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BURLINGAME, A.H.		
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EG&G ROCKY FLATS

EG&G ROCKY FLATS, INC.
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December 9, 1994 — 94-RF-12149

000046919

Jessie M. Roberson
Acting Assistant Manager for
Environmental Restoration
DOE/RFFO

Attn: S. R. Grace

TRANSMITTAL OF THE DRAFT FINAL TECHNICAL MEMORANDUM NO. 5 "HUMAN HEALTH RISK ASSESSMENT 903 PAD, MOUND, AND EAST TRENCHES AREAS OPERABLE UNIT NO. 2 EXPOSURE SCENARIOS" – SGS-638-94

Action: Review and comment of Draft Final Technical Memorandum No. 5.

Enclosed are three copies of the Draft Final Technical Memorandum No. 5 titled, "Human Health Risk Assessment 903 Pad, Mound and East Trenches Areas Operable Unit No. 2 Exposure Scenarios". As per your verbal instructions, copies are being provided to the Colorado Department of Public Health and Environment (CDPHE) and the Environmental Protection Agency (EPA). Please advise CDPHE and EPA to provide comments by January 3, 1995.

If you have any questions or require additional information, please contact Pete Laurin at extension 8702.

S. G. Stiger, Director
Environmental Restoration Program Division

PJL:bll

Orig. and 1 cc - J. M. Roberson

Enclosures:
As Stated (3)

cc:
M. N. Silverman - DOE/RFFO w/o Enc.
E. A. Dillé - SAIC

TECHNICAL MEMORANDUM NO. 5
EXPOSURE SCENARIOS

HUMAN HEALTH RISK ASSESSMENT
903 PAD, MOUND, AND EAST
TRENCHES AREAS
OPERABLE UNIT NO. 2

DRAFT FINAL

ROCKY FLATS ENVIRONMENTAL TECHNOLOGY SITE

U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

ENVIRONMENTAL RESTORATION PROGRAM
December 7, 1994

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EXECUTIVE SUMMARY

This Technical Memorandum No. 5, Exposure Assessment, is presented in support of the baseline human health risk assessment (HHRA) for Operational Unit Number 2 (OU2), which includes the 903 Pad, Mound, Northeast Trenches, and Southeast Trenches areas located at Rocky Flats Environmental Technology Site (RFETS). Each of the areas contains several Individual Hazardous Substance Sites (IHSSs) where past waste disposal activities or releases occurred. OU2 also contains a large area of the buffer zone, extending east to Indiana Street, where no IHSSs are present.

This technical memorandum identifies potentially complete exposure pathways and human receptors at OU2 and presents quantitative values for exposure parameters and equations for estimating central tendency (CT) and reasonable maximum exposures (RMEs) to be used in the HHRA. This technical memorandum does not quantify chemical intake, which is dependent on the chemical concentration at exposure points.

The following subjects are covered in this technical memorandum:

- Identification of current on-site and off-site land uses and characterization of future land use scenarios as credible or improbable, depending on likelihood of occurrence.

- Identification of potential receptors based on current and future land use scenarios.

- Development of a conceptual site model (CSM), which is a schematic representation that summarizes information regarding chemical sources, chemical release mechanisms, environmental transport media, and human intake routes, The CSM also identifies pathways as potentially complete (significant), potentially complete (relatively insignificant), or incomplete and negligible.

- Identification of quantitative values for exposure parameters and equations to be used in estimating central tendency and reasonable maximum chemical intake for each of the potentially complete exposure pathways and receptors at OU2.

Current land use at OU2 includes on-site security surveillance and environmental restoration activities and off-site open space, agricultural, commercial/industrial, and residential land use. Future on-site land use scenarios that could reasonably be expected to occur at RFETS include on-site commercial/industrial, ecological reserve (open space), and gravel mining. Future off-site land use scenarios include open space, agricultural, commercial/industrial, and residential land use. Future on-site residential land use is considered to be improbable (unlikely to occur).

Potential receptors identified for evaluation in the HHRA include:

- Current off-site residential receptor
- Current on-site worker
- Future off-site residential receptor
- Future on-site industrial/office worker
- Future on-site construction worker
- Future on-site ecological researcher
- Future on-site gravel miner
- Although future on-site residential use is not consistent with future land-use plans and is considered improbable, hypothetical future on-site residential exposures will also be evaluated in the HHRA

Current off-site exposure locations selected to be evaluated in the HHRA are the nearest residence to RFETS and the nearest residence to RFETS that is in the predominant wind direction. Future off-site exposure locations selected to be evaluated in the HHRA are a hypothetical residence on Indiana Street at South Walnut Creek and a hypothetical residence on Indiana Street at Woman Creek. South Walnut Creek and Woman Creek form the northern and southern boundaries, respectively, of OU2 (Figure 3-1).

Exposures of current and future on-site receptors will be evaluated in the HHRA at two areas of concern (AOCs) in OU2 (Figure 3-2). AOCs are identified as one or several contaminant source areas that are in close proximity and can be evaluated as a unit in the HHRA. AOC No. 1 contains the source areas used historically for waste disposal, including the 903 Pad, Mound, and Northeast Trenches source areas (these three source areas are hydrogeologically connected) and the Southeast Trenches area (which does not contain groundwater). AOC No. 2 includes the East of IHSSs area, located in the buffer zone between the IHSSs and Indiana Street. No IHSSs or other waste disposal areas are present in this AOC.

In the HHRA, exposures of current and future on-site workers and hypothetical future on-site residents will be evaluated in both AOC No. 1 and AOC No. 2, using a data set representing the entire AOC. In addition, maximum exposure scenarios in AOC No. 1 will be evaluated for hypothetical future on-site residents in a 10-acre plot in the 903 Pad area, for future industrial/office workers in a 30-acre area including and extending northeast of the 903 Pad area, and for future ecological researchers in a 50-acre area.

Potential release mechanisms from contaminated soil in OU2, identified in the CSM, include storm water runoff, volatilization, wind suspension, infiltration and percolation to groundwater, direct oral and dermal contact with soil, root uptake from surface soil, and radioactive decay. Transport media include groundwater, surface water, and air. Based on evaluation of information on chemical sources, chemical release and environmental transport mechanisms, exposure points, and human intake routes, OU2 pathways are characterized as either potentially complete and significant, potentially complete and relatively insignificant, or negligible or incomplete. Negligible or incomplete pathways are discussed but are eliminated from further consideration in the quantitative HHRA. A summary of potentially complete exposure pathways to be quantitatively evaluated in the HHRA is provided in Table ES-1.

Quantitative values for exposure factors to be used for estimating central tendency and reasonable maximum chemical intake are identified for each of the potentially complete exposure pathways and receptors as recommended by EPA (EPA 1992). Exposure factors are shown in tables in Attachment 1. Exposure factors are reasonable estimates of numerous variables including body weight, daily inhalation volume, daily ingestion rates, body surface area, soil or food matrix effects, and frequency and duration of exposure. Exposure point concentrations (determined by chemical analytical results and fate and transport modeling) will be used with these exposure parameters and equations to obtain pathway-specific chemical intakes for use in the HHRA.

TABLE ES-1
ROCKY FLATS OU2
POTENTIALLY COMPLETE EXPOSURE PATHWAYS TO BE QUANTITATIVELY EVALUATED

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
Off-site resident	Current	Inhalation of airborne particulates from OU2 surface soil Soil ingestion (following deposition of particulates) Dermal contact with soil (following deposition of particulates) Ingestion of garden produce (surface deposition of particulates)
On-site worker	Current	Inhalation of airborne particulates from surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil
Hypothetical off-site resident	Future	Inhalation of airborne particulates from OU2 surface soil Ingestion of surface soil (following deposition of particulates) Dermal contact with soil (following deposition of particulates) Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Ingestion of garden produce (surface deposition of particulates)
On-site worker (industrial/office)	Future	Inhalation of airborne particulates from surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil Inhalation of indoor VOCs (from migration through foundation)
On-site construction worker	Future	Inhalation of airborne particulates from subsurface soil Ingestion of subsurface soil Dermal contact with subsurface soil External irradiation from subsurface soil

TABLE ES-1
(Concluded)

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
On-site ecological researcher	Future	Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Inhalation of airborne particulates Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil
On-site gravel miner	Future	Inhalation of airborne particulates from subsurface soil Inhalation of VOCs from subsurface soil (negligible) Ingestion of subsurface soil Dermal contact with subsurface soil External irradiation from subsurface soil
Hypothetical on-site resident	Future	Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Inhalation of airborne particulates from surface soil Inhalation of indoor VOCs (from domestic use and migration through foundation) Ingestion of groundwater Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil Ingestion of vegetables (root uptake and surface deposition of particulates from surface soil)

1.0 INTRODUCTION

This Exposure Assessment Technical Memorandum (EATM) is presented to support the development of the baseline human health risk assessment (HHRA) for the 903 Pad, Mound, and East Trenches areas, otherwise known as Operable Unit Number 2 (OU2), located at the Rocky Flats Environmental Technology Site (RFETS). The HHRA will evaluate human health risks for on-site and off-site receptors under current land-use conditions and under potential future land-use conditions, assuming no remedial action takes place at OU2. The HHRA for OU2 will be submitted as part of the Phase II Resource Conservation and Recovery Act (RCRA) Facility Investigation/Remedial Investigation (RFI/RI) Report for OU2. The RFI/RI is conducted pursuant to the U.S. Department of Energy (DOE) Environmental Restoration (ER) Program; a Compliance Agreement between DOE, the U.S. Environmental Protection Agency (EPA), and the State of Colorado Department of Public Health and Environment (CDPHE), dated July 31, 1986; and the Federal Facility Agreement and Consent Order (FFACO), known as the Interagency Agreement (IAG 1991).

The objectives of this EATM are to (1) identify human receptor populations that may be exposed to chemicals released from the operable unit under current and potential future use exposure scenarios, (2) describe exposure pathways by which chemicals could be transported from sources to human exposure points, (3) identify the principal route(s) of chemical intake (e.g., inhalation or ingestion), and (4) present central tendency (CT) and reasonable maximum exposure (RME) factors to estimate chemical intake for each potential exposure pathway and receptor. This EATM does not quantify chemical intake, which is dependent on the chemical concentration at the exposure points. Exposure point concentrations will be estimated based on the analytical results of the remedial investigation and fate and transport modeling, as appropriate.

This EATM is organized as follows:

- Section 2.0, Site Description, describes site history and site characteristics such as meteorology, geology, surface water, and groundwater hydrology that affect exposure pathways.

- Section 3.0, Potential Receptors and Exposure Areas, identifies current and future human receptors that could be exposed to chemicals released from sources in OU2 based on current and potential future on-site and off-site land use scenarios. This section also describes the exposure areas and receptor locations that will be evaluated in the HHRA.

- Section 4.0, Exposure Pathways, discusses potential chemical release and transport mechanisms and identifies potentially complete exposure pathways for which chemical intake will be quantitatively evaluated in the HHRA.

- Section 5.0, Estimating Chemical Intakes, describes the methodology used to approximate the intake of chemicals from various media (e.g., soil or groundwater).

- Section 6.0 contains references cited in the EATM.

- Attachment 1 contains tables with CT and RME intake factors for each receptor scenario being evaluated.

2.0
SITE DESCRIPTION

RFETS is located on approximately 6,550 acres of federally owned land in northern Jefferson County, Colorado, approximately 16 miles northwest of Denver (Figure 2-1). Surrounding cities include Boulder, Superior, Broomfield, Westminster, and Arvada, which are located less than 10 miles to the northwest, north, northeast, and southeast, respectively. Within RFETS is an approximately 400-acre security area surrounded by an undeveloped buffer zone of approximately 6,150 acres. A general site description is presented in this section. For a more detailed description, please refer to the RFI/RI Work Plan for OU2 (EG&G 1991a).

2.1 HISTORIC AND FUTURE USE

RFETS is a government-owned and contractor-operated facility that was part of the nationwide nuclear weapons production complex. The primary mission of the facility from 1951 until 1989 was to produce metal components for nuclear weapons. These components were fabricated from plutonium, uranium, and nonradioactive metals (principally beryllium and stainless steel). Other activities have included research and development in metallurgy, machining, nondestructive testing, coatings, remote engineering, chemistry, and physics. Both radioactive and nonradioactive wastes were generated in these research and production processes. Historically, the operating procedures included on-site storage and disposal of hazardous and radioactive wastes. Current waste handling practices involve on-site and off-site recycling of hazardous materials and on-site storage of hazardous and radioactive mixed wastes.

Preliminary assessments under the Environmental Restoration (ER) Program identified some of the past on-site storage and disposal locations as potential sources of environmental contamination. The RFETS is currently performing ER activities and planning for decontamination and decommissioning, transition, economic development, and waste management. The current mission of RFETS is to manage waste and materials, clean up, and convert the Rocky Flats site to beneficial use in a manner that is safe, environmentally and socially responsible, physically secure, and cost-effective.

A group of local businesses and government representatives, referred to as the Rocky Flats Local Impacts Initiative (RFLII), has been formed to identify and mitigate negative economic impacts associated with the transition currently occurring at RFETS. One of the goals of the RFLII is to help attract manufacturing and other businesses to occupy some of the existing buildings, once cleaned and renovated (RFLII 1992). Therefore, continued beneficial commercial and industrial use of the facility is anticipated.

2.2 DESCRIPTION OF OU2

OU2 includes the 903 Pad, Mound, and East Trenches areas, as well as a large portion of the buffer zone extending east to Indiana Street. Individual hazardous substances sites (IHSSs), where waste materials were historically stored or disposed, are located in the 903 Pad, Mound, and East Trenches Areas (Figure 2-2). The following sections provide a brief history of waste disposal areas in OU2. The descriptions are based on the Phase I Installation Assessment and the RCRA Part B Operating Permit Application as reported in EG&G (1991a). These documents are based on historical records, aerial photography, and interviews with Rocky Flats personnel. More detailed information can be found in the Phase II RFI/RI Work Plan (EG&G 1991a) and the Preliminary Draft Phase II RFI/RI report (DOE 1993).

2.2.1 903 Pad Area

The 903 Pad Area includes the following five IHSSs:

- 903 Pad Site (IHSS 112)
- 903 Lip Area (IHSS 155)
- Trench T-2 (IHSS 109)
- Reactive Metal Destruction Site (IHSS 140)
- Gas Detoxification Site (IHSS 183)

The 903 Pad Site (IHSS 112) was used from October 1958 to January 1967 for storage of radioactively contaminated oil drums. Contents of the drums included plutonium, uranium, carbon tetrachloride, hydraulic oils, vacuum pump oil, trichloroethylene, perchloroethylene, silicone oils, acetone still bottoms, and ethanolamine. The storage of drums at the 903 Pad Site ended in January 1967, when drum removal efforts began. Removal of all drums and wastes was completed in June 1968, and two courses of clean fill material (6 inches of loose gravel and 3 inches of fill dirt) and an asphalt cap (approximately 3 inches thick) were applied in 1969. In 1970, additional road-base course material was applied to cover contaminated soils directly east and south of the asphalt pad.

Trench T-2 (IHSS 109) is located approximately 200 feet south of the 903 Pad. It was used prior to 1968 for the disposal of sanitary sewage sludge and flattened drums contaminated with uranium and plutonium.

The 903 Lip Area (IHSS 155) is located immediately south and east of the 903 Pad Site. Soil cleanup efforts were undertaken in 1976, 1978, and 1984 to remove plutonium-containing soils from three locations within the 903 Lip Area. After the first two cleanup efforts, the excavated area was covered with clean top soil and revegetated with native grasses. After the 1984 cleanup effort, the excavated area was backfilled with clean topsoil.

The Reactive Metal Destruction Site (IHSS 140) was used during the 1950s and 1960s primarily for the destruction of lithium metal (DOE 1986). The residues, primarily lithium carbonate, were buried. Smaller quantities of sodium, calcium, magnesium, solvents, and unknown liquids were also destroyed at this location.

The Gas Detoxification Site (IHSS 183) was used between June 1982 and August 1983 to detoxify various gases from lecture bottles. The lecture bottles held approximately one liter of compressed gases such as nitrogen oxides, chlorine, hydrogen sulfide, sulfur tetrafluoride, methane, hydrogen fluoride, and ammonia. Gas detoxification was accomplished by using commercial neutralization processes.

2.2.2 Mound Area

The Mound Area includes the following IHSSs:

- Mound Site (IHSS 113)
- Trench T-1 (IHSS 108)
- Oil Burn Pit No. 2 (IHSS 153)
- Pallet Burn Site (IHSS 154)

The Mound Site (IHSS 113) was used between 1954 and 1958 for disposal of drums containing primarily depleted uranium- and beryllium-contaminated lathe coolant. It is likely that some of the coolant also contained enriched uranium and plutonium. Some drums contained perchloroethylene. Cleanup of the Mound Site was accomplished in May 1970, and the removed materials were packaged and shipped to an off-site DOE facility for disposal.

Trench T-1 (IHSS 108) was used from 1954 until 1962. It contains approximately 125 drums filled with approximately 25,000 kg (55,125 pounds) of depleted uranium chips and plutonium chips coated with small amounts of lathe coolant. This trench is now covered with about 2 feet of soil and the corners are marked.

The Oil Burn Pit No. 2 (IHSS 153) is two parallel trenches that were used in 1957 and from 1961 to 1965 to burn drums of oil containing uranium. The drums used for the oil burning operation were generally reused; however, some empty drums were discarded by flattening and burning them in the trenches. The residues from the burning operations and the flattened drums were covered with backfill. In 1978, the area was excavated to a depth of approximately 5 feet, and the contaminated soil was removed and shipped off site to an authorized DOE disposal site.

The Pallet Burn Site (IHSS 154), southwest of Oil Burn Pit No. 2, was reportedly used to destroy wooden pallets in 1965. The types of hazardous substances or radionuclides that may have been spilled on these pallets is unknown. The site was reportedly remediated and reclaimed in the 1970s.

2.2.3 East Trenches Area

The East Trenches Area consists of nine burial trenches (IHSSs 110 and 111.1 through 111.8) and two spray fields (IHSSs 216.2 and 216.3). The burial trenches were used from 1954 to 1968 for disposal of uranium- and plutonium-contaminated sanitary sewage sludge and flattened, empty drums contaminated with uranium. The wastes in these trenches have not been disturbed since their burial.

The East Spray Fields were used for spray irrigation of sewage treatment plant effluent. Effluent containing low concentrations of chromium was inadvertently sprayed in the area in February and March 1989.

2.2.4 Buffer Zone East of IHSSs

This area extends east of the East Trenches Area to Indiana Street. No IHSSs or other waste disposal sites are present in this area.

2.3 PHYSICAL SETTING

RFETS is located east of the Front Range of the Rocky Mountains on a broad, eastward-sloping plain of coalescing alluvial fans at an elevation of approximately 6,000 feet above mean sea level. The alluvial fans extend approximately 5 miles east of their origin at Coal Creek Canyon and terminate at a break in the slope in low rolling hills. The RFETS operational area is located near the eastern edge of the fans on a terrace between stream-cut valleys (North Walnut Creek and Woman Creek).

Three intermittent streams drain the RFETS property, flowing west to east. These drainages are Rock Creek, Walnut Creek, and Woman Creek. Rock Creek drains the northwestern corner of the property and flows northeast through the buffer zone to its off-site confluence with Coal Creek. North and South Walnut Creeks and an unnamed tributary drain the northern portion of the security area. These three forks of Walnut Creek join in the buffer zone and flow toward Great Western Reservoir, which is approximately 1 mile east of the confluence. The flow in Walnut Creek is routed around Great Western Reservoir by the Broomfield Diversion Canal operated by the City of Broomfield. Woman Creek drains the southern portion of the buffer zone and flows east to Mower Reservoir and Standley Lake.

2.3.1 Meteorology

The climate east of the Front Range in Colorado is semi-arid, with an annual precipitation of approximately 15 inches. Approximately 50 percent of the precipitation is received from snowfall during the winter and spring, approximately 30 percent is from summer thunderstorms, and the remainder is received as light rain and snowfall in the fall. Annually, snowfall averages 85 inches. Annual free-water evaporation is approximately 45 inches (DOE 1992), which is greater than the amount of annual precipitation.

As shown in Figure 2-3, winds flows from the west and northwest approximately 35 percent of the year. Wind flows from the southwest approximately 16 percent of the year. The highest wind velocity is from the northwest and exceeds approximately 34.5 mph. Therefore, atmospheric dispersion from the facility would primarily affect areas to the east and southeast of the plant.

2.3.2 Geology

The surficial deposits at OU2 consist of pediment alluvium, colluvium, valley-fill alluvium, and artificial fill that overlay bedrock. The near-surface bedrock formations of the Arapahoe and Laramie formations, as well as the Rocky Flats Alluvium, are shown on Figure 2-4 and are discussed below. The regional dip of the bedrock in the vicinity of OU2 is approximately two degrees to the east.

The Rocky Flats Alluvium is a gravel deposit that overlies the bedrock. The deposit consists of poorly to moderately sorted, poorly stratified clays, silts, sands, gravels, and cobbles. In the area of OU2, it ranges in thickness from 0 to 50 feet. Creeks in OU2 have cut through the alluvium into the underlying bedrock, leaving the alluvium exposed along the valley walls, approximately 40 to 120 feet above the present valley floor.

Colluvial materials in OU2 were derived from slope wash and creep of the Rocky Flats Alluvium and from the Arapahoe and Laramie Formations. The colluvium consists of clays, sands, and gravels, and ranges in thickness from 3 to 20 feet. Artificial fill and disturbed ground occur in localized areas of the 903 Pad, Mound, and East Trenches. Recent valley-fill alluvium occurs in the active stream channels of Walnut and Woman Creeks. This material is derived from reworked older alluvial and bedrock deposits.

The Arapahoe Formation underlies the surficial material at OU2. The Arapahoe Formation, which is approximately 150 feet thick (EG&G 1991a) in the vicinity of Rocky Flats, is composed of claystones, siltstones, sandstones, and occasional lignitic coal seams and ironstones deposited in a fluvial environment. The Arapahoe occasionally outcrops along the valleys of Walnut and Woman Creeks. Multiple, overlapping sandstone sequences exist within the Arapahoe Formation (EG&G 1992). Individual sandstone lenses are local in extent and may or may not be in hydraulic communication with one another. The sandstones of the Arapahoe are primarily very fine- to coarse-grained quartz sands.

The No. 1 Sandstone channel underlies the Rocky Flats Alluvium and colluvium. It is generally located in the northwest side of the 903 Pad, Mound, and East Trenches areas of OU2. The No. 1 Sandstone is a heterogeneous sandstone body with interbedded siltstone and claystone layers. Medium- to coarse-grained sand and an occasional conglomeratic sandstone have been identified at the base of the No. 1 Sandstone in OU2. The unit ranges from 0 to 40 feet in thickness.

Claystones of the Laramie Formation, which underlies the Arapahoe Formation, are also observed in outcroppings in valley walls and in borings from subsurface soil investigations.

2.3.3 Surface Water

Two intermittent streams, Walnut Creek and Woman Creek, are located to the north and south of OU2; they flow generally west to east. These streams are ephemeral because of the seasonal response to freezing, spring runoff, and storms. Walnut Creek has two branches: North Walnut Creek and South Walnut Creek; South Walnut Creek is at the northern border of OU2 (Figures 2-2 and 3-1). North and South Walnut Creeks flow through a series of detention ponds (A and B series). Ponds B-1 through B-5 are located on South Walnut Creek and receive surface and groundwater flows from the northern portion of OU2. Intermittent groundwater seeps or springs occur near IHSS 140 in the 903 Pad Area, near IHSS 154 in the Mound Area, and northeast of the East Trenches Area, along the south side of the Walnut Creek drainage.

Water from the B-5 pond on South Walnut Creek is discharged to Pond A-4, where flow in the North and South Walnut Creeks is treated, if necessary, by membrane filtration for particulate removal and by granulated activated carbon for removal of organic compounds prior to discharge. Downstream, Walnut Creek is diverted around Great Western Reservoir via the Broomfield Diversion Ditch.

Woman Creek, which is south of OU2 (Figures 2-2 and 3-1), discharges into Mower Reservoir and Standley Lake. Detention Ponds C-1 and C-2 are located on Woman Creek. Pond C-2 receives flow only from the South Interceptor Ditch (SID), which lies on the northern flank of the Woman Creek drainage between OU2 and Woman Creek. The SID collects runoff from the southern security area, including portions of OU2. Water from Pond C-2 is not discharged to Woman Creek but is pumped to the Broomfield Diversion Ditch approximately semi-annually.

All surface water discharges from Rocky Flats are monitored in compliance with the National Pollutant Discharge Elimination System (NPDES) permit and with the EPA-approved Rocky Flats surface water management program (EG&G 1991b).

2.3.4 Groundwater

The upper hydrostratigraphic unit (UHSU) is the water-bearing unit of primary concern for potential transport of contaminants or exposure to contaminants through direct contact during hypothetical use of groundwater on-site. The UHSU at OU2 consists of Rocky Flats alluvium, colluvium, valley fill, and the Arapahoe No. 1 Sandstone. In addition, limited areas of subcropping claystone may be saturated, particularly where the claystone is fractured and weathered (EG&G 1991c). Groundwater in the UHSU exists under unconfined conditions. Groundwater flow across the area is generally west to east, but local variations occur. Groundwater in the Rocky Flats Alluvium follows the scoured lows in the underlying bedrock, while flow in the No. 1 Sandstone is controlled by the geometry of the sandstone body (EG&G 1991c). Water in the colluvium mantling the valley slopes flows toward Walnut or Woman Creeks.

Recharge to the UHSU beneath OU2 is primarily due to precipitation, snowmelt, and water loss from ditches, streams, and ponds. Groundwater levels reflect seasonal changes; groundwater levels reach their highest in the spring and early summer and decline the remainder of the year, with periodic higher flows due to precipitation or irrigation.

Groundwater discharge from the UHSU occurs at seeps and springs at the contact between the Rocky Flats Alluvium or the No. 1 Sandstone and the claystone bedrock. Seep or spring water is consumed by evapotranspiration or flows downslope through the colluvial deposits where it primarily discharges to Walnut Creek (north of OU2). Minor discharge to the south interceptor ditch (SID) (southeast of OU2) and Woman Creek (south of OU2) also occurs. UHSU groundwater does not migrate off-site in the subsurface.

2.3.5 Off-Site Domestic Wells Along the South Walnut and Woman Creek Drainages

The groundwater in the UHSU is discharged via seeps and springs into the adjoining creeks. Off-site wells located in the drainages of Walnut and Woman Creeks are therefore of interest since groundwater in OU2 discharges into these drainages.

Walnut Creek, which is the primary drainage for OU2, flows eastward and is diverted around Great Western Reservoir. Land surrounding the creek drainage beyond the Rocky Flats boundary and surrounding the reservoir is used as open space and does not contain residential or commercial developments. No water wells are registered at the Colorado State Engineer's (CSE) office for this area.

Woman Creek drains the southern portion of OU2 and discharges into Mower Reservoir and Standley Lake. Fourteen wells west of Standley Lake are registered in this drainage (Figure 2-5). Table 2-1 lists information from completion reports for these wells that are on file at the CSE Office. Screened depths given for these wells place the completion intervals within the basal Arapahoe to Upper Laramie Formations. The Upper Laramie Formation in this area is described as predominantly claystones with some thin discontinuous sandstone lenses and an occasional coal seam (DOE 1992). The thin, discontinuous character of these sandstones suggest that a hydraulic connection to the alluvium along Woman Creek is unlikely. Also, there are indications that the off-site wells may be hydraulically connected to Standley Lake, a large source of potential recharge for the wells (DOE 1992).

2.4 ECOLOGY

This section presents a brief summary of biological resources at Rocky Flats. Plants representative of tall-grass prairie, short-grass plains, lower mountain, and foothill ravine regions can be found within the boundaries of Rocky Flats. Grasses predominantly cover the steep sides of the hillsides along Walnut Creek and Woman Creek drainages. The Walnut Creek and Woman Creek drainages also host grasses, cattails, rushes, and cottonwood trees.

Since the acquisition of the property, vegetative recovery from former grazing has occurred, as evidenced by the presence of disturbance-sensitive grass species such as big bluestem and side oats grama. No vegetative stresses attributable to hazardous waste contamination have been identified (EG&G 1991c).

The animal life inhabiting Rocky Flats consists of species associated with western prairie regions. The most common large mammal is the mule deer. A number of small carnivores such as coyote, red fox, striped skunk, and long-tailed weasel are present. The bird population includes the western meadowlark, mourning doves, vesper sparrows, great horned owl, and ferruginous and American rough-legged hawks. Many varieties of ducks, killdeer, and redwing blackbirds have been observed near the ponds on Woman and Walnut Creeks. Minnows have been observed in both creeks, and it is possible that other fish may appear in the creeks, but most likely this would occur only during high-flow periods. Bull snakes and rattlesnakes can be seen on the hillsides of OU2. The western painted turtle and western plains garter snake inhabit the greens near the ponds. The Prebles meadow jumping mouse inhabits creek drainages and is a candidate for listing as an endangered species (DOE 1994c).

Ecological surveys performed in compliance with the Threatened and Endangered Species Act indicate the presence of habitat that is potentially suitable to four plant species and several wildlife species of concern. The plant species include the forktip threeawn, Colorado butterfly plant, toothcup, and Diluvium lady's tresses (EG&G 1991d). The wildlife species include the bald eagle, peregrine falcon, whooping crane, Prebles meadow jumping mouse, and the black-footed ferret (DOE 1991; USFWS 1990; DOE 1994c). Because of the unique and undisturbed nature of the buffer zone, it is possible that it may be designed as an ecological reserve.

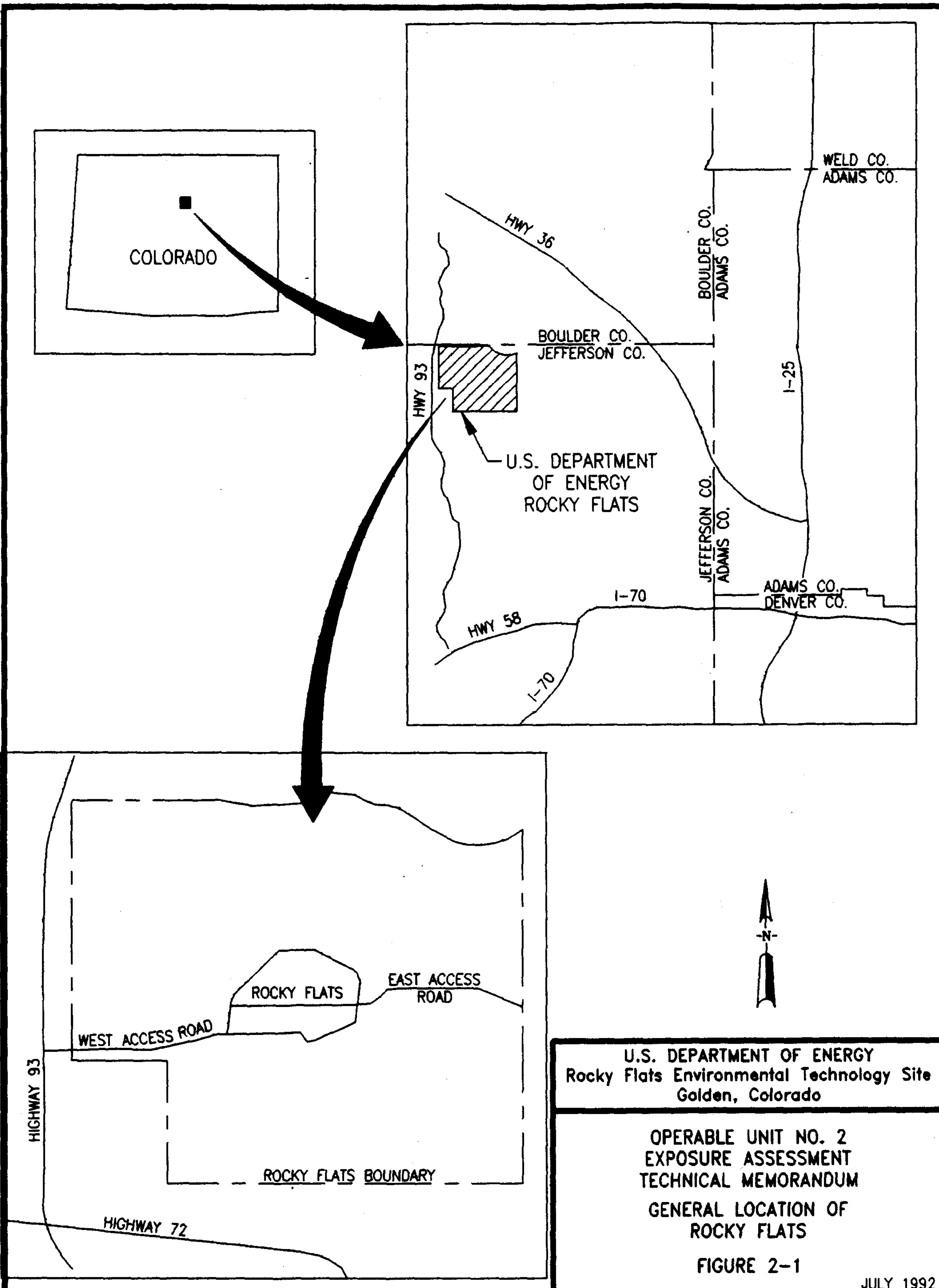
TABLE 2-1

ROCKY FLATS OU2
WELLS NEAR WOMAN CREEK*

Permit No.	Yield ** (gpm)	Total Well Depth (ft)	Screened Interval (Feet Below Ground Surface)					
			Top	Bottom	Top	Bottom	Top	Bottom
26	15	125	45	85	105	125	--	--
1246	15	67	37	67	--	--	--	--
8117	12	70	20	70	--	--	--	--
14820	8	200	100	200	--	--	--	--
18383	12	75	50	75	--	--	--	--
19069	6	100	27	36	63	90	--	--
29620	15	112	85	112	--	--	--	--
32849	14	80	23	80	--	--	--	--
45855	15	110	30	110	--	--	--	--
52028	8	122	80	96	--	--	--	--
89558	15	150	30	50	70	90	130	150
96282	14	125	65	90	--	--	--	--
103583	15	125	90	125	--	--	--	--
138834	15	71	20	71	--	--	--	--

* Source: Colorado State Engineer's Office
** Based on drillers' observations. Does not indicate sustainable well yields.
-- Not available

Source: DOE 1992



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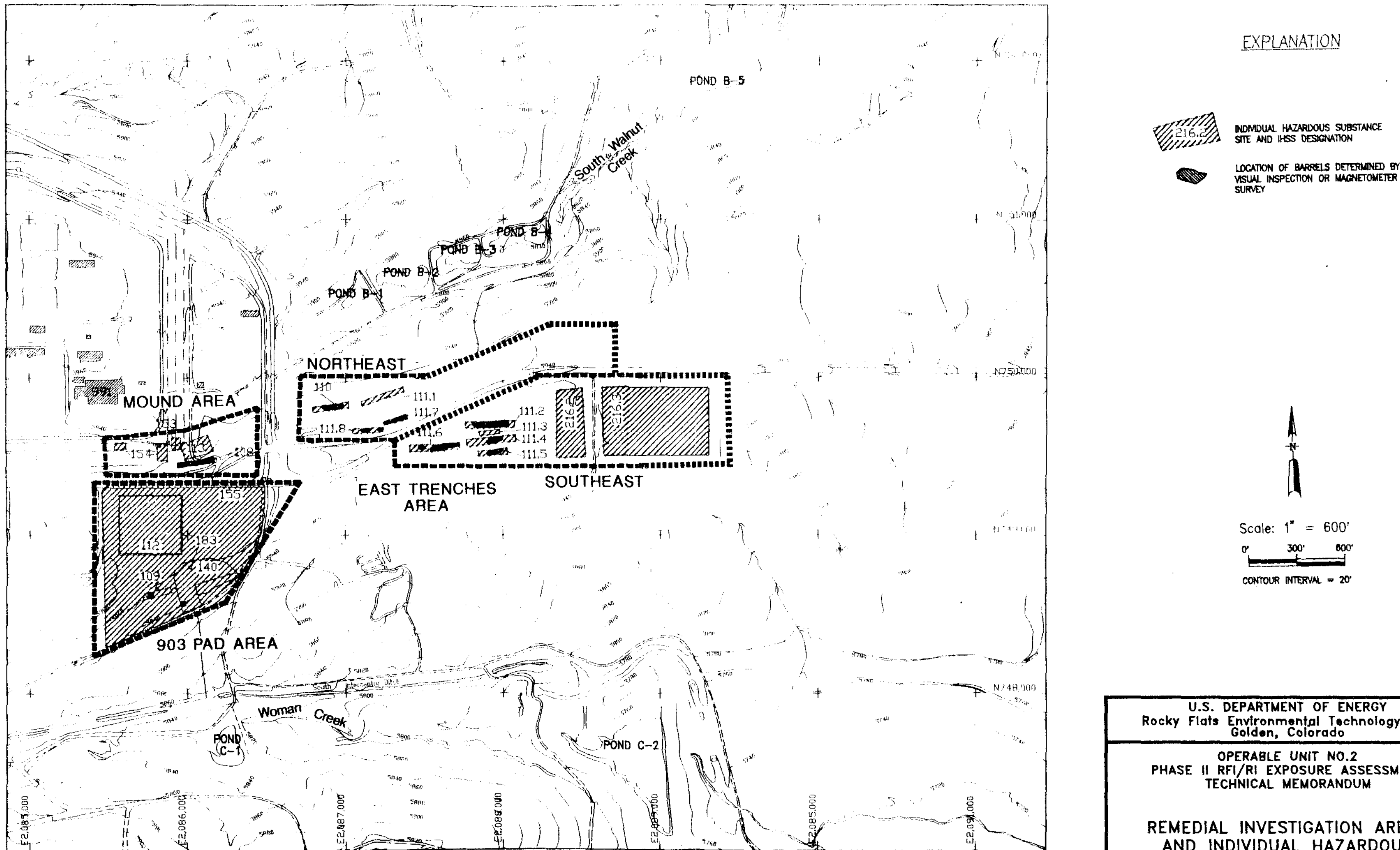
GENERAL LOCATION OF
ROCKY FLATS

FIGURE 2-1

JULY 1992

R33058



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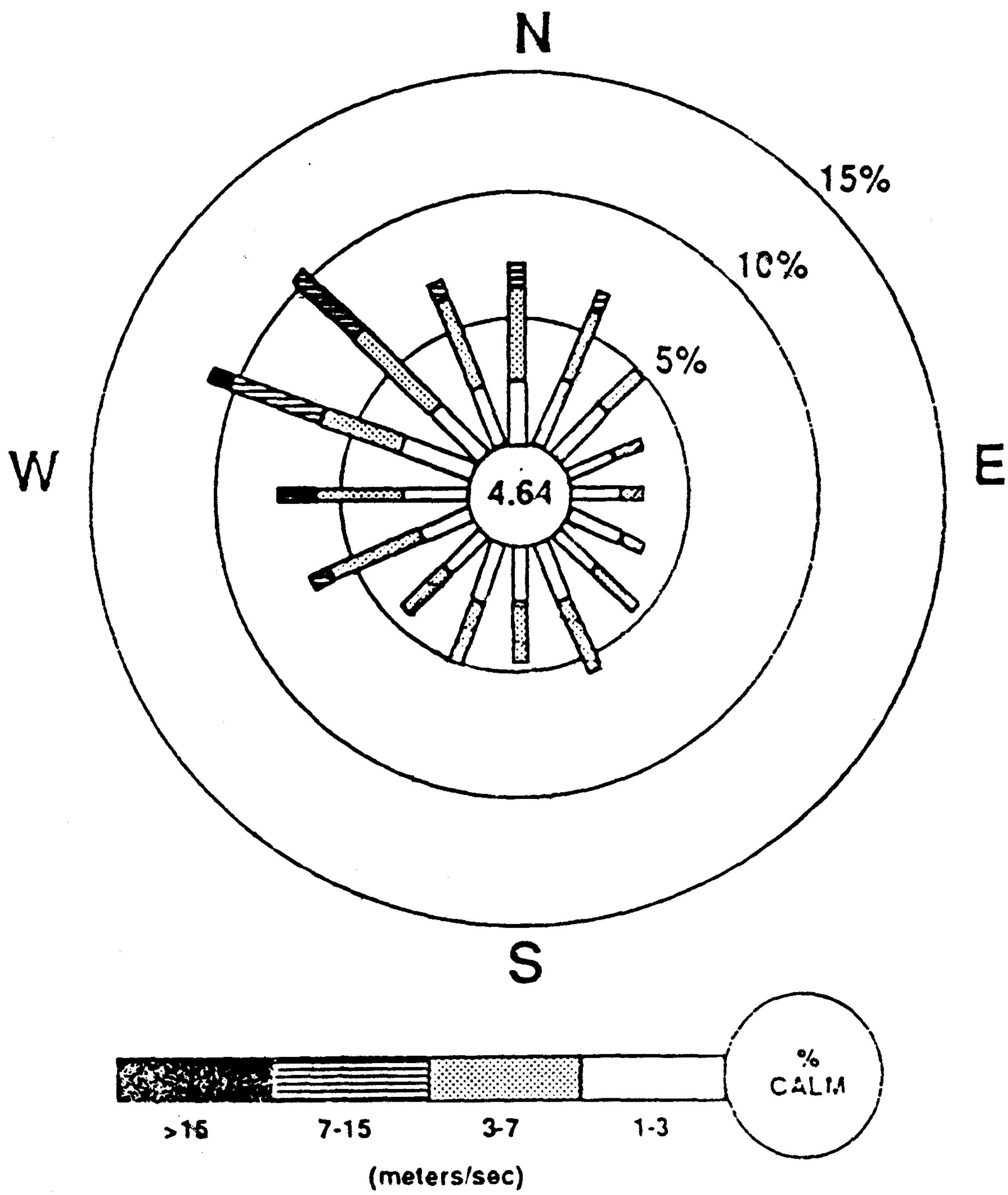
REMEDIAL INVESTIGATION AREAS AND INDIVIDUAL HAZARDOUS SUBSTANCE SITES

FIGURE 2-2 JUNE 1992



SOURCE: EG&G 1990.

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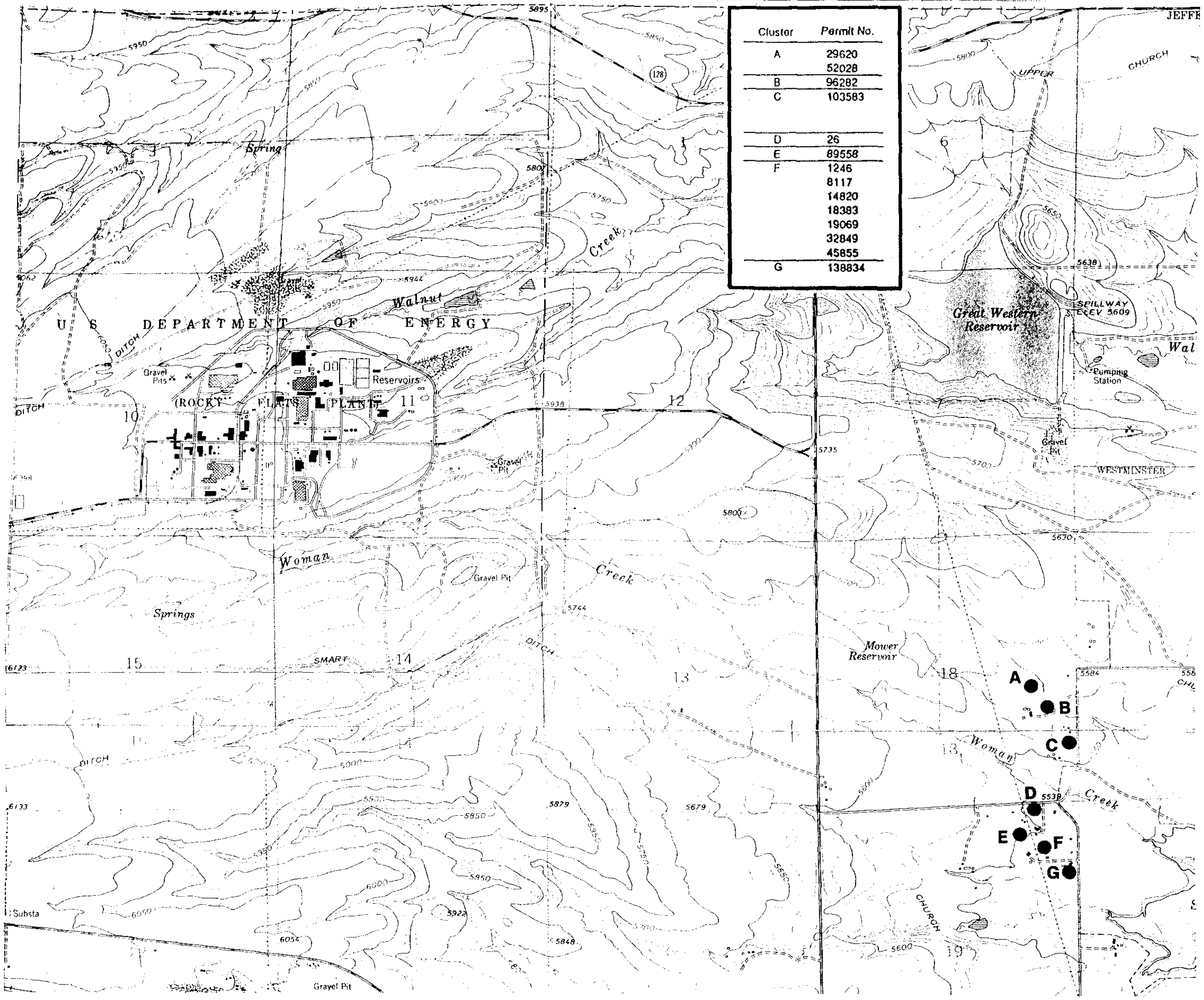
WIND ROSE FOR ROCKY FLATS
1990 ANNUAL

FIGURE 2-3 JUNE 1992



Cluster	Permit No.
A	29620
	52028
B	96282
C	103583
D	26
E	89558
F	1246
	8117
	14820
	18383
	19069
	32849
	45855
G	138834

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LOCATION OF WELLS
NEAR WOMAN CREEK

FIGURE 2–5 JUNE 1992

3.0
POTENTIAL RECEPTORS AND EXPOSURE AREAS

RFETS is located in a rural area of unincorporated Jefferson County, approximately 16 miles northwest of Denver and approximately 10 miles south of Boulder. The area to the west of RFETS is mountainous, sparsely populated, and primarily government-owned. The area east of RFETS is an arid plain, densely populated in some areas, and privately owned. Most of the development in the plains east of RFETS has occurred since the plant was built, and development is expected to continue in the future.

The most significant commercial and residential development within a 10-mile radius of the center of RFETS is located to the southeast, in the cities of Westminster, Arvada, and Wheat Ridge. The cities of Boulder, to the northwest; Broomfield, Lafayette, and Louisville, to the northeast; and Golden, to the south, are also present within this 10-mile radius.

3.1 CURRENT AND FUTURE LAND USE

Table 3-1 summarizes the current patterns of land use on and near RFETS and categorizes future land use scenarios as (1) improbable (unlikely to occur) or (2) credible (could reasonably occur or is expected to occur). Current and future land use is discussed in more detail in the following sections.

3.1.1 Current Off-Site Land Use

Land surrounding RFETS is used for open space (recreational), agricultural, residential, and commercial/industrial purposes. Predominant land uses in the area immediately southeast of RFETS include open space, single-family detached dwellings, and horse-boarding operations. The nearest residence is located across Indiana Street at the southeast corner of the RFETS property line. Another nearby residence in the predominant wind direction (southeast) is located about 0.8 miles east of Indiana Street, also near the southeast boundary of RFETS. Small cattle herds (approximately 10 to 60 cattle in each herd) have been observed grazing in fields east and southeast of the site. Industrial facilities to the south include the TOSCO laboratory, Great Western Inorganics Plant, and Frontier Forest Products (DOE 1990).

3.1.2 Future Off-Site Land Use

The northeastern Jefferson County area near RFETS has been one of the most active areas of industrial development in the Denver metropolitan area. The "Northeast Community Profile" (Jefferson County 1989) contains a baseline profile of growth and land use in the area and projects compatible with future development scenarios. As a result of this study, Jefferson County expects that industrial land use will dominate the northeastern portion of the county. Industrial and commercial development of the area is attractive to businesses and developers because of the lower cost and lower taxes associated with locating on undeveloped land in an unincorporated portion of the county. With the increase in industrial development, household and population growth is expected to increase only moderately because of the reduced availability of land for residential development.

Future land use in the area is also the topic of "The North Plains Community Plan" (Jefferson County 1990). The plan is intended to serve as a guide to the county and cities to achieve compatible land use and development decisions, regardless of the jurisdiction in which they are proposed. The plan was developed by representatives of Jefferson County, five cities (Arvada, Broomfield, Golden, Superior, and Westminster), and participants from a variety of interest groups including homeowners, businesses, builders/developers, environmentalists, and special districts. The plan identifies Rocky Flats and the Jefferson County Airport as potential constraints to future residential development in the area and recommends office and light industrial development. The plan further identifies the acquisition of land for open-space uses as a high priority for the area, recommending that large amounts of undeveloped land be provided for this purpose (Jefferson County 1990).

Under the plan, the predominant future land uses to the south and southeast of Rocky Flats will consist of commercial, industrial, and office space. Directly to the east, the zoning and usage are expected to remain open-space and agricultural or vacant. The areas closest to Rocky Flats are planned for industrial, commercial, or office space, with the areas further from Rocky Flats designated for residential development.

To the north of Rocky Flats, in Boulder County, the predominant land uses include open-space, park land, and industrial development. Two areas adjacent to Rocky Flats have been annexed by the cities of Broomfield and Superior. These two cities have participated in the

Jefferson County cooperative planning process and are planning business, industrial, and mixed land uses for the area (Jefferson County 1990; City of Broomfield 1990; Boulder County 1991).

The above information indicates that land adjacent to RFETS is lightly populated, with current use being primarily open space and agricultural. These uses, as well as commercial/industrial development, are likely to continue in the future. Residential development in the area northeast of the site may be impeded by the growth of business and industry that is expected to occur. However, land use in the area immediately east and southeast of the site is likely to continue to be open space, residential, agricultural, and commercial/industrial. Thus, future off-site use of land for commercial/industrial development, residential communities, agriculture, and recreational activities were each considered credible scenarios.

3.1.3 Current On-Site Land Use

RFETS operations and maintenance activities do not occur in OU2. The 903 Pad portion of OU2 is capped. Most of OU2 is located in the buffer zone, beyond the security fence and developed portion of the facility. Current activities in OU2 consist of environmental investigations, monitoring, cleanup, and routine security surveillance.

Elsewhere in the RFETS buffer zone, along the western edge of the RFETS property, gravel mining operations have been conducted since the early 1900s. Since 1990, Western Aggregates, Inc. has operated a mine and processing plant there.

3.1.4 Future On-Site Land Use

RFETS is currently performing environmental restoration activities and planning for decontamination and decommissioning, waste management, transition, and economic development.

The Rocky Flats Local Impacts Initiative (RFLII) is working with the DOE and local economic development agencies to identify and attract businesses to occupy existing buildings at the RFETS (RFLII 1992). Private industry could occupy existing buildings and use existing equipment after decontamination is complete. The RFLII is working to achieve this objective and promote the transformation of Rocky Flats into socioeconomic and environmental advantages.

Large portions of the buffer zone surrounding the developed portions of the plant, including portions encompassed by OU2, could remain open space. When the U.S. Atomic Energy Commission (AEC) acquired the undeveloped land surrounding the production area, it established plans to preserve the land as open space (AEC 1972). Because open space is located adjacent to the RFETS property, it is possible that the buffer zone and OU2 area will be preserved as open space or as an ecological reserve.

Ecological surveys of the buffer zone, performed in compliance with the Threatened and Endangered Species Act, have identified the presence of several listed species at Rocky Flats. Additional threatened and endangered species surveys are ongoing and may be performed in the future to identify and provide for the protection of any threatened and endangered species at the site, if necessary. Because the buffer zone has not been impacted by commercial development for many years, thus allowing progressive re-establishment of quality native habitats, the future use of this area as an ecological reserve is reasonable. This usage is consistent with DOE policy and plans (DOE 1992) and with the Jefferson County Planning Department's recommendations for the provision of large amounts of undeveloped land in the area (Jefferson County 1990). The Jefferson County Board of Commissions has also adopted a resolution stating its support of maintaining, in perpetuity, the undeveloped buffer zone of open space around Rocky Flats for environmental, safety, and health reasons (Jefferson County Board of Commissions 1994).

Extensive development of the buffer zone is unlikely due to the potential for conversion of the buffer zone into an ecological reserve and the steep topography in parts of the drainages. The steep slopes associated with some of the drainages in the area, particularly the Walnut Creek drainage, are not conducive to extensive residential or commercial development. Due to the potential hazards associated with unstable slopes, landslides, and slope failures, Jefferson County emphasizes that development should only occur on slopes with grades of 30 percent or less (Jefferson County 1990). Approximately 25 percent of the land in the eastern portion of RFETS is at or approaching this grade.

Gravel mining is also evaluated as a future land use scenario, given the presence of current mining operations in the western portions of the RFETS buffer zone.

In summary, future on-site residential development is inconsistent with land use plans for the area. Future land use would more likely involve industrial or office complexes at the developed portions of the plant and open-space uses in the buffer zone. Thus, on-site commercial/industrial uses of facilities and designation of the buffer zone as an ecological reserve were considered to be credible future land use scenarios, whereas on-site use of land for residential or agricultural purposes was considered to be improbable.

3.2 RECEPTORS SELECTED FOR QUANTITATIVE RISK ASSESSMENT

Receptor populations selected for quantitative evaluation in the human health risk assessment at OU2 are summarized in Table 3-2. They include current and future off-site residents, current on-site workers, hypothetical future on-site residents, and future on-site industrial/office workers, construction workers, ecological workers, and gravel miners. Each of these receptors is described in further detail below.

- Current Off-Site Residents: The two closest current residences to RFETS, each located near its southeast border, were selected to represent current off-site receptors (Figure 3-1).

- Current On-Site Workers: Current on-site workers are RFETS plant personnel who are assumed to conduct routine patrols within OU2.

- Future On-Site Workers: Future on-site industrial/office workers, construction workers, ecological researchers, and gravel miners will be evaluated in the HHRA. The future industrial/office worker is assumed to work indoors in a building complex with extensive paved areas and well-maintained landscaping. The future on-site construction worker is assumed to contact subsurface soil during excavation activities associated with the construction of commercial buildings on the site. It is assumed that field work by the future ecological researcher will involve contact with surface soil, surface water, and sediments.

A future on-site gravel miner is assumed to have direct contact with subsurface soil.

- Future Off-Site Residents: To evaluate future off-site receptors, two hypothetical residences located on Indiana Street at Woman Creek and at Walnut Creek will be assessed. These hypothetical receptor locations are at the RFETS property boundary, adjacent to surface water being discharged from the site, and are located in the direction of prevailing winds. Locations are shown in Figure 3-1.

- Future On-Site Residents: Although on-site residential use is not consistent with future land-use plans and is considered improbable, hypothetical future on-site residential exposures will be evaluated in the HHRA.

3.3 RECEPTOR LOCATIONS AND EXPOSURE AREAS

For HHRAs conducted at RFETS, on-site exposures will be evaluated in separate Areas of Concern (AOCs) identified in the operable unit. AOCs are defined as one or several contaminant source areas that are in close proximity and can be evaluated as a unit in the HHRA. Five contaminant source areas were identified in OU2: the 903 Pad, Mound, Northeast Trenches, Southeast Trenches, and East of IHSSs areas (DOE 1994a).

AOC No. 1 includes the 903 Pad, Mound, Northeast Trenches, and Southeast Trenches source areas, which contain all of the IHSSs that were investigated in OU2 (Figure 3-2). The 903 Pad, Mound, and Northeast Trenches source areas are hydrogeologically connected; the Southeast Trenches area does not contain groundwater. Elevated maximum concentrations of chlorinated hydrocarbons have been detected in groundwater from 903 Pad, Mound, and Northeast Trenches source areas. The probable source of contamination of groundwater in these areas is subsurface soil contamination. These source areas form a logical AOC based on their historical use for waste disposal and the presence of contiguous groundwater contaminant plumes.

The following on-site receptors will be evaluated in AOC No. 1:

- Current worker
- Future industrial/office worker
- Future construction worker
- Future ecological researcher
- Future gravel miner
- Hypothetical future on-site resident

In addition, health risks will be evaluated for a hypothetical future on-site resident in a 10-acre maximum exposure area, for a future industrial/office worker in a 30-acre maximum exposure area, and for an ecological researcher in a 50-acre area. The maximum residential exposure area (a 10-acre area that would be expected to pose the maximum risk to health) is located in the 903 Pad source area (Figure 3-3). This area has the highest contaminant levels of any source area in AOC No. 1 and will provide an upper-bound estimate of potential risk in AOC No. 1. The maximum exposure areas for the future on-site industrial/office worker and ecological researcher are the 30-acre and 50-acre areas, respectively, that include the 903 Pad Source area and adjacent areas, as shown in Figure 3-3.

AOC No. 2 is the East of the IHSSs area, located in the buffer zone between the IHSSs and Indiana Street (Figure 3-2). No IHSSs or other waste disposal areas are present in this AOC. Receptor scenarios evaluated in AOC No. 2 include those listed for AOC No. 1, except that risks will not be evaluated separately for 10-acre residential, 30-acre industrial, and 50-acre ecological exposure areas within AOC No. 2. Data from samples collected in the entire East of IHSSs area will be used to estimate chemical exposure. All samples taken from east of the IHSSs area will be used because the data set is relatively small for the entire AOC, which precludes the use of data from individual 10- or 30-acre plots; contaminant levels are relatively low and the analytical results appear to characterize the area well; there is no evidence for "hot spots" that would warrant separate evaluation; and historical data indicate that no waste disposal occurred in this area (DOE 1994a).

In addition, current and future off-site residential receptors will be evaluated for potential exposure to chemicals transported in air from AOC No. 1 and from AOC No. 2.

Groundwater modeling (to predict discharges to surface water) and surface water modeling are being performed on an OU-wide basis. The modeling will yield estimates of chemical concentrations in surface water in Walnut and Woman creeks at Indiana Street for use in evaluating both on- and off-site exposure scenarios that include exposure to surface water/ suspended sediment.

TABLE 3-1

ROCKY FLATS OU2
SUMMARY OF CURRENT AND FUTURE LAND USES

	Current		Future	
Land Use Category	**Off Site**	**On Site**	**Off Site**	**On Site**
Residential	Yes	No	Credible[a]	Improbable[b]
Commercial/Industrial	Yes	Yes	Credible	Credible[c]
Recreational	Yes	No	Credible	Credible[d]
Ecological Reserve	No	No	Improbable	Credible[d]
Agricultural	Yes	No	Credible	Improbable
Gravel Mining	Yes	No	Credible	Credible

[a] Credible is used to indicate scenarios that could reasonably occur.
[b] Improbable is used to indicate scenarios that are unlikely to occur.
[c] Expected in the currently developed area of the plant site.
[d] Expected in the buffer zone.

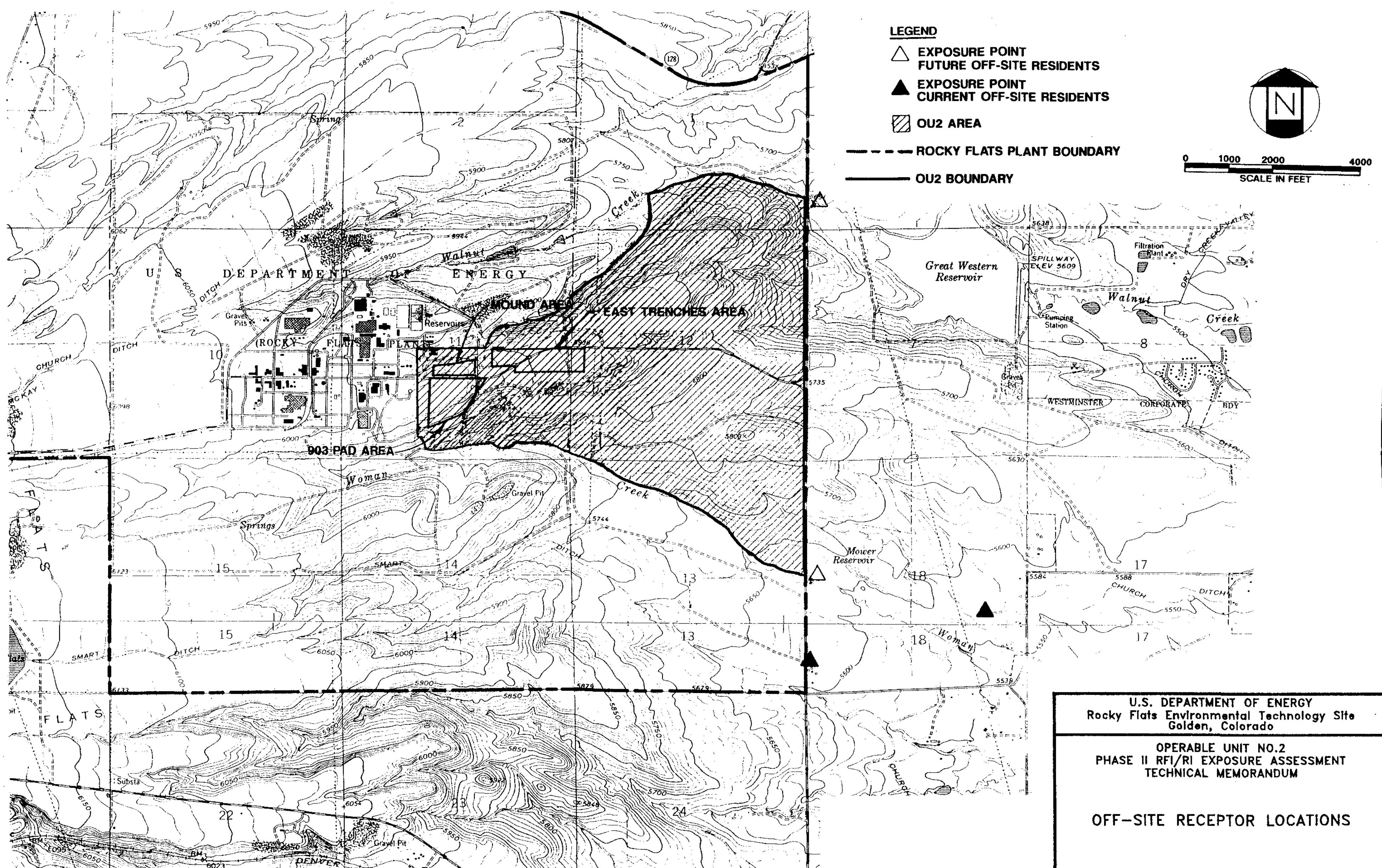
TABLE 3-2

ROCKY FLATS OU2
POTENTIALLY EXPOSED RECEPTORS

Current Scenario	Future Scenario
Off-site resident	Hypothetical off-site resident *
On-site worker	On-site worker (industrial/office and construction)
	On-site ecological researcher
	On-site gravel miner
	Hypothetical on-site resident

* A future off-site hypothetical resident will be evaluated at the following locations:

(a) Point at which Walnut Creek intersects the eastern RFETS property boundary
(b) Point at which Woman Creek intersects the eastern RFETS property boundary



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OFF-SITE RECEPTOR LOCATIONS

FIGURE 3-1 JANUARY 1993

EXPLANATION

- INDIVIDUAL HAZARDOUS SUBSTANCE SITE LOCATION
- APPROXIMATE EXTENT OF GROUNDWATER CONTAMINATION
- AREA OF CONCERN NO. 1

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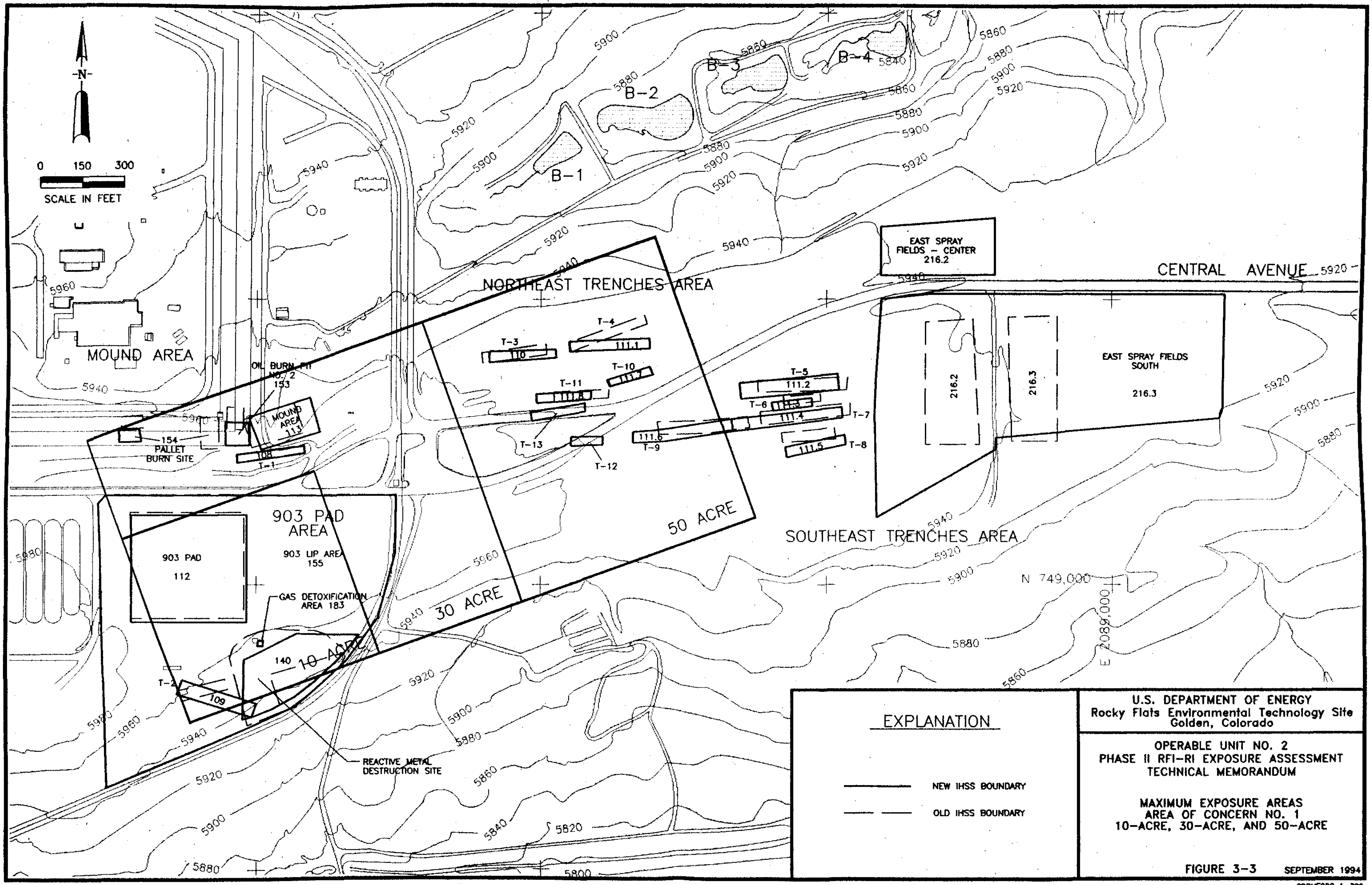
SOURCE AREA BOUNDARIES AND AREAS OF CONCERN

FIGURE 3-2 SEPTEMBER 1994

CDPHE001 1=500

CDPHE001



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MAXIMUM EXPOSURE AREAS
AREA OF CONCERN NO. 1
10-ACRE, 30-ACRE, AND 50-ACRE

FIGURE 3-3 SEPTEMBER 1994

CDPHE008 1=300

4.0
EXPOSURE PATHWAYS

This section discusses the potential release and transport of chemicals from OU2 and identifies exposure pathways by which the receptor populations identified in Section 3.0 may be exposed to site chemicals.

An exposure pathway describes a specific environmental pathway by which chemicals may be transported to human exposure points. A complete exposure pathway requires each of the following five elements:

- Source of chemicals
- Mechanism of chemical release
- Environmental transport medium
- Exposure point
- Human intake route

If one of these elements is lacking, the pathway is incomplete, and no human exposure can occur. Incomplete pathways, as well as negligible pathways that would not contribute to overall risk estimates, are identified in this technical memorandum but are not evaluated in the risk assessment.

4.1 CHEMICAL SOURCES AND RELEASE AND TRANSPORT MECHANISMS

The primary source of chemicals in OU2 is contaminated surface and subsurface soil at the 903 Pad, Mound, and East Trenches areas. Potential release mechanisms from contaminated soil to the environment include storm water runoff, volatilization, wind suspension, infiltration and percolation to groundwater, direct contact, root uptake, and radioactive decay. Transport media include groundwater, surface water, and air. These release and transport mechanisms and affected media are illustrated in the CSM presented in Figure 4-1.

4.2 EXPOSURE POINTS

An exposure point is a specific location where human receptors can come in contact with site-related chemicals. Exposure points are selected so that reasonable maximum exposures will be quantitatively evaluated. Evaluation of risks at these exposure points will bound the risks for receptors at other locations where chemical exposure is lower. Receptor locations were discussed in Section 3.2 and are summarized below.

Current Use

- Off-site residential receptor. Nearest residence to RFETS (located at the southeast corner of the RFETS property boundary) and nearest residence to RFETS which is in the predominant southeasterly wind direction. These locations will be assessed for impacts from AOC No. 1 and AOC No. 2.

- On-site worker. AOC No. 1 and AOC No. 2.

Future Use

- Off-site residential receptors. (1) On Indiana Street at South Walnut Creek and (2) on Indiana Street at Woman Creek. These locations will be assessed for impacts from AOC No. 1 and AOC No. 2.

- On-site industrial/office worker. AOC No. 1 (all), AOC No. 1 (30-acre maximum exposure area), and AOC No. 2.

- On-site construction worker. AOC No. 1 and AOC No. 2.

- On-site ecological researcher. AOC No. 1 (all), AOC No. 1 (50-acre maximum exposure area), and AOC No. 2.

- On-site gravel miner. AOC No. 1 and AOC No. 2.

- Hypothetical on-site residential receptors. AOC No.1 (all), AOC No. 1 (10-acre maximum exposure area), and AOC No. 2.

4.3 HUMAN INTAKE ROUTES

A human intake route is the mechanism by which a chemical is taken into the body. There are four basic human intake routes: dermal absorption, inhalation, ingestion and, for radionuclides, external irradiation. Quantifying chemical intake by these routes is described further in Section 5.0.

4.4 POTENTIAL EXPOSURE PATHWAYS

Figure 4-1 shows a CSM of potential human exposure pathways for OU2. The CSM is a schematic representation of the chemical sources, chemical release mechanisms, environmental transport media, human intake routes, and human receptors for OU2. The purpose of the CSM is to provide a framework for problem definition, to identify exposure pathways that may result in human health risks, to aid in identifying data gaps, and to aid in identifying effective cleanup measures, if necessary, that are targeted at significant contaminant sources and exposure pathways.

The CSM identifies three types of exposure scenarios: (1) potentially complete and significant exposure pathways, (2) potentially complete and relatively insignificant exposure pathways, and (3) negligible or incomplete exposure pathways. Potentially complete pathways will be quantitatively addressed in the risk assessment and CT and RME intake factors for these pathways and receptors are presented in Attachment 1. Negligible or incomplete exposure pathways are discussed but are eliminated from further consideration in the quantitative HHRA.

The following subsections describe the exposure pathways shown in the CSM and the assumptions used in characterizing them. A summary of potentially complete exposure pathways that will be quantitatively evaluated in the HHRA is provided in Table 4-1.

4.4.1 Site-Wide Incomplete Exposure Pathways

The CSM indicates that the following exposure pathways are negligible or incomplete (indicated with an N) for all receptors. These pathways will not be quantitatively addressed in the risk assessment.

- Ingestion of fish in Woman or Walnut creeks is an incomplete exposure pathway for all receptors. Flow in Walnut and Woman creeks is intermittent, with flow varying from no flow in dry seasons to approximately four times the annual average flow during heavy rains (Advanced Sciences 1990). Fish ingestion should be evaluated in risk assessment if subsistence fishing occurs (EPA 1991). However, due to intermittent flow and the absence of seasonal populations of food or sport fish, subsistence fishing is unlikely, nor has it been observed to occur in the area. Therefore, ingestion of fish is an incomplete exposure pathway for current and future receptors.

- Ingestion of beef from livestock watering in the creeks is also an incomplete pathway for all receptors. Livestock raising for home butchering is not known to occur in the Walnut and Woman Creek drainages adjacent to RFETS. Small herds of cattle are grazed temporarily in fields east of RFETS, but these stock cattle are shipped out of the area each season. Furthermore, the intermittent flow in the creeks does not support consistent livestock watering. Therefore, ingestion of beef from livestock is negligible exposure pathway for both current and future receptors.

- Inhalation of volatile organic chemicals (VOCs) released to outdoor air through volatilization from soil or groundwater is considered a negligible pathway for all receptors. Volatile chemicals in surface soils, if once present, will have already volatilized; VOCs released from groundwater will be significantly retarded through the subsurface soil and diluted in the ambient air; and VOCs released from subsurface soil upon excavation or mining will also be diluted to negligible concentrations in the outdoors.

- Significant concentrations of volatile organics and metals have not been detected in the Lower Hydrostratigraphic Unit (LHSU) (DOE 1993). Therefore, exposure to groundwater in the LHSU is negligible for all receptors.

- For on-site receptors, exposure to airborne particulate matter that was eroded from and redepositioned on surface soil is negligible via ingestion, dermal contact, and external irradiation routes because the exposures are accounted for through evaluating direct contact with and irradiation from surface soil.

4.4.2 Current Off-Site Resident

For the current off-site resident, only exposure pathways associated with wind suspension and deposition of particulates are potentially complete. These pathways are soil ingestion, inhalation of airborne particulate matter, dermal contact with soil, and ingestion of garden produce following deposition of particulates.

Exposure to surface water or sediment off-site in Woman or Walnut creeks are not evaluated for the current off-site residents because, under the RFETS surface water management plan, surface water is monitored and discharged at concentrations that meet applicable federal and state surface water requirements. Therefore, the creeks do not provide a means of off-site exposure to site contaminants. (Exposure to modeled concentrations of contaminants in the creeks is evaluated for the future off-site residential scenario).

Root uptake of contaminants deposited as windblown particulates on soil is considered to be a negligible pathway because metals bind tightly to soil, reducing their bioavailability to plants, and chemical concentrations from particulates deposited on residential soil will be significantly diluted by tilling. For these reasons, chemical concentrations in garden produce due to surface deposition are expected to be greater than that due to uptake by roots. Therefore, chemical intake from garden produce will only be evaluated for surface deposition of particulates.

External irradiation exposures to off-site residents resulting from deposition of radionuclides in airborne particulate matter is considered a negligible pathway because concentrations of radionuclides in off-site soil are relatively low (DOE 1994b). For example, the maximum activity of plutonium detected in 45 off-site surface soil samples was 2.95 pCi/g in a sample collected at Indiana Street due east of RFETS (DOE 1994b). The next highest result was 0.745 pCi/g. These levels are below a conservative (health-protective) risk-based level of 3.43 pCi/g for long-term residential exposure to soil (DOE 1994d). Furthermore, the primary radionuclides of concern at RFETS, plutonium and americium, do not have highly penetrating radiation associated with them.

As shown in the CSM, no exposure to on-site soil at OU2, groundwater, surface water, or sediments is assumed for the off-site resident because access to RFETS is restricted.

Groundwater in the UHSU is hydraulically disconnected from the lower-confined aquifer by an impermeable claystone. Thus, potential exposure pathways to UHSU groundwater via domestic wells located west of Standley Lake and along the Woman Creek drainage are considered negligible. There are no domestic wells located west of Great Western Reservoir in the Walnut Creek drainage.

In summary, potentially complete human exposure pathways for the current off-site resident are:

- Inhalation of airborne particulates from OU2 surface soil
- Soil ingestion (following deposition of particulates)
- Dermal contact with soil (following deposition of particulates)
- Ingestion of garden produce (following deposition of particulates on edible surface)

4.4.3 Current On-Site Worker

For the current on-site worker, exposure pathways associated with wind suspension of particulates and exposure to surface soil (incidental ingestion, dermal contact, and external irradiation) are potentially complete.

Incidental ingestion of and dermal contact with surface water, suspended sediments, and subsurface soil are negligible exposure pathways for current on-site workers because their work does not bring them into contact with Walnut or Woman creeks, or with subsurface soil. Ingestion of produce grown on site is also an incomplete pathway for on-site workers.

Exposure of current on-site workers to UHSU groundwater is an incomplete pathway because drinking water for on-site workers is supplied by a municipal water supply that does not tap aquifers at RFETS.

Currently, no offices or other permanent structures are located on OU2. Thus, the inhalation of VOCs migrating from subsurface soil or groundwater into buildings is an incomplete exposure pathway.

In summary, potentially complete human exposure pathways for the current on-site workers are:

- Inhalation of airborne particulates
- Ingestion of surface soil
- Dermal contact with surface soil
- External irradiation from decay of radionuclides in surface soil

4.4.4 Future Off-Site Resident

Potentially complete exposure pathways for future off-site residents are those associated with wind suspension, storm water runoff to surface water, and groundwater discharge to surface water.

Chemicals may be transported to surface water and sediments in Walnut or Woman creeks by storm water runoff or by groundwater discharges to the drainages. Incidental ingestion of surface water and sediments is considered a potentially complete exposure pathway for the future off-site resident because it is assumed under a hypothetical future scenario that surface water discharges are not monitored, intercepted, or treated. Dermal contact with surface water and sediments in the future scenario is considered a relatively insignificant but potentially complete exposure pathway for this receptor.

Groundwater in the UHSU either discharges to surface water in Walnut and Woman creeks or is lost to evapotranspiration at seeps. The UHSU is hydraulically disconnected from the lower-confined aquifer by an impermeable claystone. Thus, exposure to groundwater via domestic wells located west of Standley Lake is considered incomplete.

Ingestion of homegrown produce potentially contaminated by deposition of airborne particulates represents a potentially complete exposure pathway. As discussed for the current off-site residential scenario in Section 4.4.2, root uptake of contaminants by plants is considered a negligible pathway. Therefore, future off-site residential intake of chemicals via ingestion of produce will only be evaluated for surface deposition of particulates. Inhalation of airborne particulate matter and ingestion and dermal exposure to contaminants deposited on soil are potentially complete pathways for the future off-site resident.

As discussed in Section 4.4.2, external irradiation exposures to future off-site residents resulting from deposition of radionuclides via airborne particulates is considered a negligible pathway.

In summary, potentially complete human exposure pathways for the future off-site resident are:

- Inhalation of airborne particulates
- Soil ingestion (following deposition of particulates)
- Dermal contact with soil (following deposition of particulates)
- Ingestion of surface water/suspended sediment
- Dermal contact with surface water/suspended sediment
- Ingestion of homegrown produce (following deposition of particulates on edible surface)

4.4.5 Future On-Site Industrial/Office Workers

For the future on-site industrial/office worker, pathways associated with wind suspension of particulates and exposure to surface soil are potentially complete. In addition, migration of VOCs from groundwater or subsurface soil through foundations, with a resultant accumulation in indoor air, represents a potentially complete inhalation exposure pathway.

Incidental ingestion of and dermal contact with surface water and sediments are considered incomplete exposure pathways for future on-site industrial/office workers because they will not work in the creek channels. It is assumed that drinking water will continue to be supplied from off-site sources and that direct groundwater exposure pathways are incomplete for future on-site workers. Contact with subsurface soil is an incomplete pathway for the industrial/office worker.

In summary, potentially complete human exposure pathways for the future on-site industrial/office workers are:

- Inhalation of airborne particulates from surface soil
- Surface soil ingestion
- Dermal contact with surface soil
- External irradiation from decay of radionuclides in surface soil
- Inhalation of VOCs migrating from subsurface soil or groundwater through foundations to indoor air

4.4.6 Future On-Site Construction Worker

The on-site construction worker scenario is used to evaluate potential exposures to subsurface soil at OU2. Exposure to surface soil is evaluated for other on-site receptors and is not included in the construction worker exposure scenario. Therefore, for the future on-site construction worker, pathways associated with wind suspension of particulates from subsurface soil and direct contact with subsurface soil are potentially complete. Contact with surface water and sediments is incomplete because construction is not assumed to occur in the creek beds. Groundwater exposure pathways are also incomplete because drinking water is expected to continue to be supplied from off-site sources. Since work occurs outdoors, inhalation of VOCs that may accumulate in buildings, following migration from subsurface sources, is also an incomplete pathway. Garden produce ingestion is not included in the construction worker scenario.

Complete exposure pathways to be evaluated for the construction worker scenario are:

- Inhalation of airborne particulates from subsurface soil
- Subsurface soil ingestion
- Dermal contact with subsurface soil
- External irradiation from decay of radionuclides in subsurface soil

4.4.7 Future On-Site Ecological Researcher

For the future on-site ecological researcher, exposure pathways associated with surface water/sediment, wind suspension, and exposure to surface soil are potentially complete.

Chemicals in surface soil may be transported in storm water runoff to surface water and sediments. Contaminants may also be released to surface water via groundwater discharges at seeps. Therefore, incidental ingestion of and dermal contact with surface water and sediments are potentially complete exposure pathways for the ecological researcher who may be wading in Walnut or Woman creeks.

Inhalation, ingestion, dermal, and external irradiation exposure to contaminants in surface soil are each potentially complete pathways for future on-site ecological researchers.

Direct exposure to groundwater, ingestion of plants and animals, and indoor air exposure are incomplete pathways for future on-site ecological researchers.

In summary, potentially complete exposure pathways for the future ecological researcher are:

- Surface water and sediment ingestion
- Dermal contact with surface water and suspended sediment
- Inhalation of airborne particulates from surface soil
- Ingestion of surface soil
- Dermal contact with surface soil
- External irradiation from decay of radionuclides in surface soil

4.4.8 Future On-Site Gravel Miner

For the future on-site gravel miner, exposure pathways derived from wind suspension, volatilization from subsurface soil, direct contact with subsurface soil, and external irradiation from subsurface soil are considered potentially complete pathways. Pathways associated with exposure of future on-site gravel miners to surface soil are considered negligible and will not be evaluated because only a few days are required for excavation and removal of surface soil and therefore the exposure duration is negligible.

Storm water runoff and groundwater may carry chemicals to surface water bodies on OU2. However, ingestion and dermal exposure to surface water is a negligible pathway for future on-site gravel miners who would not be expected to come into contact with surface water in their work. Generation of airborne particulates from subsurface soil may occur during gravel mining, excavation, and processing procedures. Inhalation of airborne particulates from subsurface soil and direct contact with subsurface soil may occur during gravel mining excavation and processing procedures. Ingestion, dermal, and external radiation exposure to subsurface soil are also potentially complete pathways for the future on-site gravel miner.

In summary, potentially complete pathways for the future on-site gravel miner are:

- Inhalation of airborne particulates (from subsurface soil)
- Ingestion of subsurface soil
- Dermal contact with subsurface soil
- External radiation from decay of radionuclides in subsurface soil

Inhalation of VOCs released from subsurface soil during earthmoving, although a negligible exposure pathway, is also evaluated in this exposure scenario.

4.4.9 Future On-Site Resident

For the future on-site residents, exposure pathways derived from storm water runoff, volatilization, wind suspension and deposition, groundwater, direct contact with surface soil, external radiation from surface soil, and root uptake from surface soil by plants were considered potentially complete.

Chemicals may be transported to surface water and sediments in Walnut or Woman creeks by storm water runoff or by groundwater discharges to the drainages. Incidental ingestion of surface water and sediments is considered a potentially complete exposure pathway. Dermal contact with surface water and sediments is a relatively insignificant but potentially complete exposure pathway for this receptor.

Although no domestic or commercial-use wells are located at RFETS, it is assumed that groundwater in the UHSU may be used by hypothetical on-site residents. Thus, ingestion and inhalation of VOCs released during domestic use were considered potentially significant exposure pathways. Migration of VOCs from groundwater and subsurface soil through building foundations represent a potentially complete indoor inhalation exposure pathway for future on-site residents.

Hypothetical on-site residents may be directly exposed to contaminants in surface soil by inhalation of airborne particulate matter. Direct contact with surface soil represents potentially complete oral and dermal exposure pathways for the hypothetical on-site resident. External irradiation from exposure to surface soil is also a potentially complete exposure pathway.

Homegrown produce, contaminated by deposition of airborne particulates represent a potentially complete exposure pathway. Although uptake of contaminants from soil by plants is probably an insignificant pathway, root uptake of contaminants from surface soil will be evaluated for future on-site residents.

In summary, potentially complete exposure pathways for the hypothetical future on-site resident are:

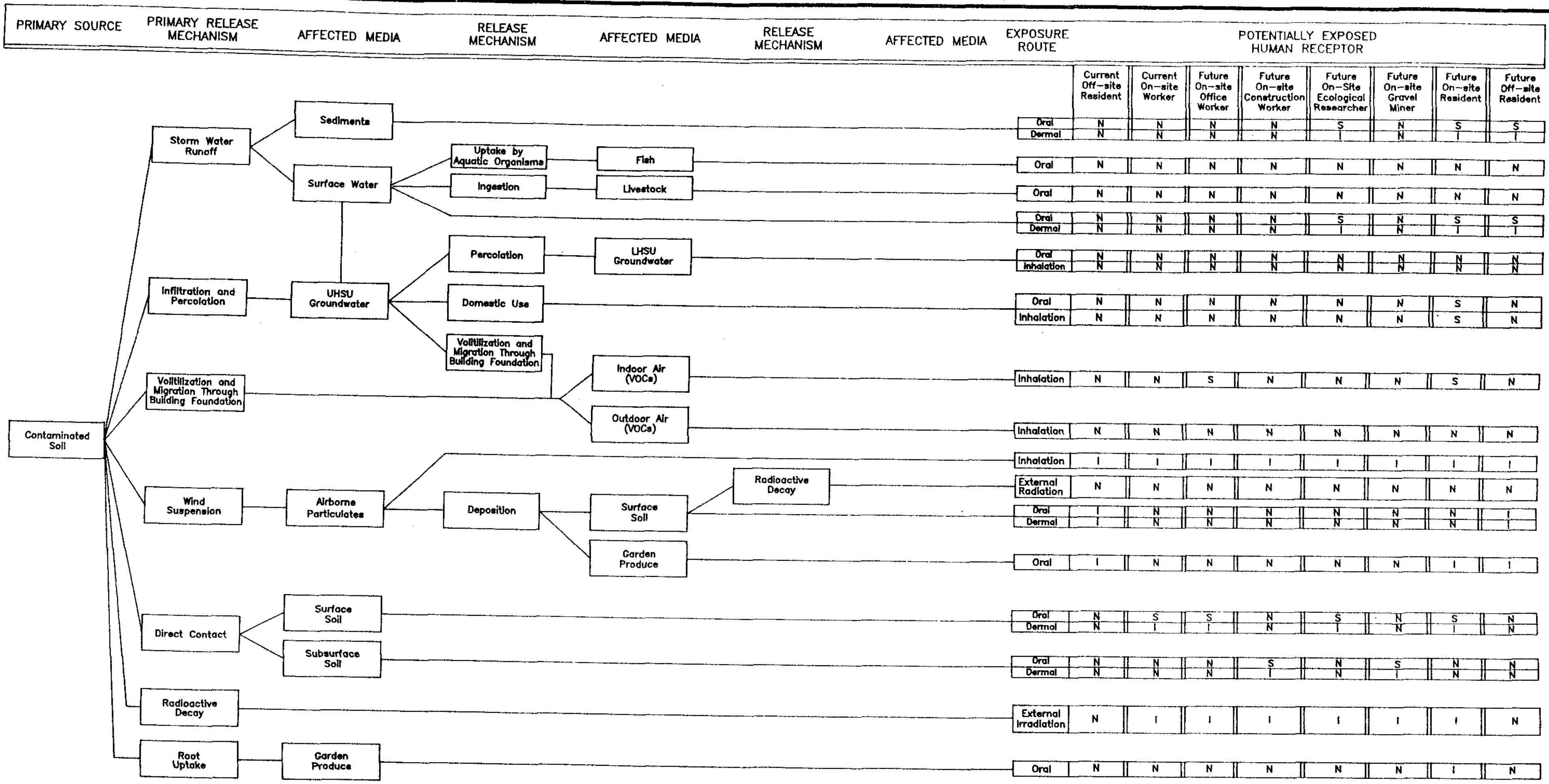
- Ingestion of surface water and sediment (Walnut and Woman creeks)
- Dermal contact with surface water and sediment
- Inhalation of airborne particulates from surface soil
- Inhalation of VOCs indoors (from domestic use of groundwater and migration through the foundation)
- Groundwater ingestion
- Surface soil ingestion

TABLE 4-1
ROCKY FLATS OU2
POTENTIALLY COMPLETE EXPOSURE PATHWAYS TO BE QUANTITATIVELY EVALUATED

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
Off-site resident	Current	Inhalation of airborne particulates from OU2 surface soil Soil ingestion (following deposition of particulates) Dermal contact with soil (following deposition of particulates) Ingestion of garden produce (surface deposition of particulates)
On-site worker	Current	Inhalation of airborne particulates from surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil
Hypothetical off-site resident	Future	Inhalation of airborne particulates from OU2 surface soil Ingestion of surface soil (following deposition of particulates) Dermal contact with soil (following deposition of particulates) Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Ingestion of garden produce (surface deposition of particulates)
On-site worker (industrial/office)	Future	Inhalation of airborne particulates from surface soil Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil Inhalation of indoor VOCs (from migration through foundation)
On-site construction worker	Future	Inhalation of airborne particulates from subsurface soil Ingestion of subsurface soil Dermal contact with subsurface soil External irradiation from subsurface soil

TABLE 4-1
(Concluded)

Potentially Exposed Receptor	Scenario	Potentially Complete Exposure Pathways
On-site ecological researcher	Future	Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Inhalation of airborne particulates Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil
On-site gravel miner	Future	Inhalation of airborne particulates from subsurface soil Inhalation of VOCs from subsurface soil (negligible) Ingestion of subsurface soil Dermal contact with subsurface soil External irradiation from subsurface soil
Hypothetical on-site resident	Future	Ingestion of surface water/suspended sediment Dermal contact with surface water/suspended sediment Inhalation of airborne particulates from surface soil Inhalation of indoor VOCs (from domestic use and migration through foundation) Ingestion of groundwater Ingestion of surface soil Dermal contact with surface soil External irradiation from surface soil Ingestion of vegetables (root uptake and surface deposition of particulates from surface soil)



LEGEND
- S Significant Potential Exposure Pathway
- I Insignificant Potential Exposure Pathway
- N Negligible or Incomplete Exposure Pathway
- UHSU Upper Hydrostratigraphic Unit
- LHSU Lower Hydrostratigraphic Unit

Note: Significant and insignificant potential exposure pathways will be quantitatively evaluated.

U.S. DEPARTMENT OF ENERGY
Rocky Flats Environmental Technology Site
Golden, Colorado

OPERABLE UNIT 2
EXPOSURE ASSESSMENT
TECHNICAL MEMORANDUM

CONCEPTUAL SITE MODEL FOR HUMAN EXPOSURE PATHWAYS

FIGURE 4-1 OCTOBER, 1994

RFCONC1

5.0
ESTIMATING CHEMICAL INTAKES

This section describes how intake is calculated for chemicals and radionuclides. Intake factors for central tendency (CT) and reasonable maximum exposure (RME) for each of the receptors and exposure pathways identified in Section 4.0 are presented in Attachment 1. Chemical intakes are not present in this memorandum since they are dependent on exposure point concentrations determined from chemical data and from fate and transport modeling, as appropriate.

5.1 METHOD FOR CALCULATING INTAKE

Using the exposure point concentrations of chemicals in soil, surface water, and air, it is possible to estimate the potential human intake of those chemicals via each exposure pathway. Chemical intake is expressed in terms of milligram (mg) chemical ingested, inhaled, or dermally absorbed per kilogram/body weight per day (mg/kg-day). Intakes are calculated following guidance in "Risk Assessment Guidance for Superfund" (EPA 1989a), the "Exposure Factors Handbook" (EPA 1989b), other EPA guidance documents, relevant scientific literature, and professional judgment regarding probable site-specific exposure conditions. Intakes are estimated using reasonable estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, frequency and duration of exposure, and chemical concentration.

Intakes are estimated for average CT and for RME conditions, as recommended by EPA (EPA 1992). The RME is estimated by selecting values for exposure variables so that the combination of all variables results in the maximum exposure that can reasonably be expected to occur at the site. The CT is estimated by selecting average values for exposure variables.

The general equation for calculating chemical intake in terms of mg/kg-day is:

$$\text{Intake} = \frac{\text{chemical concentration} * \text{contact rate} * \text{exposure frequency} * \text{exposure duration}}{\text{body weight} * \text{averaging time}}$$

with corresponding units of:

$$\text{mg/kg/day} = \frac{\text{mg/volume or mass} * \text{volume or mass/day} * \text{day/year} * \text{year}}{\text{kg} * \text{day}}$$

The variable "averaging time" is expressed in days to calculate daily intake. For noncarcinogenic chemicals, intakes are calculated by averaging over the period of exposure to yield an average daily intake. For carcinogens, intakes are calculated by averaging the total dose over a lifetime, yielding "lifetime average daily intake." Different averaging times are used for carcinogens and noncarcinogens because it is thought that their effects occur by different mechanisms. The approach for carcinogens is based on the scientific opinion and EPA policy that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime, and that even very low doses of carcinogens have the potential to cause cancer. Therefore, the intake of a carcinogen is averaged over a 70-year lifetime (EPA 1989a). Intake of noncarcinogens is averaged only over the period of exposure in order to compare an estimate of actual daily dose to a reference dose considered safe for a lifetime of exposure.

Omitting chemical concentrations from the intake equation yields an "intake factor" that is constant for each exposure pathway/receptor combination. The intake factor can then be multiplied by the concentration of each chemical to obtain the pathway/receptor-specific intake of that chemical. Intake factors will be calculated separately for each potentially exposed receptor and exposure pathway that was identified in Section 4.0. Contact rates, such as dermal contact, food intake, and inhalation (but not soil ingestion) are approximately proportional to body weight. It is acknowledged that body weight is not exactly proportional to body surface area and that age-specific body weight/inhalation rates differ by factors of two or less. However, these differences are assumed to be negligible. Therefore, child residential intakes are not estimated for any exposure pathway except soil ingestion. Should residential exposure and risk continue to be a concern, additional potentially complete pathways for children may be evaluated qualitatively in the Uncertainty section of the HHRA.

5.2 CALCULATING THE AIR CONCENTRATION OF VOCs FROM DOMESTIC USE OF WATER

Based primarily on experimental data on the volatilization of radon from household uses of water, Andelman (1990) derived a volatilization constant that defines the relationship between the concentration of a contaminant in household water and the average concentration of the volatilized contaminant in air. In the derivation, all uses of household water are considered (e.g., showering, laundering, dish washing). Certain reasonable assumptions are made in deriving the volatilization fraction (VF). For example, assumptions are made about water usage for a family of four, the volume of the dwelling and the air exchange rate. Furthermore, it is assumed that the average transfer efficiency weighted by the type of water use is 50 percent (i.e., half of the concentration of each chemical in water will be transferred into air by all types of water uses).

An upper-bound value for the VF of 0.5 mg/m^3 air per mg/l water can be multiplied times the average concentration of contaminant in water to yield the RME airborne concentration. Equivalently, a CT value for the VF of 0.065 mg/m^3 air per mg/l water (Andelman 1990) may be multiplied by the upper-bound concentration of contamination in water (95 percent UCL of the arithmetic mean) to yield the RME airborne concentration. Since upper-bound water concentrations are used for the ingestion and dermal contact pathways, the latter method is used to estimate the RME concentration of contaminant in air.

5.3 CALCULATING RADIATION EXPOSURES

5.3.1 Internal Exposure to Radionuclides

Internal exposure to radionuclides identified as chemicals of concern will be evaluated in two ways. First, the committed effective dose equivalent per year exposure based on the annual intake of radionuclides via ingestion or inhalation will be calculated and compared to annual radiation protection standards. The second method for evaluating internal radionuclide exposure is to calculate the lifetime intake of each radionuclide and multiply that intake by the respective EPA-derived carcinogenic slope factor (EPA 1989a). The result of this calculation is the unitless lifetime carcinogenic risk associated with ingestion or inhalation of a given radionuclide of concern.

Calculation of intake for radionuclides is conducted in a similar manner as for nonradioactive chemicals of concern. Intake of radionuclides by either ingestion or inhalation is a function of radionuclide activity concentration, intake rate (or the amount of contaminated medium contacted per unit time or event), and exposure frequency and duration (for lifetime intake). The only difference between calculating intake for radionuclides and nonradioactive substances is that the averaging time and body weight are excluded as divisors from the intake equation.

To calculate the committed effective dose equivalent for comparison to radiation protection standards, the annual intake of radionuclides through inhalation or ingestion is estimated using the following equation:

$$Intake_{,int} = C * IR * EF$$

Where:

$Intake_{,int}$	=	Annual internal radionuclide intake via inhalation or ingestion (picocuries/yr or pCi/yr)
C	=	Activity concentration of a radionuclide at the exposure point (pCi/m^3, pCi/l, or pCi/kg)
IR	=	Intake rate (m^3/day, l/day, or kg/day)
EF	=	Exposure frequency (days/year)

The result is an estimate of the annual intake of the radionuclide, expressed in units of activity per year (pCi/yr). This value is then multiplied by a dose conversion factor to estimate the committed effective dose equivalent. The dose conversion factor is expressed in units of Sieverts (Sv) per pCi. The committed effective dose equivalent can then be compared to a radiation protection standard expressed in Sv/yr.

To estimate lifetime excess cancer risk, intake is calculated using the following equation:

$$\text{Intake} = C * IR * IF * EF * ED$$

Where:

Intake	=	Lifetime internal radionuclide intake via inhalation or ingestion (pCi)
ED	=	Exposure duration (yr)

Excess lifetime cancer risk is then estimated by multiplying the total intake in pCi by the cancer slope factor expressed in units of risk/pCi.

5.3.2 External Irradiation

To calculate an effective dose equivalent for external radiation exposures, first an adjusted areal activity concentration is calculated:

$$AC = C * \frac{10^3 g}{kg} * SD * D * (1-Se) * Te$$

Where:

AC	=	Areal activity concentration in soil, adjusted for a gamma shielding factor and an exposure time factor (pCi/m^2)
C	=	Mass activity concentration of a radionuclide at the exposure point (pCi/g soil)
SD	=	soil density (kg/m^3)
D	=	soil depth (m)
Se	=	gamma shielding factor (unitless)
Te	=	gamma exposure time factor (unitless)

The adjusted areal activity concentration in pCi/m^2 is multiplied by the external dose conversion factor (Sv/hr per pCi/m^2) and the number of hours of exposure per year to obtain the annual radiation effective dose equivalent in Sv per year. The annual effective dose equivalent can then be compared to radiation protection standards, also in units of Sv per year.

To estimate lifetime excess cancer risk, external radiation exposure is estimated using the following equation:

$$ER = C * (1-Se) * Te * ED$$

Where:

ER	=	External radiation exposure (pCi/g soil per year, or pCi-yr/g)
ED	=	Exposure duration (years)

ER is then multiplied by the EPA slope factor for external irradiation expressed in risk per pCi/g per year, to yield excess lifetime cancer risk.

5.4 INTAKE FACTOR CALCULATIONS

Parameters to be used for calculations of intake factors are shown in the tables in Attachment 1. Exposure point concentrations will be used with these parameters to obtain pathway-specific intakes.

6.0
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TABLE 1. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	POTENTIALLY EXPOSED RECEPTORS						
	Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
SOIL/DUST INGESTION:							
Ingestion Rate—Child (mg/day) RME ☞ CT ☞	**200**[1,3] 100[2,4]	NA NA	NA NA	NA NA	NA NA	**200**[3] 100[4]	**200**[3] 100[4]
Ingestion Rate—Adult (mg/day)	**100**[1,3] 50[2,4]	**50**[5] 10[6]	**50**[5] 5[7]	**480**[8] 95[9]	**50**[5] 15[10]	**100**[3] 50[4]	**100**[3] 50[4]
Fraction Ingested from Contaminated Source—Child	0.82[11] 0.82[11]	NA NA	NA NA	NA NA	NA NA	0.82[11] 0.82[11]	0.82[11] 0.82[11]
Fraction Ingested from Contaminated Source—Adult	0.64[11] 0.64[11]	0.9[12] 0.9[12]	0.9[12] 0.9[12]	0.9[12] 0.9[12]	0.9[12] 0.9[12]	0.64[11] 0.64[11]	0.64[11] 0.64[11]
Matrix Effect in GI Tract (Absorption Factor)	CS[13] CS[13]	CS CS	CS CS	CS CS	CS CS	CS CS	CS CS
Exposure Frequency (days/yr)	**350**[5] 245[14]	**250**[5] 219[15]	**250**[5] 219[15]	30[16] 30[16]	65[16] 65[16]	**350**[5] 245[14]	**350**[5] 245[14]
Exposure Duration—Child/Adult (years)	**6/24**[5] 2/7[17]	**25**[5] 4[18]	**25**[5] 4[18]	1[16] 1[16]	2.5[16] 2.5[16]	**6/24**[5] 2/7[17]	**6/24**[5] 2/7[17]

	POTENTIALLY EXPOSED RECEPTORS						
FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
Body Weight—Child/Adult (kg)[5]	**15/70** 15/70	**70** 70	**70** 70	**70** 70	**70** 70	**15/70** 15/70	**15/70** 15/70
Averaging Time—Child/Adult: Non-carcinogen (days)[19]	2190/8760 730/2555	9125 1460	9125 1460	365 365	915 915	2190/8760 730/2555	2190/8760 730/2555
Averaging Time: Carcinogen (days)[20]	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1991a) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(CS) Chemical-specific exposure parameter determined from quantitative analysis and toxicology literature.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) EPA RAGS, HHEM, Standard Default Exposure Factors (1991). A defensible alternative HE value for the child is 110 mg/day, the approximate 95th %ile using Zr tracer study of Calabrese and others, 1989 (Md = 16 mg/day, 95% CI = 8-24 mg/day, n = 128, American Industrial Health Council, 1994). An alternative HE assumption for the adult is 55 mg/day (0.5 x child rate).

(4) Preliminary CT default values (EPA, 1993). A defensible alternative CT value for the child is 16 mg/day based on Calabrese and Stanek (1992); also estimated by AIHC (1994) using the dataset of Calabrese and others (1989). An alternative CT assumption for the adult is 8 mg/day based on EPA (1991) assumption of 0.5 x child rate (16 mg/day) and on Calabrese and others (1990) estimated at 0.1-10 mg/day by American Industrial Health Council (1994).

(5) EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a.

(6) Average of CT soil ingestion rates of 15 mg/day (outdoor industrial worker) and 5 mg/day (indoor industrial worker) based on inferences drawn from Finley and Paustenbach, 1994.

(7) One-half of industrial workers based on inferences drawn from Finley and Paustenbach, 1994; soil ingestion rates for workers indoors (e.g., office workers) are one-half the average of workers both indoors and outdoors (e.g., industrial workers).

(8) Hawley, 1985, and EPA Exposure Factors Handbook, 1989a. A more defensible HE default is 205 mg/day based on adjusting Hawley's soil adherence value from 3.5 mg/cm^2 to the correct upper bound of 1.5 mg/cm^2 (EPA, 1992a) (480 x 1.5/3.5).

(9) Estimated using HE ingestion rate ratio of construction worker to industrial worker (480/50 = 9.6; CT = 9.6 x 10 mg/day), but a more defensible CT default is 40 (see Note 8).

(10) Three times the office worker based on inferences drawn from Finley and Paustenbach, 1994; soil ingestion rates for workers outdoors (e.g., ecological workers) are three times the rates for workers indoors (e.g., office workers).

(11) Based on average time spent at home (0.64 adult; 0.82 child) (American Industrial Health Council, 1994); EPA RAGS, HHEM Pt. A (1989b), recognizes the need for a soil "fraction ingested" (FI) from a contaminated source to reflect "population activity patterns."

(12) As in Note 11 based on average weekly time spent at work (0.9) using a base of 40 hours per week.

(13) In the absence of a CS value, consult methods to estimate maximum oral bioavailability (absorption in the gastrointestinal tract) such as reported by EPA, 1994, for lead in soil and by Finley and Paustenbach, 1994, for TCDD in soil. Assuming chemical toxicity values are based on absorption from drinking water, absorption adjustments are indicated because toxic chemicals only partially desorb from soil particles (EPA RAGS, HHEM Pt. A, 1989b—Appendix A).

(14) Average of two exposure frequencies: outdoor soil/dust CT value of 150 days (Finley and Paustenbach, 1994) and indoor dust CT value of 335 days, assuming 15 days of vacation travel and 15 days of employment travel or overnight visits.

(15) Preliminary CT default value (EPA, 1993).

(16) Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994.

(17) Preliminary CT default values, adding to 9 years total exposure duration (EPA, 1993). A current alternative value for total CT exposure duration is EPA's Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(18) American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994.

(19) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(20) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 2. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE		POTENTIALLY EXPOSED RECEPTORS: Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
SOIL/DUST INHALATION:								
Inhalation Rate (m^3/hr)	RME ☞	**0.83** (1,3)	**0.83** (3)	**0.83** (3)	1.25 (6)	**0.83** (3)	**0.83** (3)	**0.83** (3)
	CT ☞	0.63 (2,4)	0.83 (3)	0.63 (5)	1.25 (6)	0.83 (3)	0.63 (4)	0.63 (4)
Respirable Fraction (PM_{10})		0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)
		0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)	0.36 (7)
Exposure Time (hr/day)		**24** (3)	**8** (3)	**8** (3)	**8** (3)	**8** (3)	**24** (3)	**24** (3)
		15 (8)	7.2 (9)	7.2 (9)	7.2 (9)	7.2 (9)	15 (8)	15 (8)
Exposure Frequency (days/yr)		**350** (3)	**250** (3)	**250** (3)	30 (6)	65 (6)	**350** (3)	**350** (3)
		234 (10)	219 (10)	219 (10)	30 (6)	65 (6)	234 (10)	234 (10)
Exposure Duration (years)		**30** (3)	**25** (3)	**25** (3)	1 (6)	2.5 (6)	**30** (3)	**30** (3)
		9 (11)	4 (12)	4 (12)	1 (6)	2.5 (6)	9 (11)	9 (11)
Body Weight (kg) (3)		**70**	**70**	**70**	**70**	**70**	**70**	**70**
		70	70	70	70	70	70	70

	POTENTIALLY EXPOSED RECEPTORS						
FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	**Current Off-Site Resident**	**Current On-Site Industrial Worker**	**Future On-Site Office Worker**	**Future On-Site Construction Worker**	**Future On-Site Ecological Worker**	**Future On-Site Resident**	**Future Off-Site Resident**
Averaging Time: Non-carcinogen (days)(13)	10950 3285	9125 1460	9125 1460	365 365	915 915	10950 3285	10950 3285
Averaging Time: Carcinogen (days)(14)	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1991a) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a.

(4) CT residential inhalation rate (adult) based on EPA RAGS, HHEM Part B, 1991b. Note that the CT rate for the child—81% of adult rate based on 6-year-old and adult males at moderate activity (EPA Exposure Factors Handbook, 1989a)—cannot result in a greater inhalation intake for the child, assuming EPA standard

default values for exposure duration and body weight (adult = 0.63 m^3/hr x 24 yr/70 kg = 0.22 m^3/hr-kg/yr; child = 0.63 m^3/hr x 0.81 x 6 yr/15 kg = 0.20 m^3/hr-kg/yr.

(5) CT worker inhalation rate of 0.63 m^3/hr (adult indoors) based on EPA Exposure Factors Handbook, 1989a.

(6) Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994.

(7) Five-year (1988-1992) mean annual ratio of PM_{10} soil or dust particles to total suspended particulates (TSP) as reported in 1992 RFP Site Environmental Report; EPA Exposure Factors Handbook (1989a) recognizes the need for a "respirable fraction of particulates" (RF) to indicate the total respirable fraction assumed deposited in the lung (100% of PM_{10}).

(8) Based on average time spent at home (0.64 adult) (American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994).

(9) Based on average time spent at work (36 hr/wk) (American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994).

(10) Preliminary CT default value (EPA, 1993).

(11) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(12) American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994.

(13) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(14) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 3. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	POTENTIALLY EXPOSED RECEPTORS: Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
SOIL/DUST DERMAL CONTACT:							
Exposed Skin Surface (cm^2)	RME ☞ **5300**[1,3] CT ☞ 2000[2,4]	3400 [5] 3400 [5]	2100 [5] 2100 [5]	4700 [5] 4700 [5]	4700 [5] 4700 [5]	**5300** [3] 2000 [4]	**5300** [3] 2000 [4]
Fraction Contacted from Contaminated Source	0.64 [6] 0.64 [6]	0.9 [7] 0.9 [7]	0.9 [7] 0.9 [7]	0.9 [7] 0.9 [7]	0.9 [7] 0.9 [7]	0.64 [6] 0.64 [6]	0.64 [6] 0.64 [6]
Soil Adherence (mg/cm^2)	**1.0** [3] 0.2 [3]	**1.0** [3] 0.2 [3]	**1.0** [3] 0.2 [3]	**1.0** [3] 0.2 [3]	**1.0** [3] 0.2 [3]	**1.0** [3] 0.2 [3]	**1.0** [3] 0.2 [3]
Skin Absorption Factor	CS [8] CS [8]	CS CS	CS CS	CS CS	CS CS	CS CS	CS CS
Exposure Frequency (days/yr)	**350** [9] 245[10]	**250** [9] 219[11]	**250** [9] 219[11]	30[12] 30[12]	65[12] 65[12]	**350** [9] 245[10]	**350** [9] 245[10]
Exposure Duration (years)	**30**[10] 9[13]	**25** [9] 4[14]	**25** [9] 4[14]	1[12] 1[12]	2.5[12] 2.5[12]	**30** [9] 9[13]	**30** [9] 9[13]
Body Weight (kg)[9]	**70** 70	**70** 70	**70** 70	**70** 70	**70** 70	**70** 70	**70** 70

POTENTIALLY EXPOSED RECEPTORS

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
Averaging Time: Non-carcinogen (days)(15)	10950 3285	9125 1460	9125 1460	365 365	915 915	10950 3285	10950 3285
Averaging Time: Carcinogen (days)(16)	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550	25550 25550

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1992a; EPA 1991a) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(CS) Chemical-specific exposure parameter determined from quantitative analysis and toxicology literature.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) EPA Dermal Exposure Assessment: Principles and Applications, 1992a.

(4) CT adult skin surface exposed is 11% of *mean* surface area (18150 cm^2) (EPA Dermal Exposure Assessment: Principles and Applications, 1992a). Note that the CT skin surface of the child—41% of adult surface area based on 6-year-old and adult males (EPA Exposure

Factors Handbook, 1989a)—cannot result in a greater dermal intake for the child, assuming EPA standard default values for exposure duration and body weight and twice the fraction exposed (adult = 18150 cm^2 x 0.11 x 24 yr/70 kg = 685 cm^2/kg-yr; child = 18150 cm^2 x 0.41 x 0.22 x 6 yr/15 kg = 655 cm^2/kg-yr).

(5) Industrial worker HE value is an average between exposed skin surfaces of 4,700 cm^2 (outdoor construction or ecological worker) and 2,100 cm^2 (indoor office worker) based on EPA Exposure Factors Handbook, 1989a; indoor worker exposure assumes median surface area of adult head and hands (1,200 cm^2 + 900 cm^2), whereas outdoor worker assumes median surface area of adult head, hands, and arms (1,200 cm^2 + 900 cm^2 + 2,600 cm^2).

(6) Based on average time spent at home (0.64 adult; 0.82 child) (American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994).

(7) As in Note 6 based on average weekly time spent at work (0.9) using a base of 40 hours per week.

(8) In the absence of a CS value, consult EPA Region IV Interim Guidance dated 11 February 1992 (default values: 0.01 organics; 0.001 inorganics) (EPA, 1992c). However, alternative values of 0.06 (organic compounds) and 0.01 (metals) are based on maximum dermal bioavailability as reported in "Dermal Absorption Factors for Multiple Chemicals" (15 December 1992; EPA, 1992d).

(9) EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a (for consistency with soil/dust ingestion and inhalation).

(10) Average of two exposure frequencies: outdoor soil/dust CT value of 150 days (Finley and Paustenbach, 1994) and indoor dust CT value of 335 days, assuming 15 days of vacation travel and 15 days of employment travel or overnight visits. EPA RAGS, HHEM Part A, 1989b, indicates about 140 outdoor dermal contact "events" per year for the child.

(11) Preliminary CT default value (EPA, 1993).

(12) Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994.

(13) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(14) American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994.

(15) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(16) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 4. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE		POTENTIALLY EXPOSED RECEPTORS: Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
SURFACE WATER/ SUSPENDED SEDIMENT INGESTION*:								
Ingestion Rate (L/hr)	RME ☞ CT ☞	NA NA	NA NA	NA NA	NA NA	0.05 [1,3] 0.01 [2,4]	**0.05** [5] 0.01 [4]	**0.05** [5] 0.01 [4]
Exposure Time (hr/day)		NA NA	NA NA	NA NA	NA NA	1 [6] 1 [6]	**2.6** [7] 1.0 [8]	**2.6** [7] 1.0 [8]
Exposure Frequency (days/yr)		NA NA	NA NA	NA NA	NA NA	7 [3] 7 [3]	**7** [9] 5 [10]	**7** [9] 5 [10]
Exposure Duration (years)		NA NA	NA NA	NA NA	NA NA	2.5 [3] 2.5 [3]	**30** [11] 9 [12]	**30** [11] 9 [12]
Body Weight (kg)		NA NA	NA NA	NA NA	NA NA	70 [3] 70 [3]	**70** [11] 70 [11]	**70** [11] 70 [11]
Averaging Time: Non-carcinogen (days) [13]		NA NA	NA NA	NA NA	NA NA	915 915	10950 3285	10950 3285
Averaging Time: Carcinogen (days) [14]		NA NA	NA NA	NA NA	NA NA	25550 25550	25550 25550	25550 25550

* Direct ingestion of exposed *in situ* shoreline sediments will utilize *OU-specific* exposure factors.

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1991b; EPA, 1989b) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\bar{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994.

(4) On the premise that actual swimming rather than wading is unlikely, the CT ingestion rate while wading is assumed to be one-fifth as much as while swimming.

(5) Default value for ingestion of surface water and suspended sediment while *swimming* (EPA RAGS, HHEM Pt. A, 1989b); *wading* ingestion rate is indeterminate from available sources.

(6) An exposure "event" for the ecological worker (see Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994) is assumed to last 1 hour per day.

(7) Default value for *swimming* exposure time (EPA RAGS, HHEM Pt. A, 1989b); *wading* exposure time is indeterminate from available sources.

(8) On the premise that actual swimming rather than wading is unlikely, the CT exposure time while wading is assumed to be 1 hour.

(9) Default value for *swimming* exposure frequency (I PA RAGS, HHEM Pt. A, 1989b); *wading* exposure frequency is indeterminate from available sources.

(10) On the premise that actual swimming rather than wading is unlikely, the CT exposure frequency while wading is assumed to be 5 events per year.

(11) Appendix B.1, EPA RAGS, HHEM Pt. B, 1991b.

(12) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(13) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(14) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 5. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE		POTENTIALLY EXPOSED RECEPTORS						
		Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
SURFACE WATER DERMAL CONTACT*:								
Exposed Skin Surface (cm^2)	RME ☞ CT ☞	NA NA	NA NA	NA NA	NA NA	9275 (1,3) 9275 (2,3)	**18150** (4) 9275 (5)	**18150** (4) 9275 (5)
Dermal Permeability (cm/hr)		NA NA	NA NA	NA NA	NA NA	CS (6) CS (6)	CS (6) CS (6)	CS (6) CS (6)
Exposure Time (hr/day)		NA NA	NA NA	NA NA	NA NA	1 (7) 1 (7)	**2.6** (8) 1.0 (9)	**2.6** (8) 1.0 (9)
Exposure Frequency (days/yr)		NA NA	NA NA	NA NA	NA NA	7 (10) 7 (10)	**7** (11) 5 (12)	**7** (11) 5 (12)
Exposure Duration (years)		NA NA	NA NA	NA NA	NA NA	2.5 (10) 2.5 (10)	**30** (13) 9 (14)	**30** (13) 9 (14)
Body Weight (kg)		NA NA	NA NA	NA NA	NA NA	70 (10) 70 (10)	**70** (13) 70 (13)	**70** (13) 70 (13)

* Direct dermal contact with exposed *in situ* shoreline sediments will utilize *OU-specific* exposure factors.

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	POTENTIALLY EXPOSED RECEPTORS: Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
Averaging Time: Non-carcinogen (days)(15)	NA NA	NA NA	NA NA	NA NA	915 915	10950 3285	10950 3285
Averaging Time: Carcinogen (days)(16)	NA NA	NA NA	NA NA	NA NA	25550 25550	25550 25550	25550 25550

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1989a; EPA 1989b) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(CS) Chemical-specific exposure parameter determined from quantitative analysis and toxicology literature.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) On the premise that actual swimming by the ecologist, rather than wading, is highly unlikely, the exposed adult skin surface while wading and reaching underwater is assumed to include the legs (5950 cm^2), feet (1250 cm^2), forearms (1175 cm^2), and hands (900 cm^2) (EPA Exposure Factors Handbook, 1989a).

(4) Typical value for total adult skin surface area exposed while swimming (EPA Exposure Factors Handbook, 1989a).

(5) On the premise that actual swimming by the resident rather than wading is unlikely, the exposed adult skin surface while wading is assumed to include the legs (5950 cm^2), feet (1250 cm^2), forearms (1175 cm^2), and hands (900 cm^2) (EPA Exposure Factors Handbook, 1989a).

(6) In the absence of a CS value, consult methods to estimate maximum dermal bioavilability. Possible maxima are: HE value of 1.0 cm/hr determined experimentally for ethylbenzene and toluene among *organic* compounds; HE value of 0.001 cm/hr determined experimentally for cadmium chloride and mercuric chloride among *inorganic* compounds (EPA Dermal Exposure Assessment: Principles and Applications, 1992a).

(7) An exposure "event" for the ecological worker (see Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994) is assumed to last 1 hour per day.

(8) Default value for *swimming* exposure time (EPA RAGS, HHEM Pt. A, 1989b); *wading* exposure time is indeterminate from available sources.

(9) On the premise that actual swimming, rather than wading, is unlikely, the CT exposure time while wading is assumed to be 1 hour.

(10) Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994 (for consistency with surface water ingestion).

(11) Default value for *swimming* exposure frequency (EPA RAGS, HHEM Pt. A, 1989b); *wading* exposure frequency is indeterminate from available sources.

(12) On the premise that actual swimming rather than wading is unlikely, the CT exposure frequency is assumed to be 5 events per year.

(13) EPA RAGS, HHEM Pt. A, 1989b.

(14) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(15) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(16) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 6. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

	POTENTIALLY EXPOSED RECEPTORS						
FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	**Current Off-Site Resident**	**Current On-Site Industrial Worker**	**Future On-Site Office Worker**	**Future On-Site Construction Worker**	**Future On-Site Ecological Worker**	**Future On-Site Resident**	**Future Off-Site Resident**
HOMEGROWN PRODUCE INGESTION:							
Ingestion Rate (g/day)	RME ☞ **200/140** (1,3) CT ☞ 200/140 (2,3)	NA NA	NA NA	NA NA	NA NA	**200/140** (1,3) 200/140 (1,3)	**200/140** (1,3) 200/140 (1,3)
Fraction Ingested from Contaminated Source	**0.4/0.3** (4) 0.25/0.2 (4)	NA NA	NA NA	NA NA	NA NA	**0.4/0.3** (4) 0.25/0.2 (4)	**0.4/0.3** (4) 0.25/0.2 (4)
Washoff Factor	0.5 (5) 0.5 (5)	NA NA	NA NA	NA NA	NA NA	0.5 (5) 0.5 (5)	0.5 (5) 0.5 (5)
Exposure Frequency (days/yr)	**350** (6) 150 (7)	NA NA	NA NA	NA NA	NA NA	**350** (6) 150 (7)	**350** (6) 150 (7)
Exposure Duration (years)	**30** (8) 9 (9)	NA NA	NA NA	NA NA	NA NA	**30** (8) 9 (9)	**30** (8) 9 (9)
Body Weight (kg)	**70** (8) 70 (8)	NA NA	NA NA	NA NA	NA NA	**70** (8) 70 (8)	**70** (8) 70 (8)

	POTENTIALLY EXPOSED RECEPTORS						
FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	**Current Off-Site Resident**	**Current On-Site Industrial Worker**	**Future On-Site Office Worker**	**Future On-Site Construction Worker**	**Future On-Site Ecological Worker**	**Future On-Site Resident**	**Future Off-Site Resident**
Averaging Time: Non-carcinogen (days)[10]	10950 3285	NA NA	NA NA	NA NA	NA NA	10950 3285	10950 3285
Averaging Time: Carcinogen (days)[11]	25550 25550	NA NA	NA NA	NA NA	NA NA	25550 25550	25550 25550

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1991a; EPA, 1989a) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) Average adult vegetable intake/average adult fruit intake (EPA Exposure Factors Handbook, 1989a).

(4) The HE and CT fraction ingested (FI) is based on the fraction of fruits or vegetables consumed daily that is *home-grown* (EPA Exposure Factors Handbook, 1989a).

(5) It is assumed that residents consuming their own home-grown fruits or vegetables also wash off *at least* one-half of all contaminated soil or dust particles adhering to root and leaf vegetables and to fruits.

(6) EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a. A conservative exposure frequency would be 215 days (first harvest May 1; last harvest December 1) (Jefferson County Horticulturalist Robert Cox, 21 October 1994). The default exposure frequency of 350 days per year would assume an additional 135 days consuming only *preserved* home-grown produce.

(7) Based on typical site-specific fraction of the year home-grown produce is harvested on Colorado's Eastern Plains (first harvest May 15; last harvest October 15) (Jefferson County Horticulturalist Robert Cox, 21 October 1994).

(8) EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a.

(9) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(10) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(11) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 7. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE		POTENTIALLY EXPOSED RECEPTORS						
		Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
GROUND WATER INGESTION:								
Ingestion Rate (L/day)	RME ☞	NA	NA	NA	NA	NA	**2.0**(1,3)	NA
	CT ☞	NA	NA	NA	NA	NA	1.4(2,3)	NA
Fraction Ingested from Contaminated Source		NA	NA	NA	NA	NA	0.3 (4)	NA
		NA	NA	NA	NA	NA	0.3 (4)	NA
Exposure Frequency (days/yr)		NA	NA	NA	NA	NA	**350** (5)	NA
		NA	NA	NA	NA	NA	335 (6)	NA
Exposure Duration (years)		NA	NA	NA	NA	NA	**30** (5)	NA
		NA	NA	NA	NA	NA	9 (7)	NA
Body Weight (kg)		NA	NA	NA	NA	NA	**70** (5)	NA
		NA	NA	NA	NA	NA	70 (5)	NA
Averaging Time: Non-carcinogen (days)(8)		NA	NA	NA	NA	NA	10950	NA
		NA	NA	NA	NA	NA	3285	NA
Averaging Time: Carcinogen (days)(9)		NA	NA	NA	NA	NA	25550	NA
		NA	NA	NA	NA	NA	25550	NA

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1991a; EPA, 1989a) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) HE and CT adult total water-based beverage intakes, including tap water (EPA Exposure Factors Handbook, 1989a).

(4) The CT fraction ingested (FI) is based on 64% of adult time spent at home (American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994) and on 46% tap water ingestion out of adult total water-based beverage intake (EPA Exposure Factors Handbook, 1989a) (0.64 x 0.46 = 0.3).

(5) EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a.

(6) Assuming 15 days of vacation travel and 15 days of employment travel.

(7) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(8) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(9) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 8. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE		POTENTIALLY EXPOSED RECEPTORS: Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
GROUNDWATER/SUBSOIL VOC INHALATION*:								
Inhalation Rate (m^3/hr)	RME ☞	NA	NA	**0.83**(1,3)	NA	NA	**0.63** (3)	NA
	CT ☞	NA	NA	0.63(2,4)	NA	NA	0.63 (3)	NA
Exposure Time (hr/day)		NA	NA	**8** (3)	NA	NA	**24** (3)	NA
		NA	NA	7.2 (7)	NA	NA	15 (8)	NA
Exposure Frequency (days/yr)		NA	NA	**250** (3)	NA	NA	**350** (3)	NA
		NA	NA	219 (9)	NA	NA	234 (9)	NA
Exposure Duration (years)		NA	NA	**25** (3)	NA	NA	**30** (3)	NA
		NA	NA	4(10)	NA	NA	9(11)	NA
Body Weight—(kg)(3)		NA	NA	**70**	NA	NA	**70**	NA
		NA	NA	70	NA	NA	70	NA

* Includes *indoor* VOC vapor from household use of a groundwater supply and VOC vapor infiltration from subsoil into homes and offices

	POTENTIALLY EXPOSED RECEPTORS						
FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE	**Current Off-Site Resident**	**Current On-Site Industrial Worker**	**Future On-Site Office Worker**	**Future On-Site Construction Worker**	**Future On-Site Ecological Worker**	**Future On-Site Resident**	**Future Off-Site Resident**
Averaging Time: Non-carcinogen (days)(12)	NA NA	NA NA	9125 1460	NA NA	NA NA	10950 3285	NA NA
Averaging Time: Carcinogen (days)(13)	NA NA	NA NA	25550 25550	NA NA	NA NA	25550 25550	NA NA

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1991a) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a.

(4) CT worker inhalation rate of 0.63 m^3/hr (adult indoors) based on EPA Exposure Factors Handbook, 1989a.

(6) CT residential inhalation rate (adult indoors) based on EPA RAGS, HHEM, Standard Default Exposure Factors, 1991a. Note that the CT rate for the child—81% of adult males at moderate activity (EPA Exposure Factors Handbook, 1989a)—cannot result in a greater inhalation intake for the child, assuming EPA standard default values for exposure duration and body weight (adult = 0.63 m^3/hr x 24 yr/70 kg = 0.22 m^3/hr-kg/yr; child = 0.63 m^3/hr x 0.81 x 6 yr/15 kg = 0.20 m^3/hr-kg/yr).

(7) Based on average time spent at work (36 hr/wk) (American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994).

(8) Based on average time spent at home (0.64 adult; 0.82 child) (American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994).

(9) Preliminary CT default value (EPA, 1993).

(10) American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994.

(11) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

(12) Exposure duration (years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

(13) Lifetime exposure (70 years) x 365 days (EPA RAGS, HHEM Pt. A, 1989b).

TABLE 9. Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FACTORS FOR POTENTIALLY COMPLETE ROUTES OF EXPOSURE		POTENTIALLY EXPOSED RECEPTORS: Current Off-Site Resident	Current On-Site Industrial Worker	Future On-Site Office Worker	Future On-Site Construction Worker	Future On-Site Ecological Worker	Future On-Site Resident	Future Off-Site Resident
EXTERNAL IRRADIATION:								
Gamma Exposure Time Factor (T_e)	RME ☞	NA	**0.3**(1,3)	**0.3** (3)	**0.3** (3)	**0.3** (3)	**1.0** (4)	NA
	CT ☞	NA	0.3(2,3)	0.3 (3)	0.3 (3)	0.3 (3)	0.75 (5)	NA
Gamma Shielding Factor (1-S_e)		NA	**0.8** (6)	**0.8** (6)	**1.0** (8)	**1.0** (8)	**0.8** (6)	NA
		NA	0.5 (7)	0.5 (7)	0.8 (9)	0.8 (9)	0.5 (7)	NA
Exposure Frequency Frequency (days/yr)		NA	**250** (4)	**250** (4)	30(11)	65(11)	**350** (4)	NA
		NA	219(10)	219(10)	30(11)	65(11)	234(10)	NA
Exposure Duration (years)		NA	**25** (4)	**25** (4)	1(11)	2.5(11)	**30** (4)	NA
		NA	4(12)	4(12)	1(11)	2.5(11)	9(13)	NA

NOTES:

(Bold) Standard Default Exposure Factor (EPA, 1991b) used to calculate conservative risks based on Reasonable Maximum Exposure (RME) by combining high-end (>90th %ile) and central tendency ($\overline{X}$ or Md) exposure factors to represent exposure "that is both protective and reasonable, not the worst possible case."

(NA) Not applicable because the exposure pathway is incomplete.

(1) Top entry is based on High-End (HE) exposure used to characterize the Reasonable Maximum Exposure (RME) risks in a baseline or remediation risk assessment. RME risks are derived using professional judgment to set one

or more sensitive exposure parameters at HE (90-98th %ile) values in combination with others set at Central Tendency (CT) values in order to characterize the high-end risks to a very small proportion of an exposed population.

(2) Bottom entry is based on Central Tendency (CT) used to characterize the typical case in a baseline or remediation risk assessment (or a "reasonable worst case" when used in combination with selected high-end values). Average risks are derived using professional judgment to set *all* exposure parameters at 50th %ile (median) or mean values in order to characterize the mid-range risk to the largest proportion of an exposed population.

(3) Assuming the HE fraction of time exposed (8 out of 24 hours or 0.33) according to EPA RAGS, HHEM Pt. B—Revised (Dinan, 1992).

(4) EPA RAGS, HHEM Pt. B, 1991b.

(5) Assuming the CT fraction of time spent at home (average of adult—0.64 and child—0.82) (American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994).

(6) Standard default screening value specified in EPA RAGS, HHEM Pt. B, 1991b (1 - 0.2 = 0.8), assuming substantial time shielded by structures.

(7) Estimated typical value for residents and indoor workers shielded by buildings (DOE documents for RFP, such as "Mining Exposure Scenario for Baseline Risk Assessments at the Rocky Flats Environmental Technology Site" (9 August 1994).

(8) Standard default screening value specified in EPA RAGS, HHEM Pt. B, 1991b, assuming limited time shielded by structures.

(9) Assumed typical value for outdoor workers with only limited shielding indoors.

(10) Preliminary CT default value (EPA, 1993).

(11) Final Rocky Flats Programmatic Risk-Based Preliminary Remediation Goals, 1994.

(12) American Industrial Health Council, 1994; Gephart, Tell and Triemer, 1994.

(13) Preliminary CT default value (EPA, 1993). A current alternative value is EPA's CT Residential Occupancy Period (ROP) of 8.1 years for total population (EPA, 1992b; American Industrial Health Council, 1994).

TABLE 10 (Supplement). Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FUTURE ON-SITE GRAVEL MINE WORKER

Soil/Dust Ingestion:	**Soil/Dust Dermal Contact:**	**Soil/Dust Inhalation:**	**External Irradiation:**
Ingestion Rate (mg/day)(1)	Exposed Skin Surface (cm^2)(4)	Inhalation Rate (cm^3/hr)(7)	Gamma Exposure Time(10) (T_e)
RME 50 **CT 10**	**RME 3400** **CT 3400**	**RME 0.83** **CT 0.83**	**RME 0.3** **CT 0.3**
Fraction Ingested from Contaminated Source(2)	Fraction Contacted from Contaminated Source(2)	Respirable Fraction(8) (PM_{10})	Gamma Shielding Factor(11) ($1\text{-}S_e$)
RME 0.9 **CT 0.9**	**RME 0.9** **CT 0.9**	**RME 0.36** **CT 0.36**	**RME 0.8** **CT 0.8**
Matrix Effect in GI Tract (Absorption Factor)(3)	Soil Adherence (mg/cm^2)(5)	Exposure Time (hr/day)(9)	
RME CS **CT CS**	**RME 1.0** **CT 0.2**	**RME 12** **CT 10**	
	Skin Absorption Factor(6)		
	RME CS **CT CS**		

(1) RME: RAGS, HHEM, Standard Default Exposure Factors, (EPA, 1991a). CT: Inferred from Finley and Paustenbach, 1994; average of CT soil ingestion rates of 15 mg/day (outdoor industrial worker) and 5 mg/day (indoor industrial worker).
(2) American Industrial Health Council, 1994; average weekly time spent at work (36 hours out of 40).
(3) Chemical-specific oral bioavailability; toxic chemicals only partially desorb from soil particles.
(4) Exposure Factors Handbook (EPA, 1989a); average of 4700 cm^2 (outdoor worker) and 2100 cm^2 (indoor worker).
(5) Dermal Exposure Assessment—Principles and Applications (EPA, 1992a).

TABLE 10 (Supplement). Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment

FUTURE ON-SITE GRAVEL MINE WORKER, continued

All Routes of Exposure		
Exposure Frequency (days/yr) (12)	Exposure Duration (years)(13)	Body Weight (kg)(7)
RME 250 **CT 219**	**RME 25** **CT 4**	**RME 70** **CT 70**
Averaging Time—Noncarcinogens (days)(14)	Averaging Time—Carcinogens (days)(14)	
RME 9125 **CT 1460**	**RME 25550** **CT 25550**	

(6) Chemical-specific dermal bioavailability; default values available in Region IV Interim Guidance (EPA, 1992c).
(7) RAGS, HHEM, Standard Default Exposure Factors (EPA, 1991a).
(8) Rocky Flats Plant Environmental Report for 1992 (DOE, 1992); 5-year (1988-1992) mean annual ratio of PM_{10} soil or dust particles to total suspended particulates (TSP).
(9) Mining Exposure Scenario for Baseline Risk Assessments at the Rocky Flats Environmental Technology Site (DOE, 1994).
(10) EPA RAGS, HHEM Part B—Revised (Dinan, 1992).
(11) RAGS, HHEM Part B (EPA, 1991b); assuming limited time shielded by structures.
(12) RME: RAGS, HHEM, Standard Default Exposure Factors (EPA, 1991a). CT: Preliminary default value (EPA, 1993).
(13) RME: RAGS, HHEM, Standard Default Exposure Factors (EPA, 1991a). CT: American Industrial Health Council (1994).
(14) RAGS, HHEM Part A (EPA, 1989b).

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