfill.”*

#	Comment	Agency Response
	have been analyzed by a high resolution ICP/MS method and shown to have a natural signature.	
41	P32. Again assumptions are based on site access restrictions. Despite the presence of uranium and americium in deer from RF, FWS plans to allow hunting on the site. Recently deer from the site has been analyzed and found to contain U and Am. FWS will not release the data, but states that it is minimal. Should RF deer be hunted for food? Regarding the off site impacts from RF, the changed topography, due to the removal of roads and buildings, a new independent survey of the site needs to be done previous to the final Record of Decision.	All wildlife worldwide have uranium in their bodies. Uranium is a natural trace element found in food worldwide. The presence of uranium and americium in deer; does not mean there is a health risk associated.
42	P34. You state that RF does not provide information on foods grown in the area. DOE has repeatedly been asked to analyze the flora in the site for rad uptake. This is important as FWS plan to burn the prairie to rid it of invasive species. Despite repeated DOE assertions that "Pu does not travel", several EPA financed studies show plant uptake of Pu and Am in carefully monitored studies. Going back to 1979 there are numerous studies of this. EP A Ecological Research Series, March 1979 published by Kenneth W. Brown, Monitoring Systems Research and Development Division, Environmental Monitoring and Support Laboratory, Las Vegas, Nevada proved Pu-239 and Am-241 uptake in plants from soil. There are numerous references to similar studies. The PHA relies on one DOE financed study which shows minimal uptake. Did anyone do a literature survey of this topic or were only DOE documents considered? Thatch, if it contains radioactive compounds, will release them to the air when burned. Dispersed radioisotopes in the air pose a major health risk.	The document is referring to foods grown for human consumption. There does not appear to be significant produce grown for human consumption, in the area.
43	ATSDR refers to a 1992 analysis that found small deposits of plutonium in the bodies of seven deer from Rocky Flats, which were examined (p. 35). Genetic specialist Dietard Tautz articulates a “genetic uncertainty principle” according to which genetic harm to animals with very low-dose radiation exposures may not show up until the	Environmental risk to wildlife is the purview of the EPA and US Fish and Wildlife. ATSDR was established to look at human health and only makes recommendations for the protection of human health.

#	Comment	Agency Response
	passage of several generations, by which time nothing can be done to correct the problem (Tautz).	
44	The plutonium concentrations given on p. 36, line 11, and p. 56, line 28 are not the same, probably due to a typo.	Corrected. Was caused by not truncating to two significant digits.
45	The number of significant figures should be consistent with the uncertainties in the data, and should not be excessive. For example, on Page 36, line 11, the concentrations for plutonium 239/240 are given to four significant figures, while those for americium-241 are given to only two significant figures. Rounding to two significant figures should be adequate and will facilitate reading.	Rounded to two significant digits as recommended.
46	The discussion of the off-site exposure pathways and exposure should consider plutonium in soil from fallout from atmospheric weapons testing, and how much this source may have contributed to the admittedly low exposure vis-à-vis the releases from the site.	Already discussed on page 36 in the 3rd bulleted paragraph.
47	ATSDR refers to soil sampling done by DOE along the property line in which the highest deposits of plutonium it found measured 10 picoCuries per gram in the top two inches of soil (p. 36). Not only is there no documentation provided, sampling from the top two inches is not a surface sample. ATSDR fails to point out that the DOE does not report the concentration in the top one centimeter – that is, in soil that is likely to be resuspended by wind, and it is considerable.	The top two inches of soil is defined as a surface soil sample in EPA methods.
48	ATSDR cites an EPA assertion that at a distance of 2 to 3 miles east of the site boundary plutonium and americium concentrations return to background (p 36). This is not true.	The data ATSDR has reviewed confirms EPA's assertion.
49	The available data, while limited and incomplete, are clearly sufficient to provide reasonable estimates of potential doses and health hazards. However, some indication of the reliability (i.e. uncertainty) of the data would be welcome, particularly where estimates are made as in the first bullet item on page 38.	Including uncertainty data would have made tables difficult to read, as the font size would have to be reduced further to fit on the page.

#	Comment	Agency Response
50	ATSDR says that the CDPHE Rocky Flats Dose Reconstruction Project study concluded that routine plutonium releases from Rocky Flats were “essentially comparable” to background deposits of plutonium in the Denver area from atmospheric testing of bombs (p. 47). Adding the quantity from routine releases to that from bomb tests thus roughly doubles the amount of plutonium to which Denver-area residents are exposed. This is inaccurate as these amounts are very small, however it doesn’t mean they are inconsequential.	Disagree.
51	Some indication of the presence of other isotopes of plutonium (e.g. 238, 241) and an evaluation of isotopic ratios to determine the contribution from weapons test fallout plutonium might have also been included.	Isotopic breakdown was not available for all samples and therefore not possible.
52	ATSDR makes no reference to Gregg S. Wilkinson’s 1987 study of Rocky Flats workers exposed to plutonium.	Although ATSDR is familiar with Wilkinson’s study, off-site exposures to plutonium were not at the same levels as workers. Therefore, it was not appropriate to reference Wilkinson’s work. Worker health is the responsibility of NIOSH.
53	Cancer is NOT the only health affect, and plutonium is NOT the only contaminant of concern at or around Rocky Flats.	ATSDR agrees.
54	As an alternative to expressing concentrations or other values as "so many times lower than the corresponding health based comparison values" (cf, for example p. 51, line 19), consideration might be given expressing them as a percentage or even fraction (e.g. "less than 1 percent of the corresponding health based comparison values' in the example cited). This not only might be better understood by the nonscientist readers, but is also more correct. The term "so many times lower" is ambiguous, and technically incorrect.	Disagree. We believe that “X times lower” is an easier to understand concept than percentage.
55	Page 57, Section 2, second paragraph: The text should read: ".. .less than 2 miles off the eastern RFETS property line.. ..."	Changed to: *less than 2 miles beyond the eastern RFETS property line*
56	Page 58, Paragraph 4, Line 10: "...RFETS property line and that provides." ends in an incomplete statement.	Added: “…provides drinking water.”

#	Comment	Agency Response
57	Section C.2, page 58: As stated in CDPHE Comment Number 6, the shallow groundwater in the center of the Site daylights to surface water onsite and does not reach the eastern boundary of .Rocky Flats. In 1986 CDPHE did sample for VOC's at 5 private groundwater wells located east and south of Rocky Flats. The data are not public information at the request of the well owners, although no contaminants were detected. This study was briefly mentioned in the ChemRisk Task 6 report, response # 25 to questions from the May 26, 1993 Public Meeting. Groundwater monitoring at Rocky Flats down gradient of existing contaminant plumes, as well as on Walnut and Woman Creeks at the Site boundary, will continue to be maintained and sampled after Site closure. We would recommend an evaluation of the data quality information associated with the sporadic hits of chlorinated organic compounds before suggesting these data represent potential contamination. Additionally, the second full paragraph on page 58 contains an incomplete sentence ending with the word "provides".	The incomplete sentence was corrected. Removed language about "…sporadic hits of chlorinated organic compounds…" as a justification for sampling by CDPHE.
58	The report refers repeatedly (as on p. 65) to "closure" of Rocky Flats in 1989, which is a misnomer. Production halted in 1989 because it could not be done safely or within the law. But the next two years were spent on unsuccessful efforts to get back into production. In 1992, DOE finally changed the mission from production to cleanup.	Changed "closure" to "ceased production"
59	The reference to Cobb et al. cited on page 70, line 16 and 28, does not appear in the references at least I could not find it.	Corrected. It should have been (EPA 1982).
60	Page 73, last paragraph, first sentence: Change "detected" to "detect"	Changed as suggested.
61	The ATSDR report acknowledges that children are especially vulnerable to hazardous substances, as likewise are the elderly and the ill (pp. ii, 74-75). Yet it operates on the flawed assumption that even for these high-risk groups exposures below a particular level (the comparative value) have no adverse health effect.	Please refer to Appendix D. Comparison Values.

#	Comment	Agency Response
62	The public health assessment is generally well done, but could have been strengthened by a more thorough and detailed discussion of exactly how the conclusions were arrived at. One aspect for which additional information is needed relates to the 1957 fire, and episodic event during which nearly 90% of the total plutonium released by the site to the atmosphere was released. Although the atmospheric monitoring data are sparse and in some cases lacking as is true for certain key meteorological data, the public health evaluation should have included consideration of the potential maximum exposed individual from this fire, and the associated cancer risk from plutonium inhalation. While this specific evaluation is unlikely to change the conclusions drawn in the report, it nonetheless is an important window into the risks associated with the site operations, providing an assessment of the risk associated with this highly significant episodic event.	The dose reconstruction performed by RAC, did not access the dose to the maximally exposed individual. RAC used the 50^{th} and 95^{th} percentile in their approach.
63	ATSDR says "oxides of plutonium are extremely insoluble in water and would not have been a hazard from ingestion" (p. 77). ATSDR does not mention or apparently consider that the ICRP has recently upgraded the danger of ingestion of plutonium, particularly for infants and children.	ATSDR used the ICRP Pub 88 dose calculator to calculate doses from radionuclides.
64	Rocky Flats plutonium operations included dissolution of plutonium, and the presence of soluble and insoluble plutonium. Some of the waste stream of soluble plutonium and nitrates found in the Walnut Creek drainage on the north side of Rocky Flats that leads to Great Western Reservoir was a result of this process. The soluble plutonium had transport for some distance before reverting to insoluble status according to Rocky Flats workers.	ATSDR reports concentrations of plutonium found in various media.
65	ATSDR says migration of plutonium in surface water is unlikely (p. 77). This is refuted by the site's Report on Soil Erosion and Surface Water Sediment Transport Modeling, August 2000 (AME)	Most of the plutonium transport was through air dispersion from the fires.

#	Comment	Agency Response
66	ATSDR recommends that any decision to allow public access to any part of the site after closure be “carefully reviewed” (p. 79). How is this recommendation helpful, given that the ATSDR report itself is so fundamentally flawed. A re-working of the report, taking these comments into consideration, would provide a more useful tool for the US Fish and Wildlife Service which will make the decision about public access.	Removed last recommendation, since it was written prior to the final closure plan.
67	Page 79. CDPHE would not expect that additional sampling of private wells near Rocky Flats would detect the presence of contamination attributable to the Site.	Changed to recommend the Boulder and Jefferson Counties test private wells at the owner’s request, as these counties have an established program for well testing.
68	The recommendations, in addition to calling for continuation of monitoring and sampling, should also call for reevaluation of risks. For example, in the last bulleted Recommendation, the words "and reevaluate risks" could be added to the next to last line.	This is covered in the PHAP, in DOE’s CRA work.
69	Section IX.C, page 80, Planned Actions: It is important to note that DOE has developed a Comprehensive Risk Assessment (CRA) Work Plan and Methodology outlining the approach to be used in performing a CRA at the site. This methodology was prepared with input from CDPHE, EPA and FWS, and was approved by CDPHE and EPA in September 2004. The CRA will evaluate and quantify risks to human and ecological receptors posed by residual contamination at RFETS. The CRA will address all areas within the RFETS boundary, based on the anticipated future use of RFETS as a wildlife refuge as designated by the Rocky Flats National Wildlife Refuge Act of 2001.	Changed to suggested language.
70	Pages 83-89, XI. References: Recommend the references be placed in alphabetical order or order in which used within the body of the PHA. Recommend that all references within the body of the PHA be in "XI. References," and all References in "XI. References" be used within the body of the PHA.	References have been reformatted, alphabetized and have been cross checked with the body of the PHA.
71	Page 86, U.S. DOE 2003a: Change "Rock" to "Rocky"	Changed as suggested.

#	Comment	Agency Response
72	p A-6, Fig. 4: In this black and white rendition of this figure, Open Space/Agricultural and Suburban Residential land uses cannot be distinguished. Perhaps this requires color or another kind of cross-hatching.	Unfortunately, this is the only image available.
73	Pages B-7 through B-9, Tables 4-6, Column 6 (Number of Concentrations Greater Than CV): Recommend that next to column values, in parentheses, that value for "% of Total Samples Collected" be added.	Percent of samples above comparison value was added to column 6 of tables.
74	p. B-13, 2 places in Table 10: "pCi-y/m3" is not "picocuries per year per cubic meter" as stated in the footnote; it is "picocurie-years per cubic meter," which is a number of nuclear transitions in a cubic meter of air during a year.	Correction made as suggested.
75	p. B-13, In the Note to Table 10, it is stated that the 50th percentile is reported. The 50th %ile is not the correct central tendency of the lognormal distribution (or any other distribution) to use for dose assessments. The arithmetic mean, a larger number, should be used, since it will be unbiased on the average.	ATSDR is simply reporting how the RAC Dose Reconstruction presented its findings.
76	Page B-13, Table 10, Column 2, Row 2 and 4: Cell value is ">0.005 pCi/m3", which means there is no upper bound. Should the cell value be "<0.005 pCi/m3"?	Value should be "<0.005 pCi/m3 and has been corrected.
77	Appendix C, The ATSDR Glossary of Environmental Health Terms, doesn't really address issues that confuse the public regarding radiation doses, radiation dose rates, radioactive materials activity, radioactivity concentration, time-integrated activity concentration, and the distinctions between and among these concepts.	Added Appendix E Radiation and Radioactive Material, which explains the concepts involved.