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HUMAN HEALTH RISK ASSESSMENT METHODOLOGY

Prepared on Behalf of:

EG&G ROCKY FLATS
ENVIRONMENTAL TECHNOLOGY SITE
P.O. Box 464
Golden, Colorado 80402-0464

Prepared for:

U.S. DEPARTMENT OF ENERGY
Golden, Colorado

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ACRONYMS

AEC	Atomic Energy Commission
AOC	Area of Concern
BGCR	Background Geochemical Characterization Report
BRA	Baseline Risk Assessment
C	Celcius
CDPHE	Colorado Department of Public Health and Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHWA	Colorado Hazardous Waste Act
CLP	Contract Laboratory Program
CNS	central nervous system
COC	contaminant of concern
CRAVE	Carcinogen Risk Assessment Verification Endeavor
CRDL	contract required detection limit
CRQL	contract required quantitation limit
CSFs	cancer slope factor
CTS	concentration-toxicity screen
DIL	diluted
DOE	U.S. Department of Energy
DQOs	data quality objective
DRCOG	Denver Regional Council of Governments
EATM	exposure assessment technical memorandum
EE	Ecological Evaluation
EG&G	EG&G Rocky Flats, Inc.
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
F	Fahrenheit
ft	feet
FWHM	full width half maximum
GC	Gas Chromatograph
GRRASP	General Radiochemistry and Routine Analytical Services Protocol
GFAA	graphite furnace atomic absorption
HEAST	Health Effects Assessment Summary Tables
HHRA	Human Health Risk Assessment
HI	Hazard Index
HQ	Hazard Quotient

IAG	Interagency Agreement
IDL	instrument detection limit
IHSS	Individual Hazardous Substance Site
in	inches
IRIS	Integrated Risk Information System
kg	kilogram
km	kilometer
L	liter
LHSU	lower hydrostratigraphic unit
m	meter
MDA	minimum detectable activity
MFs	modifying factors
mg	milligram
mi	mile
MLE	maximum likelihood estimator
MS	mass spectrometry
MSA	method of standard addition
μg	microgram
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
OU	Operable Unit
pCi	picocurie
PCOC	Potential Contaminant of Concern
PGR	Preliminary Remediation Goals
PPRG	Programmatic Preliminary Remediation Goal
QAPjP	Quality Assurance Project Plan
QC	quality control
rad	radionuclide
RAGS	Risk Assessment Guidance for Superfund
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act
RfCs	Reference Concentrations
RfD	reference dose
RFEDS	Rocky Flats Environmental Database System
RFETS	Rocky Flats Environmental Technology Site
RFI/CMS	RCRA Facility Investigation/Corrective Measures Study
RI/FS	Remedial Investigation/Feasibility Study
RFLII	Rocky Flats Local Impacts Initiative

RI/RFI	Remedial Investigation/RCRA Facility Investigation
RME	reasonable maximum exposure
SOP	standard operating procedures
SPARCC	sensitivity, precision, accuracy, representativeness, completeness, and comparability
SQL	sample quantitation limits
TDS	total dissolved solids
TIC	tentatively identified compound
TM	technical memorandum
TOC	total organic carbon
UCL	upper confidence level
UHSU	upper hydrostratigraphic unit
UTL	upper tolerance limit
VOC	volatile organic compound

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1.0 INTRODUCTION

This document prescribes the methodology for conducting the Human Health Risk Assessment (HHRA) portion of Baseline Risk Assessment (BRA) for the Rocky Flats Environmental Technology Site (RFETS). The HHRA, coupled with the Environmental Evaluation (EE), comprises a BRA. Per the requirements of the Interagency Agreement (IAG) (1991) among the U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA), and the State of Colorado, BRAs are performed for each of the Operable Units (OUs) defined in the agreement.

1.1 Purpose

The purpose of this HHRA methodology is to direct risk assessors for RFETS to relevant documents and site-specific agency agreements to produce HHRA's that are acceptable to both the EPA and the State of Colorado. The State of Colorado is represented by the Colorado Department of Public Health and Environment (CDPHE). To achieve this purpose, it is necessary to understand the purpose of an HHRA.

The purpose of the HHRA is to develop a quantitative description and assessment of the risk to the public posed by the contaminants of concern (COCs) at an OU. Specifically, goals of the HHRA include providing:

- An analysis of baseline risks to help determine the need for action at sites
- A basis for determining levels of contaminants that can remain onsite and still be adequately protective of public health
- A basis for comparing potential health impacts of various remedial alternatives
- A consistent process for evaluating and documenting risks to public health
- Information for effective risk management.

1.2 Scope

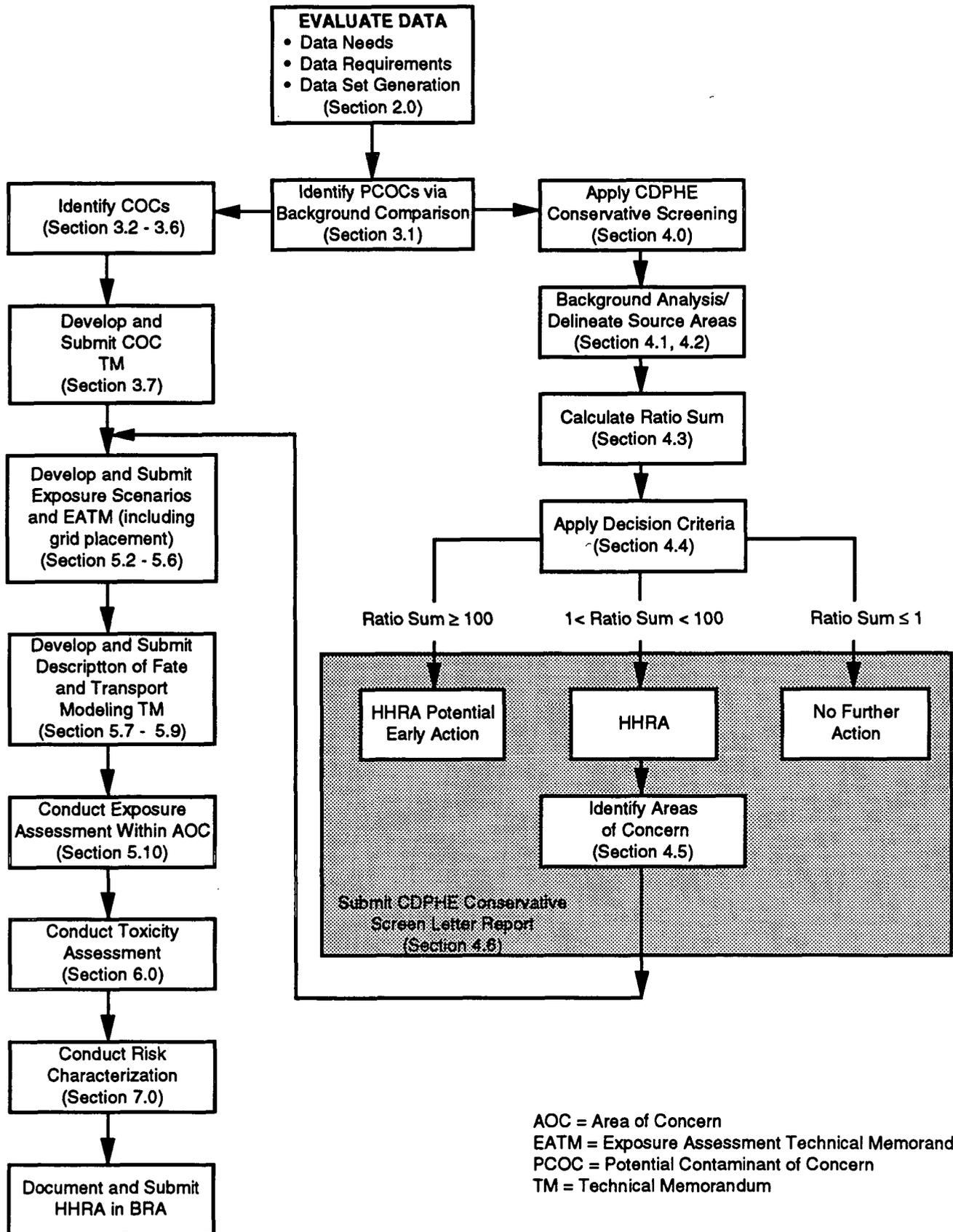
The scope of this document is to summarize key sections of existing agency guidance, and integrate RFETS-specific documents and agency agreements into published agency guidance. Current EPA guidance for risk assessment, Risk Assessment Guidance for Superfund (RAGS) (EPA, 1989a), encompasses the full spectrum of situations that may be encountered at Superfund sites. As a result, it is written in general terms. This HHRA methodology reviews some of the key sections that directly apply to RFETS, and refers the reader to RAGS for additional background.

In addition to RAGS, several risk assessment topics have been the subject of discussion and agreement among DOE, EPA, and CDPHE. Where appropriate, this document references or summarizes existing DOE, EPA, and CDPHE documents or agreements. Figure 1-1 illustrates the RFETS HHRA methodology specified in the DOE, EPA, and CDPHE agreements. References to relevant sections of this document are also provided. Supporting material for conducting specific steps of risk assessment has been developed at RFETS and are referenced or summarized in this methodology. In addition, example text or table shells are provided to guide the risk assessor in documenting the HHRA. Risk assessors for each OU must ensure that the content of the HHRA satisfies the OU-specific objectives.

1.3 Rocky Flats Environmental Technology Site Information

General information about RFETS that is relevant to an HHRA includes the site history, the regulatory framework, and a physical description of the site. Each of these topics are discussed in the following subsections. OU-specific information may be found in detail in the individual OU Workplans and the first few sections of the Remedial Investigation/Resource Conservation and Recovery Act (RCRA) Facility Investigation (RI/RFI) report. This information may be summarized from the RI/RFI report and included in the HHRA to allow it to be a "stand alone" document. References can direct the reader to the source document for further detail.

Figure 1-1, HHRA METHODOLOGY



The information presented in Sections 1.3.1. through 1.3.3 briefly describes the RFETS. It may be used as an example of summary material in the HHRA.

1.3.1 Site History

RFETS is a government-owned, contractor-operated facility, and was part of the nationwide nuclear weapons production complex. The historical mission of RFETS was to fabricate nuclear weapons components from plutonium, uranium, and nonradioactive metals (principally beryllium and stainless steel). Additionally, the facility reprocessed plutonium that was removed from obsolete weapons. Both radioactive and nonradioactive wastes were generated at the plant. Present waste-handling practices involve recycling of hazardous materials, on-site storage of hazardous, radioactive, and mixed wastes, as well as off-site disposal of radioactive materials. 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. These locations are considered OUs under the IAG.

RFETS' new mission is environmental restoration and waste management. The activities underway at RFETS are consistent with the down-sizing and consolidation of the DOE weapons complex. A transition team consisting of EG&G Rocky Flats, Inc. (EG&G) and DOE personnel is leading these efforts.

The RFETS ER Program is part of the national DOE ER Program, which was established to remediate inactive waste sites at DOE facilities. The DOE ER Program is mandated to remediate waste sites in compliance with environmental laws and regulations, while minimizing impacts to human health and the environment. Specifically, the program includes site identification and characterization, remedial design and remedial action, and post-closure activities such as monitoring and field inspections at inactive radioactive, hazardous, and mixed-waste sites.

1.3.2 Regulatory Framework

Remediation of DOE sites must be performed in compliance with applicable federal and state environmental laws and regulations. Before the enactment of current federal environmental legislation, DOE managed waste storage and disposal under requirements established by authority of the Atomic Energy Act. In response to subsequent regulations, DOE established programs to comply with environmental laws relevant to (1) generation, treatment, storage, disposal, and transportation of wastes produced in operating facilities and (2) contaminant characterization and cleanup at inactive waste sites.

The principal regulatory requirements for remedial actions are those derived from the RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). These federal statutes require that hazardous-waste sites and hazardous-substance spills and releases be investigated, characterized, and cleaned up. CERCLA and RCRA contain parallel guidance for the sequence of clean-up activities. The germane component of the CERCLA process is the RI/FS; the germane component of the RCRA process is the RCRA Facility Investigation/Corrective Measures Study (RFI/CMS).

The DOE is currently performing both CERCLA and RCRA activities at RFETS; therefore, both RI/FS and RFI/CMS activities are being conducted. To establish a common basis of understanding and to integrate the requirements of federal regulators with those of the CDPHE, the IAG was negotiated among the DOE, EPA, and CDPHE and signed on January 22, 1991. The IAG establishes legally enforceable framework to coordinate clean-up and oversight efforts, and to standardize requirements. The IAG establishes specific milestones and time frames for remedial actions. The IAG establishes the parameters for cleanup of potential radioactive, hazardous, and mixed-waste contamination resulting from past operations at RFETS.

For IAG implementation, Individual Hazardous Substance Sites (IHSSs) were identified, aggregated into OUs, and prioritized. The priorities for RFETS OUs were established through

the IAG. Assessment, characterization, and remedial activities for IHSSs are conducted for each OU. The OUs form the basis for planning, scheduling, budgeting, and prioritizing environmental restoration activities. The IAG contains specific requirements for the environmental investigation and cleanup of RFETS. Paragraph VII.D.1 of the statement of work of the IAG stipulates the requirements for conducting an HHRA at each OU. To initiate the HHRA, DOE is required to submit the following TM for each OU: (1) Identification of COCs; (2) Description of Exposure Scenarios and Exposure Assumptions; (3) Description of Fate and Transport Models; and (4) Toxicity Assessment for COCs.

1.3.3 Physical Description

Sections 1.3.3.1 through 1.3.3.5 summarize physical properties of the RFETS.

RFETS is located in northern Jefferson County, approximately 26 kilometers (km), [16 miles (mi)] northwest of Denver. Other nearby cities include Boulder, Broomfield, Westminster, and Arvada, which are located less than 16 km (10 mi) to the northwest, east, southeast, and south respectively. The site consists of approximately 2,630 hectares (6,500 acres) of federally owned land in Sections 1 through 4 and 9 through 15 of Township 2 South, Range 70 West. Major buildings are located within the RFETS security area, which encompasses approximately 162 hectares (400 acres). A buffer zone of approximately 2,490 hectares (6,150 acres) surrounds the secured area.

1.3.3.1 Topography - The natural environment of RFETS and vicinity is influenced primarily by its proximity to the Front Range of the Rocky Mountains. RFETS is directly east of the north-south trending Front Range, and is located about 26 km (16 mi) east of the Continental Divide at an elevation of approximately 1,830 meters (m) [6,000 feet (ft) above mean sea level. RFETS is located on a broad, eastward sloping plain of coalescing alluvial fans developed along the Front Range. The fans extend about 8 km (5 mi) in an eastward direction from their origin at Coal Creek Canyon and terminate on the east at a break in slope to low

rolling hills. The operational area at the RFETS is located near the eastern edge of the fans on a terrace between stream-cut valleys (North Walnut Creek and Woman Creek).

1.3.3.2 Geology - Geologic units beneath RFETS consist of unconsolidated surficial units of Quaternary age (Rocky Flats Alluvium, various terrace alluvia, valley fill alluvium, and colluvium), which unconformably overlie Cretaceous-aged bedrock (Arapahoe Formation, Laramie Formation, and Fox Hills Sandstone). This geologic sequence forms part of a monoclinical fold whose western edge is composed of uplifted strata of Mesozoic age that become younger to the east.

1.3.3.3 Hydrology - Groundwater may be present in the unconsolidated surficial material, consisting of the Rocky Flats Alluvium, colluvial material, and the valley fill alluvium. Groundwater is also inferred to occur locally in the upper portion [i.e., 0 to 7.6 m (0 to 25 ft)] of the Laramie claystone bedrock. These units contain unconfined groundwater and comprise the upper hydrostratigraphic unit (UHSU). Confined groundwater occurs in deeper [>7.6 m (25 ft)] bedrock sandstones and claystones of the upper Laramie Formation. This bedrock unit is labeled the lower hydrostratigraphic unit (LHSU).

Portions of the RFETS UHSU are only seasonally wet, and contain groundwater only in the spring months when there is high precipitation. Groundwater levels across the site are higher in spring than in the remainder of the year.

Recharge to the UHSU is primarily through infiltration of precipitation, which ranges from 0.05 m (2 in) per hour for initial infiltration, to 0.025 m (0.5 in) per hour for final (saturated) infiltration. Localized sources of recharge may also occur, such as seepage from the Rocky Flats Alluvium to colluvial materials. Discharge occurs largely through evapotranspiration and discharge by seeps to surface water units such as the three series of ponds, Woman Creek, Walnut Creek, Rock Creek, the South Interceptor Ditch, and the French Drain.

Three intermittent streams drain RFETS, with flow generally from west to east. These drainages are Rock Creek, Walnut Creek, and Woman Creek. Rock Creek drains the northwestern corner of the RFETS and flows northeast through the buffer zone to its off-site confluence with Coal Creek. An east-west trending interfluvial separates the Walnut Creek and Woman Creek drainages. North and South Walnut Creeks and an unnamed tributary drain the northern portion of the RFETS security area. These three forks of Walnut Creek join in the buffer zone and flow toward Great Western Reservoir, which is approximately 1.6 km (1 mi) east of the confluence. However, this flow is routed around Great Western Reservoir by the Broomfield Diversion Canal, which is operated by the City of Broomfield. Woman Creek drains the southern RFETS buffer zone flowing eastward. The Woman Creek flow is diverted onsite to Mower Reservoir via the Mower Ditch. The South Interceptor Ditch lies between RFETS and Woman Creek. The South Interceptor Ditch collects runoff from the southern RFETS security area and diverts it to Pond C-2 where it is monitored, treated, and then pumped to the Walnut Creek watershed where it is released to the Broomfield Diversion Canal.

1.3.3.4 Climate and Meteorology - The RFETS area has a semi-arid climate and receives about 0.3 m (15 in) of annual precipitation, 40 percent of which falls in the spring. Thunderstorms from June to August contribute approximately 30 percent of the annual precipitation. Snowfall averages 2.1 m (85 in) per year. Temperatures are moderate, ranging from 13 to 30° Celcius (C) [55 to 85° Fahrenheit (F)] in the summer and 20 to 45° F in winter. The average relative humidity is 46 percent. Winds at RFETS are predominantly from the northwest.

1.3.3.5 Flora and Fauna - The majority of the plant species at RFETS contributing to the terrestrial communities belong to two groups — vascular cryptogams (i.e., spore producing plants) and vascular plants. Grassland habitats are dominant, representing about 82 percent of the total area. Nine percent of the area is either developed or disturbed. Marsh habitats occupy 4 percent, woodland habitat constitutes 4 percent, and shrub habitats account for the remaining area. Wildlife species are typical of those in similar habitats throughout the foothills area. In several regions of the buffer zone, Preble's meadow jumping mouse has been observed. If

declared threatened and endangered, this could impact the likelihood of certain HHRA exposure scenarios, such as the on-site residential and the mining scenarios.

As a result of limited and inconsistent surface water supplies, aquatic species with short life cycles and smaller habitat requirements, such as benthic macroinvertebrates, have developed more diverse communities than fish.

1.4 HHRA Methodology Organization

This document is organized into the following sections, which together represent the components of the DOE, EPA, and CDPHE agreements integrated with the traditional CERCLA/RCRA HHRA methodology:

- Data Evaluation
- Identification of COCs
- CDPHE Conservative Screen of PCOCs
- Exposure Assessment
- Toxicity Assessment
- Risk Characterization
- HHRA Report.

2.0 DATA EVALUATION

The first step in the methodology for HHRA at RFETS is data evaluation. Components of data evaluation include identification of data needs and data requirements prior to data collection and the subsequent generation of a usable data set for the HHRA. These components are discussed in the following sections.

2.1 Data Needs Identification

Identifying data needs specifically for the HHRA is one component of overall RI/FS planning. The definition of HHRA data needs is integrated with the definition of data quality objectives (DQOs) for the RI/FS. Data for each of the major components of the HHRA are needed to adequately assess the current and future risk posed by a site. However, because the data input to site characterization and the exposure assessment are site specific (i.e., are unique to the contaminants and physical characteristics of a site), emphasis during the planning stages is on these components. Data needs associated with the toxicity assessment and risk characterization are assessed after the site characterization is complete and in parallel with the exposure assessment. Data for the toxicity assessment typically consists of EPA-derived toxicity constants and uncertainty factors.

This section discusses the data needs relevant to the components of the HHRA process. Additional instruction is provided in *Guidance for Data Useability in Risk Assessment, (Parts A and B)*, (EPA, 1992a) and RAGs, (EPA, 1989a) as well as:

- *Guidance for Planning for Data Collection in Support of Environmental Decision-Making Using the Data Quality Objectives Process*, (EPA, 1994a)
- *Draft RFETS Data Management Plan for ER Management* (EG&G, 1994a)
- *Rocky Flats Plant Site-Wide Quality Assurance Project Plan for CERCLA RI/FS and RCRA RFI/CMS Activities* (EG&G, 1991).

Data needs for site characterization, exposure assessment, toxicity assessment, and risk characterization are discussed in the following subsections.

2.1.1 Site Characterization Data

Data collected to support site characterization are used in the RI/FS/Remedial Design/Remedial Action process; thus the development of HHRA data requirements parallels the data requirements to meet the DQOs. For HHRA purposes, the output of the site characterization is measured or modeled concentrations of contaminants in each of the source areas (i.e., IHSSs) and media of concern. Data needs are formulated in terms of characterizing the source-pathway-receptor. Generally data used for the HHRA include characterization of:

- The source of contamination
- The extent of contamination in each medium potentially affected
- The potentially affected media with which a current or future receptor may come in contact.

Depending on the detail of source characterization data available in historical information (e.g., disposal records, previous investigations, removal records), the source characteristics may be well known or interpolated. The *Historical Release Report* (DOE, 1992) documents an extensive effort to gather information at the IHSS level for use in determining the potential source characteristics. The need for additional source characterization is determined during project scoping and, if additional characterization is conducted, should include an analyte suite which encompasses the list of chemicals of potential concern and transformation products for those chemicals.

As discussed in Sections 4.0 and 5.0, the contaminant concentration distributions will be used to delineate source areas and areas of concern at the OU level. Characterization of the extent of contamination encompasses contaminant concentration distributions within the IHSSs and those contaminants that have potentially migrated outside of the IHSSs. Fate and transport modeling can be used to predict concentrations that may effect future receptors. For the RI as

well as the HHRA, all media presenting a potential exposure route or transport mechanism should be characterized for the chemicals suspected in the source. This characterization allows the development of the conceptual site model. The number and locations of samples included in the HHRA allows for characterization of:

- Statistical comparison with background concentrations for each medium of concern
- Statistical distributions of contaminant concentrations for each medium of concern
- Contaminant levels that can be compared to risk-based concentrations
- All potential exposure points within each medium (i.e., source area and area of concern delineation)
- Migration to potential exposure points including input data for fate and transport models
- Potential exposures based on possible future land uses.

2.1.2 Exposure Assessment Data

The exposure assessment uses the site characterization data to estimate exposure-point concentrations for each medium of concern and area of concern. Via conceptual model development and fate and transport modeling, exposure-point estimates can be calculated for future receptors. Data needs for the exposure assessment are summarized as follows:

- Contaminant release rates from the source (either known or modeled)
- Physical, chemical, and biological parameters for evaluating transport and transformation of site-related chemicals
- Parameters to characterize receptors according to their activity, behavior, and sensitivity
- Estimates of exposure concentrations for COCs, environmental media, and receptors at risk
- Estimates of chemical intake or dose for receptors via all exposure pathways and in exposure areas.

2.1.3 Toxicity Assessment Data

As indicated in Section 2.1, the data for toxicity assessment typically consists of EPA-derived information regarding the potential for particular contaminants to cause adverse health effects. In a toxicity assessment, data are collected from acceptable sources of information. Toxicity assessments are procedural and include the following steps:

1. Gather qualitative and quantitative toxicity information for contaminants of concern
2. Determine toxicity values for noncarcinogenic effects
3. Determine toxicity values for carcinogenic effects
4. Summarize the toxicity information.

Data required for the toxicity assessment include:

- Toxicity values for all chemicals and exposure pathways
- Uncertainty factors and confidence measures for reference doses (RfDs) and weight-of-evidence classifications for cancer slope factors (CSF).

2.1.4 Risk Characterization Data

The risk characterization is an integral component of the HHRA that combines the output of the exposure assessment and toxicity assessment to interpret, present, and quantify the results of the HHRA. Because of this output, specific data needs for risk characterization are similar to data needs previously identified.

2.2 Data Quality Objectives Development

The development of DQOs identifies the data requirements for the HHRA. As a follow-up to DQO development, data quality should be assessed to confirm that the required data have been collected. The following sections discuss DQO development and data quality assessment.

2.2.1 Data Quality Objectives

DQOs greatly affect the HHRA because DQO development guides the overall site characterization strategy and presents qualitative and quantitative goals for data quality and, subsequently, data useability. Because the HHRA results are one of the key inputs to decisions regarding the status of a site (i.e., no remedial action versus remedial action), the HHRA site characterization data needs (Section 2.1.1) are integral to the development of DQOs. DQO development involves the definition of those needs and the types of data required to meet those needs.

DQO development at RFETS is detailed in the *Rocky Flats Plant Site-Wide Quality Assurance Project Plan for CERCLA RI/FS and RCRA RFI/CMS Activities*, (EG&G, 1991). EPA guidance emphasizes a seven-step problem-solving procedure as outlined in the *Data Quality Objectives Process*, (EPA, 1994a). This procedure is shown in Figure 2-1. Although DQO development is sequential, it is also iterative. The outputs from one step may influence prior steps and cause them to be redefined. The goal of DQO development is to optimize data collection. The *Guidance for Data Useability in Risk Assessment, Parts A and B*, (EPA, 1992a) also contains detailed information on data collection for risk assessment.

To adequately characterize contaminant concentrations, the analytical suite and each media of concern (i.e., data types) may differ. By evaluating existing data and the site characterization on a data-type-specific basis, the collection strategy is more manageable and representative of the actual data needs.

2.2.2 Data Quality Assessment

Data quality assessment, as defined in the *Draft RFETS Data Management Plan for ER Management* (EG&G, 1994), "...uses validated data to evaluate environmental conditions with identifiable levels of confidence." The assessment considers variability from all sources across sampling and analysis and as specific to the site-specific DQOs. Measurement data is assessed for adequacy according to intended use by comparing the data with acceptance criteria.

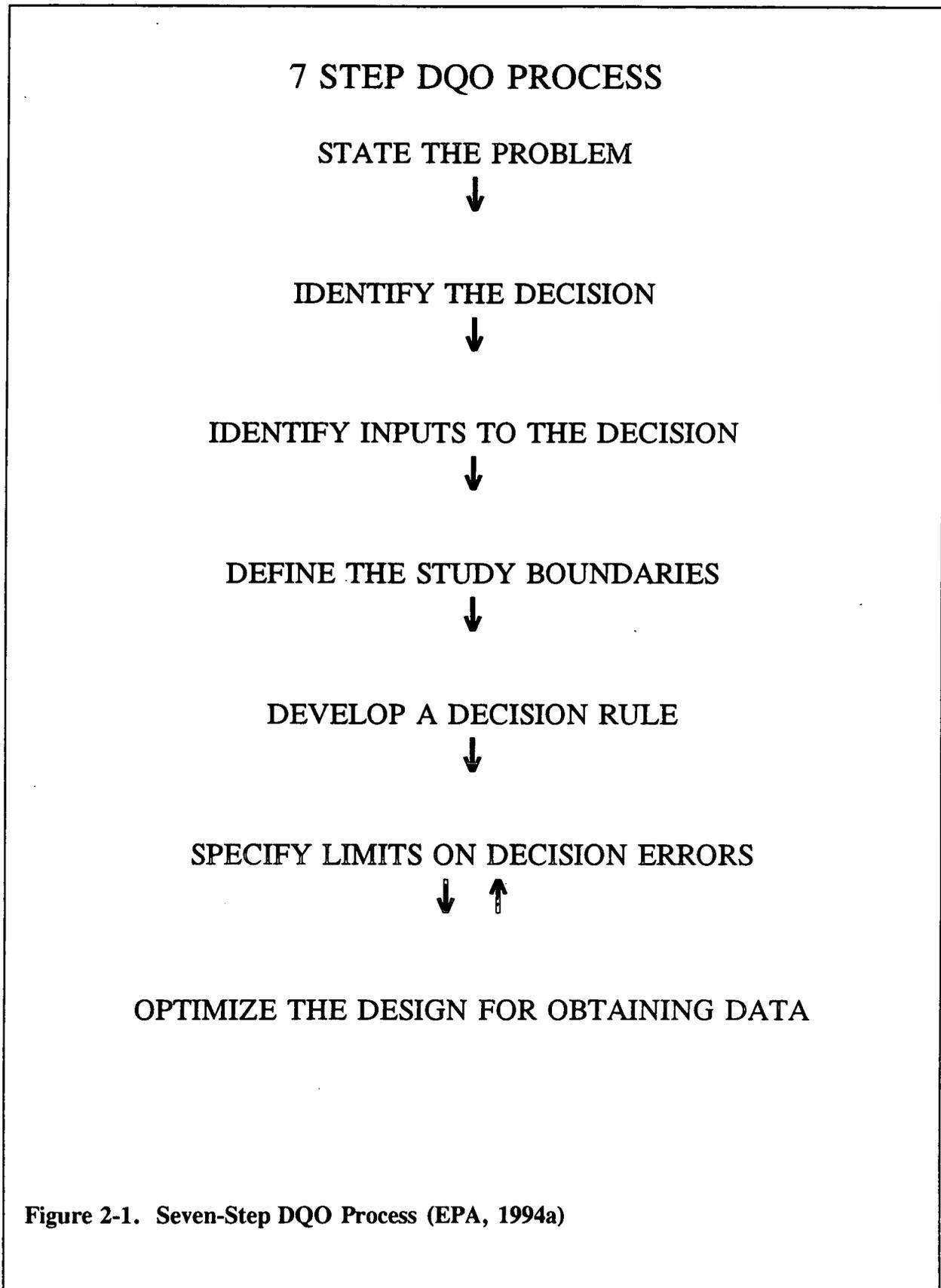


Figure 2-1. Seven-Step DQO Process (EPA, 1994a)

Components of the data quality assessment include data validation and data useability discussed in the following subsections.

2.2.2.1 Data Validation – Generally, analytical data (or a representative subset) used in the HHRA should be validated to assess the effect of quality-control issues on data useability in the HHRA (EPA, 1989a). At present, all analytical data generated for the RFETS ER Program is validated by an independent contractor per EPA Contract Laboratory Program (CLP) National *Functional Guidelines for Inorganic and Organic Data Review* (EPA, 1988a and EPA, 1988b), and *Radiochemical Data Validation Guidelines* (EG&G, 1994). The data validation process is detailed in the *Draft RFETS Data Management Plan for ER Management* (EG&G, 1994a) and the ER QAPjP (EG&G, 1991). A listing of validation Standard Operating Procedures (SOPs) is in the QAPjP (EG&G, 1991).

The ER Program includes the following three classes of data quality.

- "V"-Valid and usable without qualification
- "A"-Acceptable for use with qualification(s)
- "R"-Rejected (unacceptable).

Valid data meet the following objective standards, where applicable:

- *1. Analytical methods are followed
2. Acceptance criteria are achieved
3. Sufficient number and type of quality control (QC) samples are analyzed
- *4. QC limits are achieved
- *5. Compounds and analytes are correctly identified
- *6. Equipment/instrumentation calibration criteria are achieved
7. Sample holding times are met.

* Primary validation criteria.

Data that are acceptable with qualification meet most, but not all, of these standards. At a minimum, all of the primary validation criteria are achieved within acceptable limits. Only

data qualified "V", valid or "A", acceptable will be used in data analysis. Data that have not yet been validated may be used on an interim basis. Rejected data that fail to meet primary validation criteria will not be used in HHRAs.

Table 2-1 illustrates the laboratory qualifiers and definitions encountered when using site characterization data along with the meaning and recommended use for the HHRA. Table 2-2 presents the validation codes for RFETS ER Program data.

2.2.2.2 Data Useability – *Guidance for Data Useability in Risk Assessment, Parts A and B*, (EPA, 1992a) provides guidance on assessing data useability. This guidance recommends six useability criteria:

- Data sources
- Documentation
- Analytical methods and detection limits
- Data quality indicators
- Data review
- Reports from sampling and analysis to the risk assessor.

The *Draft RFETS ER Program Data Management Plan* (EG&G, 1994) states that data useability is assessed by performing a comprehensive evaluation of data for conformance to the DQOs and to the sensitivity, precision, accuracy, representativeness, completeness, and comparability (SPARCC) parameters. Administrative Procedure Number 2-G32-ER-ADM-08.02, *Evaluation of ER Data for Useability in Final Reports* (EG&G, 1994c), details the assessment of SPARCC parameter. This procedure addresses issues such as field duplicates, trip blanks, and equipment reinstates, the procedure also incorporates the assessment of laboratory validation and field quality control (QC) samples to establish overall data useability or adequacy.

2.3 Data Set Generation

Data sets generated from RFEDS output require "cleanup" and treatment prior to use in the HHRA. The data-set-generation steps are described in the following sections.

Table 2-1
Result Qualifiers for RFETS ER Program Data

Result Qualifiers			
Qualifier	Definition	Include in Data Analysis	Detected? (Hit?)
+	inorganics: correlation coefficient for MSA is < 0.995 (estimated value).	yes	yes
-or*	inorganics: duplicate analysis not within control limits (estimated value).	yes	yes
A	organics: indicates a TIC as a suspected aldol condensation product.	yes, but remove to TIC table	no
B	organics: warns that analyte was also detected in blank.	yes	yes
B	inorganics: reported values are less than CRDL but greater than IDL.	yes	yes
B	radionuclides (rads): constituent also detected in associated blank, where concentration in blank was > CRDL or > minimum detectable activity (MDA) (estimated value).	yes	yes
C	organics: pesticide result confirmed by GC/MS.	yes	yes
C	rads: presence of high TDS in sample increased the MDA.	yes	yes
D	organics: identified in an analysis at a secondary dilution.	yes	yes
E	organics: compound exceeded calibration range of instrument, use dilution analysis result for this analyte, not this E-qualified result.	no	no
E	inorganics: value estimated due to interference.	yes	yes
F	rads: for alpha spectrometry--FWHM exceeded acceptable limits (estimated value).	yes	yes
G	total organic carbon (TOC): dilution result exceeded range of instrument (estimated value).	yes	yes
H	rads: sample analysis performed outside of method (specified maximum hold).	yes	yes

**Table 2-1
(continued)**

Qualifier	Definition	Include in Data Analysis	Detected? (Hit?)
I	organics: interference with target peak (estimated value).	yes	yes
JB	organics: result below detection limit and analyte detected in lab blank.	yes	no
J	organics: MS data indicate presence of compound but below detection limit (estimated value).	yes	yes
Delete?	inorganics: value greater than IDL but control sample analysis not within control limits (estimated value).	yes	yes
L	undefined.	no	no
N	organics: compound presumed present (TIC).	yes, but remove to TIC table	no
N	inorganics: spiked sample recovery not within control limits (estimated value).	yes	yes
N*	inorganics: spiked sample recovery and duplicate analysis not within control limits (estimated value).	yes	yes
R	validation code for rejected data accidentally entered in lab qualifier field (unusable data).	no	no
S	inorganics: the reported value determined by the method of standard additions.	yes	yes
U	organics and inorganics: analyte analyzed below detection limit.	yes	no
UC	organics: pesticide result confirmed but below detection limit.	yes	no
UJ	organics: analyte analyzed below detection limit.	yes	no
UN	organics: compound presumed present but below detection limit	yes	no
UN	inorganics: spiked sample recovery analysis not within control limits and sample result below detection limit.	yes	no
UW	inorganics: post-digestion spike for graphite furnace atomic absorption (GFAA) analysis is out of control limits and sample result is below detection limit.	yes	no

**Table 2-1
(continued)**

Qualifier	Definition	Include in Data Analysis	Detected? (Hit?)
UX	analyte dependent, see note.	yes	no
V	validation code for valid data accidentally entered into lab-qualifier field.	yes	yes
W	inorganics: post-digestion spike for GFAA analysis is out of control limits while sample absorbance < 50% of spike absorbance.	yes	yes
X	organics (pre-1992): lab software flag (combines more than one qualifier, not defined).	no, unless accompanied by a validated result.	no, unless accompanied by a validated result.
X	inorganics (pre-1992): detection limit greater than normal, spike matrix interference.	yes	yes
X	other (OU7 RFI/RI samples): result by calculation defined in general radiochemistry and routine analytical services protocol (GRRASP).	yes	yes
Y	rads: chemical yield exceeded acceptable limits (estimated value).	yes	yes

NOTE: The use of X qualifiers is defined in the GRRASP as a result determined by calculation, not by direct laboratory analysis. Therefore, for samples analyzed during the period that the GRRASP has been in effect (since January 1992), the results qualified by an X will be treated as estimated values (similar to J). For historic data, when the GRRASP was not used by laboratories, an X qualifier has two definitions. For organics, the X is a flag entered manually by the laboratory, but is not defined in Rocky Flats environmental database system (RFEDS). Therefore, organic results qualified by X are not considered usable data, unless a validated result is given. For inorganics, an X qualifier indicates that the detection limit for the analyte is higher than normal due to matrix interference. Inorganics qualified with an X will be treated like a J result. The X qualifier is also used with other qualifiers (i.e., UX, XJ); in these cases, the meaning of X depends on the analyte and the date of the analysis.

Source: M.A. Siders, EG&G Interoffice Correspondence MAS 001-94, "Practical Suggestions for Users of RFEDS Data," April 5, 1994 update.

Table 2-2
Validation Codes for RFETS ER Program Data

Qualifier	Definition	Include in Data analysis	Detected? (Hit?)
J	estimated result (occurs in historical data only).	yes	yes
A	acceptable result	yes	yes
JA	acceptable result for estimated value (occurs in historical data only). Note: these data qualified with "U" but having validation code of "JA" are still non-detects.	yes	yes
R	rejected result.	no	no
V	valid result.	yes	yes
Y	not yet validated; validation in progress.	yes	yes
Z	validation not required.	yes	yes

Source: M.A. Siders, EG&G Interoffice Correspondence MAS 001-94, "Practical Suggestions for Users of RFEDS Data," April 5, 1994 update.

2.3.1 Data Cleanup

The "data cleanup" of RFEDS output is a task to make the data consistent. The process as provided in a memorandum from M. Siders regarding Practical Suggestions for Users of RFEDS Data, April 5, 1994 and detailed in Appendix A, consists of a series of steps which includes:

- Standardization of units
- Standardization of geologic codes
- Standardization of locations if the location designation has changed over time
- Standardization of analyte names (usage has changed over the years)
- Deletion of blank "form-generated" records for which no results are given
- Exclusion of QC data from the working data set
- Removal of any rejected data (Validation code = "R")
- Replacement of non-validated records with corresponding validated records (if available)
- Correction of incorrect units (e.g., pH should have "PH" as the unit, *not* "MG/L" as the unit)
- Treatment of DUP/REAL pairs
- Appropriate use of diluted (DIL) results
 - Outlier analysis.

2.3.2 Data Treatment

The manner in which analytical results are classified as non-detects is dependent upon the analyte group. Table 2-1 provides information relating to the use of result qualifiers in determining how and in what capacity the qualified point should be used in the data analysis. The following discusses non-detect classification for radionuclides, organic, and inorganic analytes as summarized from M. Siders memorandum dated April 5, 1994.

- All data for radionuclides should be used as detects, except for rejected data (Validation code = R). For radionuclide data, DOE Order 5400 states, "All of the actual values, including those that are negative, should be included in the statistical analyses."
- For organics, the result qualifier (entered in the Qualifier field) should be used to determine the percentage of non-detects. Non-detects for organic analytes are generally qualified "U", but other designations may also appear in the result-qualifier field.

Positive detections (i.e., "hits") of some common laboratory contaminants such as acetone, methylene chloride, and certain phthalates may indicate cross-contamination if detected in the associated laboratory blank; such sample results are designated as a "B" in the Qualifier field. EPA guidance for data validation and risk assessment (EPA, 1989a) indicates that if the concentration of a common lab contaminant in a sample is more than 10 times the concentration of the sample analyte in the associated blank, then the sample result is taken to be real (i.e., a "hit"), not attributable to laboratory contamination. For other analytes that are not typically found as laboratory contaminants, EPA guidance (EPA, 1989a) states that if the concentration in the sample exceeds five times the concentration in the associated blank, then the sample result is taken to be real, not attributable to laboratory contamination.

- For metals and other chemical parameters (inorganics), it may be ineffective to rely on the result qualifier alone. The following criteria have been employed to differentiate detects from non-detects, and are suggested as guidelines for the data:
 - If the Qualifier field contains a "U", the result is used as a non-detect (i.e., censored data point).
 - If the Qualifier field is blank and the result is greater than the reported detection limit, the result is used as a detected value, barring evidence to the contrary.
 - If the Qualifier field (for inorganics) contains a "B", which indicates that the result was above the IDL but below the CRDL, the result is used as a detected value.
 - Other characters may also be found in the Qualifier field, and, barring any other evidence to the contrary, these are generally accepted as detects.

Data-treatment requirements with respect to HHRA COC identification and calculation of exposure-point concentrations includes replacement of non-detect values. With the exception of the Gehan Test (used as part of the background comparison), non-detect values should be replaced with 0.5 times the reported detection limit in accordance with Section 5.3.3 of RAGS (EPA, 1989a). Other techniques such as probability plotting and maximum likelihood estimators (MLEs), can be employed for the replacement of non-detect values in a data set.

Probability plotting methods are described in detail in Helsel and Cohn (1988). A common MLE is described by Cohen (1961) and Sanford et al. (1993). A professional statistician should be consulted regarding the treatment of non-detects on a case-by-case basis.

Numerous studies, including Sanford et al. (1993), Gilliom and Helsel (1986), Helsel and Gilliom (1986), Helsel and Cohn (1988), Newman and Dixon (1990), Newman et al. (1989), Travis and Land (1990), and Lambert et al. (1991), generally indicate that simple substitution methods are the least-robust techniques for non-detect substitution when descriptive statistics are required from a data set. The value substituted greatly affects the outcome, and generally, simple substitution of a value of 0.5 to 0.7 of the detection limit is superior to substituting the value of the detection limit (Sandford et al., 1993).

3.0 IDENTIFICATION OF CONTAMINANTS OF CONCERN

This section describes the methodology used to identify COCs for which potential risks for each RFETS OU will be estimated. The goal of selecting COCs in this phase of the HHRA is to identify specific contaminants in each environmental medium that may pose human health hazards. Once identified, COCs will be advanced through the quantitative risk assessment to characterize risk for all current and potential future human receptors.

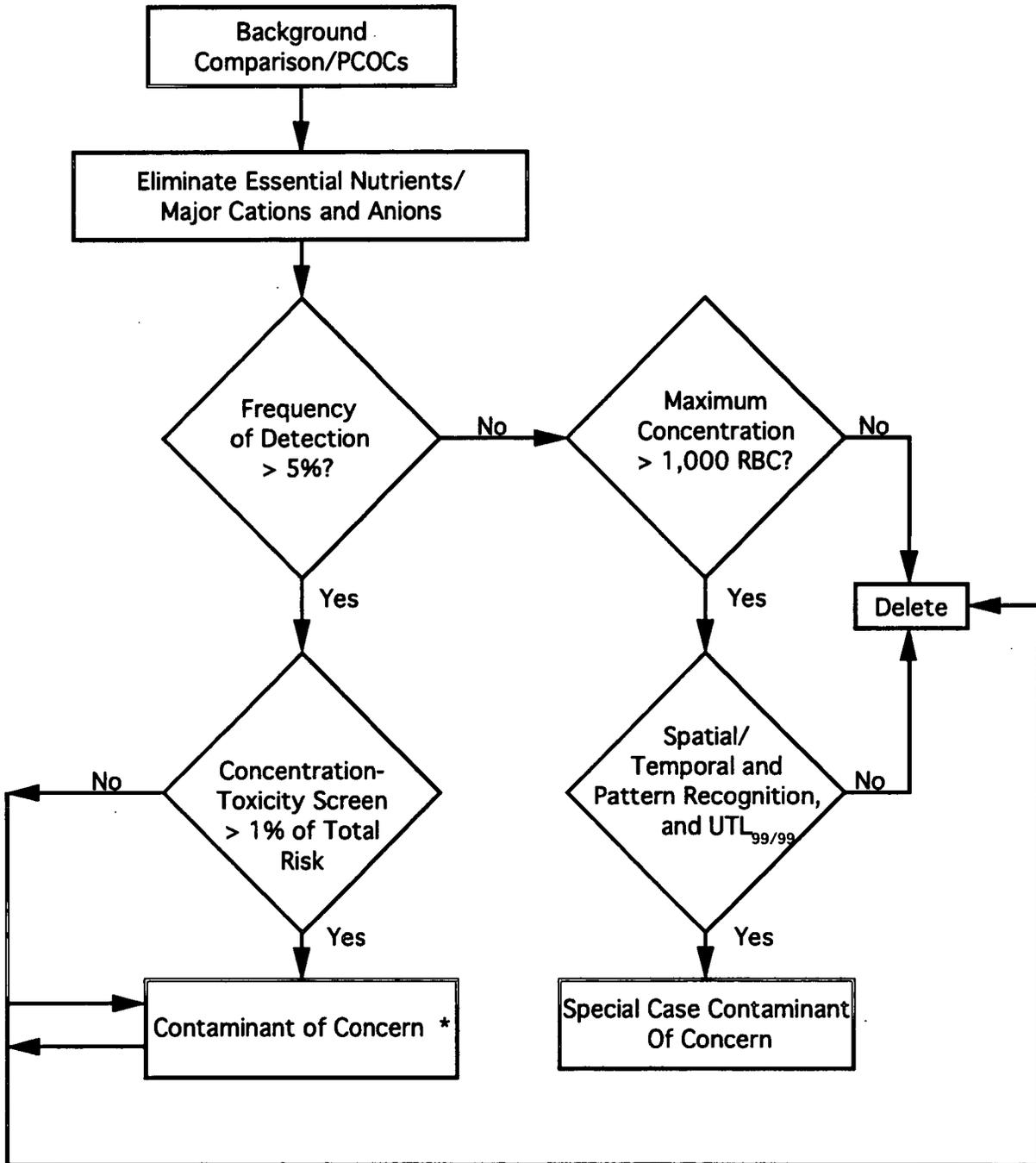
The first step of COC selection involves identifying PCOCs by distinguishing sample data from background data. Following this, the selection of COCs for the HHRA proceeds simultaneously with the CDPHE Conservative Screen (described in Section 4.0). The relationship between the CDPHE Conservative Screen and the HHRA is illustrated in Figure 1-1.

The following screening criteria will be applied to all contaminants detected in each environmental medium (surface soil, subsurface soil, surface water, groundwater, sediments, and air) to select COCs for each OU:

- Background comparison for inorganic contaminants (including radionuclides)/ PCOCs
- Human essential-nutrient analysis
- Frequency of detection analysis
- Risk-based concentration screen
- Concentration-toxicity screen
- Professional judgment.

Figure 3-1 presents the flowchart for applying the screening criteria. Elimination criteria will be applied in the order presented; at each decision point, the contaminant will be eliminated

Figure 3-1 COC Identification



* Professional Judgement Applied to These Analytes

or retained for further consideration. Prior to initiation of the screening process, data will be aggregated by medium and analyte. A summary presentation of the data will include:

- Chemical name
- Chemical-specific contract required quantitation limit (CRQL)
- Range of sample quantitation limits (SQL)
- Frequency of detection
- Minimum detected concentration
- Maximum detected concentration
- Arithmetic or geometric mean concentration.

3.1 Background Analysis

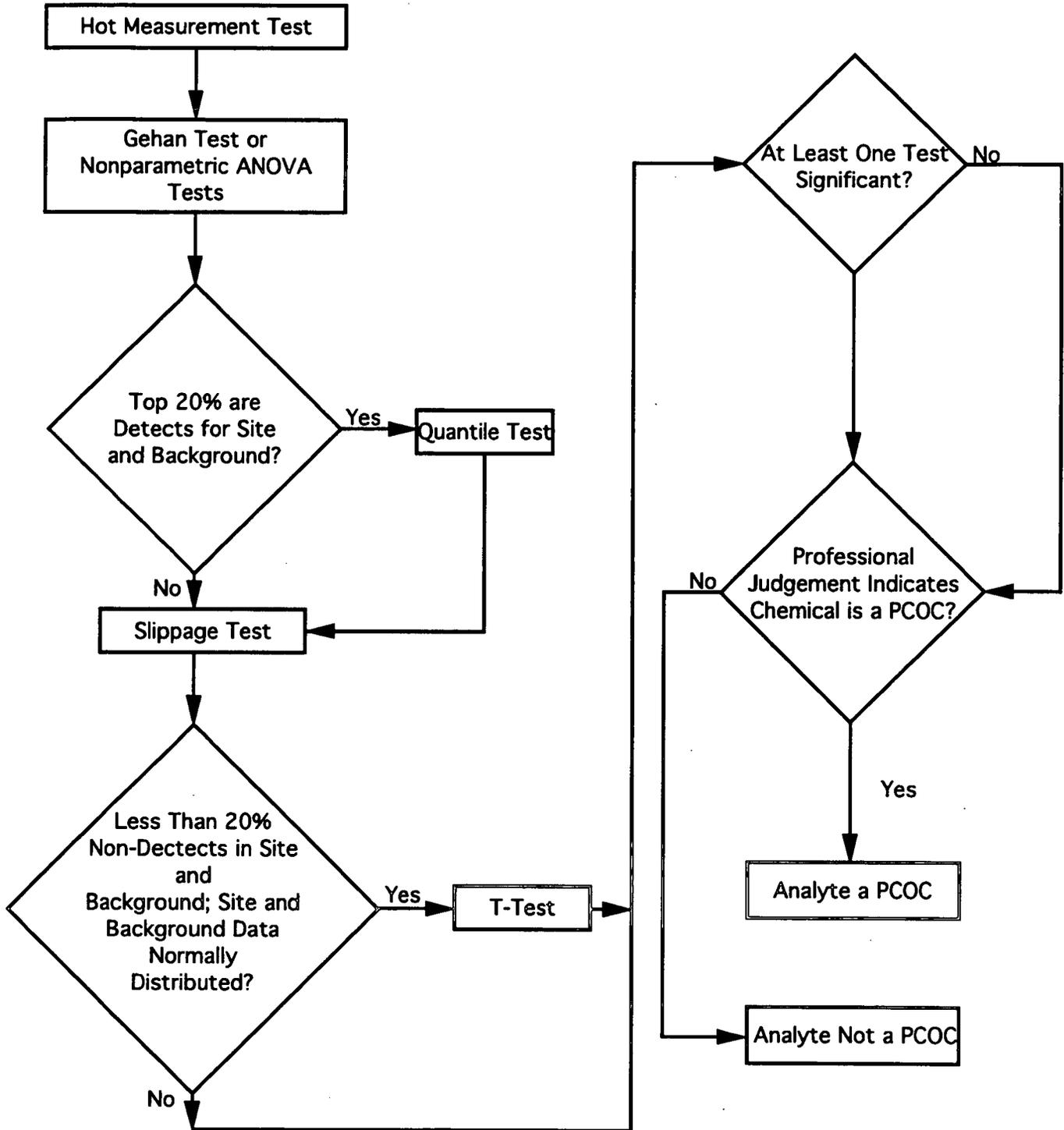
The first step in the COC selection process is to distinguish between contamination associated with site activities, and regional anthropogenic (man-made) and nonanthropogenic (naturally occurring) background conditions. To make this determination, a background analysis is conducted. The output of the background analysis is a list of PCOCs. Figure 3-2 illustrates the PCOC identification process.

The statistical methodology used to conduct the background analysis (i.e., PCOC identification) for nonanthropogenic compounds has been developed and approved by DOE, EPA, and CDPHE. This methodology is presented in Appendix B. The methodology is based on the September 29, 1993 strawman proposal submitted by DOE and accounts for modifications and clarifications provided through EPA correspondence dated October 25, 1993.

Methods used to analyze whether a metal or radionuclide exceeds background levels include:

- Analytical results for metals and radionuclides are compared to the background data using four statistical tests: the Quantile test, Slippage test, Student's t-test, and the Gehan test as described in a letter report by Gilbert (Gilbert, 1993). The analyte is considered to be above background if it fails any test at the $p \leq 0.05$ level, provided the test is supported by an appropriate data set.
- Ninety-nine percent confidence level ($UTL_{99/99}$) Comparison: Analytical results for each metal and radionuclide are compared to the 99 percent upper tolerance limit of

Figure 3-2 PCOC Identification



background data calculated at the $UTL_{99/99}$. The $UTL_{99/99}$ test is an indicator of possible hot spots (Gilbert, 1993). If any result exceeds the $UTL_{99/99}$, the analyte is identified as a PCOC, subject to spatial and temporal evaluation.

The source of background data is the *Background Geochemical Characterization Report* (BGCR) (EG&G, 1993). Because samples of surficial soils were not collected and analyzed for the original BGCR program, OUs 1 and 2 collected samples of surficial soil from the Rock Creek background area. To date, these data were the only validated background data for surficial soils. However, as a second phase of the BGCR, a study of background surficial soils was initiated in 1994. Samples for this study have been collected, and are currently undergoing chemical analysis and data validation.

Using the results of this statistical analysis, inorganic chemicals (including radionuclides) that are at or below background levels will be eliminated from further consideration. As described in Appendix B, the specific criterion for the background analysis will be that none of the statistical tests indicate a statistically significant elevation of site-specific levels over background. The criteria used to evaluate whether a metal or radionuclide exceeded background levels are summarized in this section.

If the battery of statistical tests indicates a statistical difference above background levels, the chemical will not be eliminated. An exception to this rule will be if the statistical tests are inappropriate for the data set. For example, if a Student's t-test is initially used because it is assumed that the underlying probability density function is Gaussian, but further analysis reveals this assumption to be unsubstantiated, the result from the statistical test would be invalidated. As indicated on Figure 3-2, professional judgment will be used to retain or eliminate contaminants depending on the appropriateness of the statistical test. Professional statisticians will be consulted prior to eliminating such contaminants. Presentation of the results of the background comparison will include descriptive statistics, statistical tests, power of tests, and results of the test.

The same background analysis, statistical methodology, and elimination criteria used to evaluate nonanthropogenic chemicals will be used to evaluate anthropogenic conditions. Anthropogenic compounds will be retained or eliminated on a case-by-case basis using professional judgment.

3.2 Essential Nutrients Analysis

Constituents may be eliminated from the risk assessment if they are essential human nutrients that are not present at toxic levels (EPA, 1989a). As indicated on Figure 3-1, a determination will be made in this phase of the COC selection process as to whether recognized essential nutrients are present at potentially toxic levels. Chemicals considered to be an essential part of the daily human diet (EPA, 1994a) include:

- Calcium
- Iron
- Magnesium
- Potassium
- Sodium.

A toxicologist should apply professional judgment to compare these essential nutrient concentrations and other chemicals that may be part of the human diet with appropriate toxicity values.

3.3 Contaminants of Concern Frequency of Detection Analysis

All metals above background levels and detected organic compounds are evaluated for frequency of detection. Compounds that are detected at a frequency of 5 percent or greater are considered potential OU-wide chemicals of concern. These compounds will be included in the concentration-toxicity screen (CTS) to identify compounds that could contribute significantly to total risk (Section 3.5). Compounds detected at less than 5 percent frequency are not characteristic of site contamination and the potential for exposure is low. Maximum concentrations of infrequently detected organic compounds and metals will be compared to risk-

based concentrations (RBCs) as described in Section 3.4 to identify isolated or highly localized occurrences of high concentrations of toxic chemicals (i.e., hot spots) that could pose a risk if routine exposure were to occur. These chemicals will be retained as special-case chemicals of concern for separate evaluation in the risk assessment.

3.4 Risk-Based Concentration Comparison

Although frequency of detection is an important elimination criterion to prevent spurious data from biasing estimation of risks, an approach will be used to prevent small areas containing high contaminant levels from being eliminated. As a health-protective precaution to ensure that "hot spot" contaminants are not eliminated as COCs, all contaminants that satisfy the low frequency of detection criterion will be compared to RFETS-specific RBCs, which are the chemical-specific Programmatic Preliminary Remediation Goals (PPRGs). These are presented in Appendix C. These values were developed using risk assessment methodologies and represent screening levels which should be used in the risk-based comparison. If the maximum detected value exceeds 1,000 times the chemical-specific PPRG for any pathway, the chemical will not be eliminated as a COC. Additionally, if the maximum detected value of infrequently detected contaminants exceeds 1,000 times the PPRG, a temporal analysis will be conducted to determine whether to eliminate the chemical from further analysis or to retain it as a "special-case COC." The temporal analysis applies to surface water, groundwater, and air samples collected with specified frequency over a specified time period (for example, quarterly groundwater samples collected over 2 years). If the detections can be associated with discrete fluctuations in the natural environment such as high-flow or low-flow events, even though infrequently detected, the chemical will not be eliminated as a COC.

The result of the temporal analysis will be identification of contaminants that are infrequently detected but that are detected at high concentrations and are associated with discrete events. These are termed "special-case COCs" and may warrant special consideration in any subsequent exposure assessment. That is, exposure may realistically occur only during specific events.

3.5 Concentration-Toxicity Screen

The purpose of a CTS is to reduce the number of contaminants carried through an HHRA (EPA, 1989a) and to focus the risk assessment on the chief contributors to potential risk. The CTS will be conducted separately for inorganic, radionuclide, and organic chemicals. The criteria used in this screening step include the inherent toxicity of individual contaminants and the maximum detected concentration in each environmental medium for each OU. Toxicity values used to calculate individual risk factors are CSFs for carcinogens, or the reciprocal of the RfD for screening noncarcinogenic contaminants. Thus, the risk factor for carcinogenic effects is the maximum detected concentration (or activity) multiplied by the CSF for that chemical. The risk factor for noncarcinogenic effects is the maximum detected concentration divided by the RfD for that chemical. For contaminants with separate oral and inhalation toxicity values, the most conservative value should be used in the CTS unless the most conservative is inappropriate for a specific medium. For example, only the oral toxicity value should be used for nonvolatile metals and radionuclides in ground water. Contaminants without EPA-derived toxicity values cannot be screened by this procedure and will be advanced into the qualitative uncertainty analysis.

In the first step of the CTS, a chemical score is calculated by multiplying the maximum detected concentration by the chemical-specific toxicity factor for each chemical. The following equation illustrates the process:

$$R_{ij} = C_{ij} * T_{ij} \quad (3.1)$$

where:

R_{ij} = chemical-specific risk factor for chemical i in the medium j
 C_{ij} = maximum detected concentration of chemical i in the medium j
 T_{ij} = toxicity value (either the CSF or 1/RfD) for chemical i in the medium j

Carcinogenic and noncarcinogenic contaminants will be evaluated separately for each environmental medium. Some analytes, such as arsenic, have both noncarcinogenic and carcinogenic effects and are, therefore, included in both screens. Furthermore, a separate screen

will be performed for radionuclides, due to differences in units of slope factors, [milligrams per kilogram per day⁻¹ (mg/kg-day)⁻¹] vs. [picocurie⁻¹ (pCi)⁻¹]. After calculating individual chemical-specific risk values for each medium, all risk values will be summed to obtain the total risk factor (R_j) for the medium. Individual chemical-specific values will then be divided by the total risk factor to derive a chemical-specific ratio (R_{ij}/R_j), providing an index of the relative risk factor for each chemical. All contaminants that contribute less than 1 percent (ratio of 0.01) to the overall risk factor will be eliminated from further consideration unless they are non-radionuclide class A carcinogens. Consequently, contaminants advanced into the quantitative risk assessment will represent the contaminants expected to contribute to the OU-related risk.

3.6 Professional Judgment

The last step of the COC selection process will involve applying professional judgment to ensure that hazardous contaminants are not unknowingly eliminated from the risk assessment and that only the most relevant contaminants are retained. Professional judgement will be used to reevaluate the COCs identified based on COC selection criteria described in Sections 3.1 through 3.5.

Professional judgment will be used at two points in the process of selecting COCs for the HHRA:

- Lognormal UTL_{99/99} comparison: The background UTL_{99/99} presented in the BGCR (EG&G, 1993) are calculated assuming that the background data are normally distributed, (probability plots or Shapiro-Wilks tests may be used). This assumption may not be appropriate for all analytes. Concentrations of some analytes may be within the background range according to all statistical tests performed, but one or two results may exceed the background UTL_{99/99}. This results in identifying the analyte as a potential chemical of concern. When the distribution of the background data is tested, if the better fit is a lognormal distribution, the UTL_{99/99} will be recalculated based on lognormal distribution and the site results will be compared to the lognormal-based UTL_{99/99}. This statistical re-evaluation may result in excluding some analytes as PCOCs.
- Spatial/temporal and pattern recognition: The spatial and temporal distribution and pattern characteristics of certain organic chemicals, metals, and radionuclides

identified above background levels will be evaluated to determine if they are naturally occurring or present due to environmental contamination. This evaluation may result in eliminating analytes as PCOCs. All such professional judgment will be described in each section, where relevant.

3.7 Contaminants of Concern Technical Memorandum

A TM describing the contaminant identification process is required per the IAG. The submittal requirements for the COC TM include an introduction to the PCOCs determined via the background analysis, essential nutrient analysis, and summary tables illustrating the detection frequency analysis, CTS, and PPRG comparison. Example formats for summary tables to be submitted as part of the TM are presented in Tables 3-1 through 3-8.

Table 3-6
Rocky Flats Environmental Technology Site:
COC Selection, Concentration-Toxicity Screen, for Carcinogenic Chemicals

Analyte	Carcinogen Class	Maximum Concentration	Toxicity Value (CSF)	Chemical-Specific Risk Factor (R _i)	Ratio of R _i /R _j
			Total Risk Factor (R _j)		

Table 3-7
Rocky Flats Environmental Technology Site:
COC Selection, Concentration-Toxicity Screen, for Noncarcinogenic Chemicals

Analyte	Maximum Concentration	Toxicity Value (1/RfD)	Chemical-Specific Risk Factor (Ri)	Ratio of Ri/Rj
		Total Risk Factor (Rj)		

**Table 3-8
Rocky Flats Environmental Technology Site:
COC Selection, Rationale for Selecting COCs**

Analyte	Background	Essential Nutrient	Frequency of Detection	RBC Screen	Temporal Analysis	Concentration-Toxicity Screen	Special-Case Contaminant	COC
Organics								
Radionuclides ^a								

Notes:

a Reported in picocuries per gram

4.0 COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT CONSERVATIVE SCREEN OF POTENTIAL CONTAMINANTS OF CONCERN

This section describes a conservative screen to be applied to data from each OU to ensure that the requirements of RCRA and CHWA are met. The CDPHE conservative screen was developed as part of the data aggregation process used in HHRA, for RFETS by DOE, EPA, and CDPHE. The conservative screen will be used by DOE, EPA, and CDPHE to make a decision regarding no further action, voluntary corrective action, or further analysis through an HHRA.

The steps of the CDPHE conservative screen are:

- Perform a background analysis to identify PCOCs as metals and radionuclides significantly above background levels based on statistical evaluation (Gilbert, 1993), and organic target analytes detected above reporting limits.
- Delineate source areas that contain organic PCOCs above reporting limits and/or inorganic (or radionuclide) PCOCs at concentrations above the arithmetic mean plus two standard deviations of the background data.
- Calculate the RBC ratio sum for each source area. The ratio of the maximum detected concentration or radioactivity to the RBC is calculated for each organic PCOC above reporting limits and each inorganic PCOC that occurs in the source area at a concentration or radioactivity above the background mean plus two standard deviations. The RBCs used in the CDPHE risk-based screen are presented in Appendix C.

Maximum detected concentrations or radioactivities in soil are identified from samples collected to a depth of 3.7 m (12 ft), which is the depth recommended for use by CDPHE. The chemical-specific and radionuclide-specific ratios are then summed for each medium, resulting in a ratio sum for the medium (soil and groundwater). Ratio sums for soil and groundwater (if present) are also added to yield a total ratio sum for residential exposure. If any ratio or ratio sum exceeds 1, the source area warrants further evaluation.

- Apply the CDPHE conservative screen decision criteria. Use the ratio sums to designate source areas as candidates for no further action or as candidates for further evaluation in the HHRA or possible early action. For source areas with ratio sums less than 1, DOE may pursue a no further action alternative. For source areas with ratio sums between 1 and 100, and greater than 100, DOE may

evaluate the source area further in the baseline HHRA and pursue a voluntary early action alternative, respectively.

- Define the AOCs for the HHRA for review and approval by DOE, EPA, and CDPHE.
- Prepare the CDPHE conservative screen letter report to summarize the results of the preceding steps.

The flowchart in Figure 4-1 illustrates the CDPHE conservative screen. Each step is presented in the following sections.

4.1 Perform Background Analysis

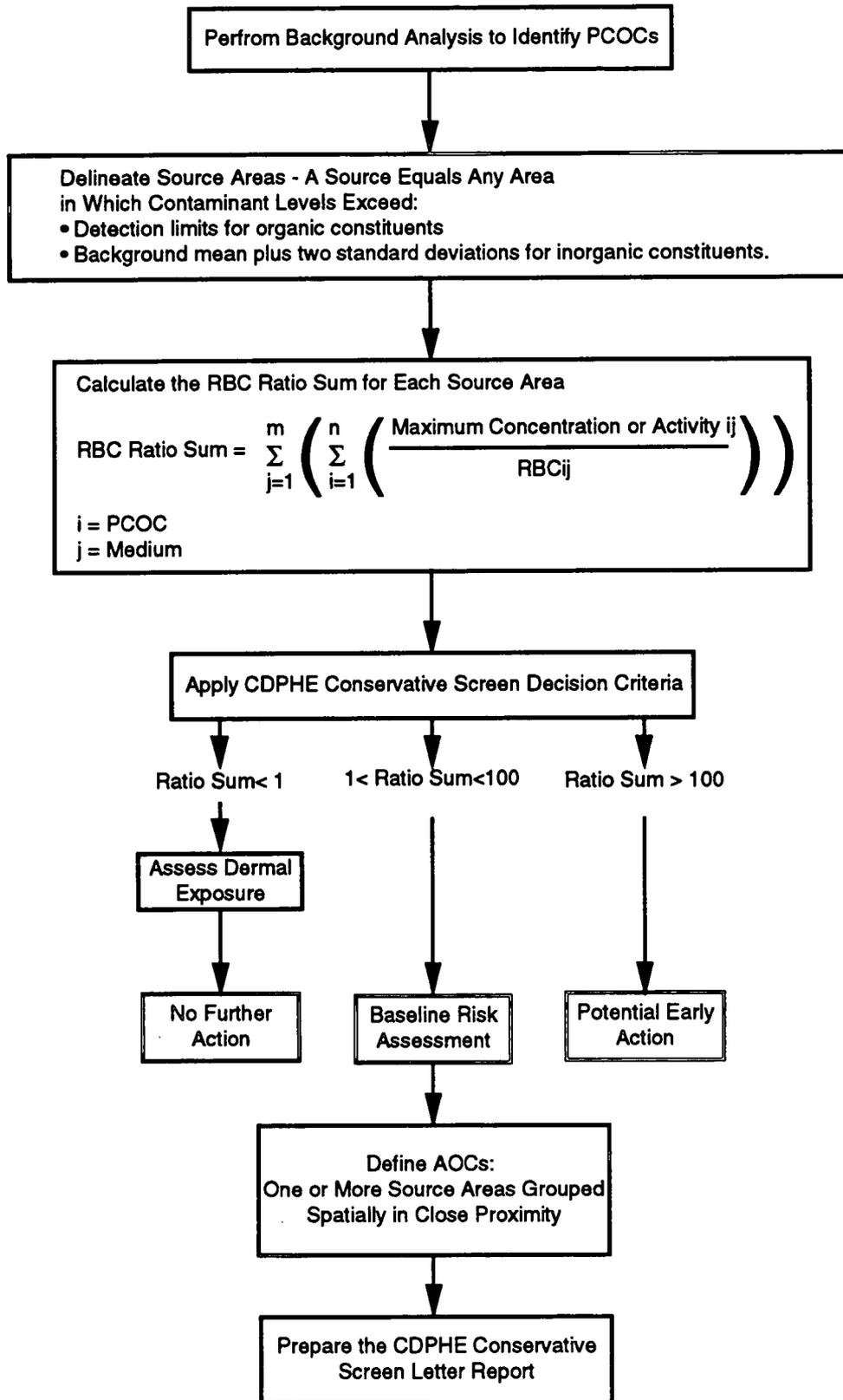
Identifying PCOCs from the background analysis described in Section 3.1 is the first step in the CDPHE conservative screen. The background analysis consists of the following statistical tests, the Gehan test, Quantile test, Slippage test, Student's t-test, and a $UTL_{99/99}$ comparison. These statistical methodologies are detailed in Appendix B.

4.2 Delineate Source Areas

The delineating of the nature and extent of contamination will include a description of source areas. For potential organic contaminants, the criterion for identifying source areas will be the detection limit; for potential inorganic contaminants, the criterion for identifying contaminant source areas will be the arithmetic mean of the appropriate background population plus two standard deviations. The spatial extent of contamination for each PCOC within a source area may vary for each source because multiple contaminants may be detected in multiple media within each source. Therefore, professional judgment will be used to define a source as all contamination that can reasonably be associated with the area based on historical use, site characterization, contaminant types, concentrations, affected media, and rates of migration.

DOE will prepare one or more maps of the source areas (depending on the complexity of the OU) and submit these maps to EPA and CDPHE for review and approval. A meeting of

Figure 4-1 CDPHE Conservative Screen



the three agencies may be required to present the rationale for identifying sources with complex media interactions or multiple potential contaminants.

4.3 Calculate the RBC Ratio Sum

Each potential contaminant in each medium has an associated medium-specific RBC that is calculated based on the following assumptions:

- Direct residential exposure
- Direct ingestion and inhalation exposure pathways
- A carcinogenic risk of 10^{-6} and a noncarcinogenic hazard quotient of 1.0.

For each source identified, the maximum detected value for each potential contaminant in each medium should be determined. If elevated non-detect values are present (e.g., qualified with a U) that exceed the maximum detected value, these should not be used as maximum values. Professional judgment should be used to examine the reasonableness of the maximum value within the data set. For example, values that are three orders of magnitude above the other data points may have been reported in incorrect units.

Each contaminant-specific maximum concentration should then be divided by its corresponding RBC with separate calculations performed for carcinogens and noncarcinogens. The PPRGs presented in Appendix C will be used as RBCs. The maximum concentration RBC ratios for the source areas should then be summed for each PCOC for each medium and then across all media within a source. This sum is referred to as the ratio sum and is the basis for remedial decisions for each source area under the CHWA. The ratio sum step is illustrated in Figure 4-1. Table 4-1 is provided as an example table shell for presenting the ratio sum calculation.

TABLE 4-1
CDPHE Conservative Screen Ratio Sums for Source Area
Soil, Surface to 12 Feet Depth (Resident)

COC	Maximum Concentration or Activity	Location of Maximum Concentration	Depth of Maximum Concentration (ft.)	RBCs Carcinogenic	RBCs Noncarcinogenic	<u>Max Conc. / RBC Carcinogen</u>	<u>Max Conc. / RBC Noncarcinogen</u>
Organics (mg/kg)							
Contaminant 1							
Contaminant 2							
Contaminant 3							
Contaminant n							
Pesticides/PCBs (mg/kg)							
Contaminant 1							
Contaminant 2							
Contaminant 3							
Contaminant n							
Inorganics (mg/kg)							
Contaminant 1							
Contaminant 2							
Contaminant 3							
Contaminant n							
Radionuclides (pCi/g)							
Contaminant 1							
Contaminant 2							
Contaminant 3							
Contaminant n							

4.4 Apply CDPHE Conservative Screen Decision Criteria

The decision criteria that will be used to evaluate source areas are illustrated in Figure 4-1. These criteria should be applied to each identified source area. The total ratio sums for carcinogenic or noncarcinogenic effects are an indication of potential risks to the receptors, assuming long-term exposure to maximum detected concentrations of PCOCs in soil and

groundwater. For carcinogens, a total ratio sum of less than one indicates a total excess lifetime cancer risk of less than 10^{-6} (1 in 1,000,000) from long-term exposure to the maximum concentrations of PCOCs in that source area. A total ratio sum for carcinogens that is greater than one but less than 100 indicates a total excess lifetime cancer risk between 10^{-4} (1 in 10,000) and 10^{-6} , which is the target cancer risk range that EPA has adopted to guide remedial decisions at hazardous waste sites. Where cancer risks estimated in a baseline HHRA do not exceed 10^{-4} , remediation is not generally warranted unless noncarcinogenic effects or ecological risks are significant (EPA, 1991b). A total ratio sum for carcinogens that is greater than 100 indicates a potentially unacceptable cancer risk from long-term exposure to maximum detected concentrations. For noncarcinogens, a ratio or ratio sum less than or equal to one indicates no toxic effects are expected. A noncarcinogenic total ratio greater than one indicates that there may be cause for concern for noncarcinogenic effects.

This risk-based screen is conservative because it assumes that a long-term resident will be routinely exposed to the maximum concentrations of contaminants found in soil and groundwater. The screen does not confirm that an actual risk exists. Ratio sums greater than one or 100 indicate that the area warrants further evaluation, but the ratios do not indicate that an actual health threat is present.

If either the carcinogenic or noncarcinogenic total ratio sum is greater than 100, that source area may be identified by DOE as a candidate for an early action. Source areas with ratio sums between one and 100 will be evaluated further in the baseline HHRA. If both the

carcinogenic and noncarcinogenic total ratio sums are less than one, the source area is a candidate for no further action based on human health risk. In these cases, the incremental risk from dermal exposure is evaluated to confirm that the total ratio sums including dermal exposure are still less than one.

4.5 Define AOCs for the HHRA

One or several sources grouped spatially in close proximity are considered an AOC. This determination is made after the source areas have been screened by the CDPHE conservative screen. If source areas are clearly separated, then each is potentially an AOC. Those source areas that overlap or are adjacent to each other may be grouped using professional judgment.

4.6 Prepare the CDPHE Conservative Screen Letter Report

The CDPHE conservative screen letter report will include map and text summaries of source areas and AOCs, and results of the CDPHE conservative screen. The letter report will serve as the basis for discussion and consensus among DOE, EPA, and CDPHE to proceed with the HHRA given the exposure areas and contaminants identified. The report will include:

- Source area maps
- Table of all potential contaminants, listing their RBCs, the maximum concentration/RBC ratio, and ratio sum
- Brief discussion of the decision criteria
- Map(s) of AOCs.

5.0 EXPOSURE ASSESSMENT

Exposure assessment for an HHRA is the quantitative or qualitative evaluation of contact between a human receptor and chemical(s) or physical agent(s). This assessment:

- Describes the intensity, frequency, and duration of contact
- Evaluates the rates at which the chemical crosses the boundary into the receptor
- Evaluates the resulting amount of the chemical that actually crosses the boundary (dose) and/or the amount absorbed (internal dose).

The primary purpose of an exposure assessment as part of an HHRA is to estimate total dose for a receptor in a given exposure area, which is combined with chemical-specific dose-response data used to estimate risk.

The exposure area is the area in which a potential receptor can reasonably be expected to contact COCs over a specified exposure duration. An exposure area can vary in size, depending on site-specific conditions and potential receptors. At some sites, the exposure area is considered to be the entire site; at others, the exposure area is only a portion of the site. For RFETS, AOCs are defined as one or several sources grouped spatially in close proximity.

The process of a chemical entering the body occurs in two steps. First an exposure, or contact with the chemical, must occur, and second, actual entry into the receptor. After entry into the receptor the amount of the chemical absorbed by the body (internal dose) can be determined.

The two major processes by which a chemical can cross the boundary from outside to inside the body are intake and uptake. Intake involves physically moving the chemical through an opening in the body such as the mouth or nose and usually occurs via inhalation, eating, or drinking. The chemical is normally contained in a carrier medium such as air, food, or drink. The estimate of how much of the chemical enters the body focuses on how much of the carrier medium enters. The uptake process of a chemical entering the body involves absorption of the

chemical through the skin or other exposed tissue such as the eye. Although the chemical is normally contained in a medium, the medium typically is not absorbed at the same rate as the chemical. Therefore, the estimates of the amount of chemical entering the body are greatly affected by such factors as the concentration gradient across the boundary and the permeability of the barrier.

The following sections describe the exposure assessment process and documentation.

5.1 Identifying Populations and Land Use

The potentially exposed populations are characterized primarily using the *1989 Population, Economic, and Land Use Data for Rocky Flats Plant* (DOE, 1990), developed by the Denver Regional Council of Governments (DRCOG). The DRCOG study encompassed an 81 km (50 mi) radius area from the center of the RFETS and included all or part of 14 counties and 72 incorporated cities with a 1989 combined population of 2,206,550. The DRCOG study projected populations through the year 2010.

The following two subsections discuss demographics and land use for current and future scenarios for on-site and off-site locations.

5.1.1 Demographics

The RFETS is located in a rural area of unincorporated Jefferson County, approximately 26 km (16 mi) northwest of Denver and approximately 16 km (10 mi) south of Boulder. RFETS is situated on a 2,653-hectare (6,550-acre) parcel of federally owned land. The facility is located in the approximate center of the parcel and is surrounded by a buffer zone of approximately 2,489 hectares (6,150 acres). The area to the west of RFETS is mountainous, sparsely populated, and primarily government-owned. The area east of RFETS is generally a high arid plain, densely populated, and privately owned. The majority of the population included in the DRCOG study is located within 48 km (30 mi) of RFETS, to the east and southeast, in the Denver metropolitan area. The majority of the development of the plains to

the east of RFETS has occurred since the facility was built, and according to projections by DRCOG, future development is expected to continue (DOE, 1990).

Within a 6.9 km (4 mi) radius of the center of RFETS, there is currently little residential or commercial development. Between 6.4 and 16 km (4 and 10 mi), development increases, with approximately 316,000 residents within a 16 km (10 mi) radius. The most significant development exists 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, also contain significant developments within this 16 km (10 mi) radius (DOE, 1990).

The nearest school is Witt Elementary School, which is approximately 4.3 km (2.7 mi) east of the RFETS buffer zone boundary (EG&G, 1992a). All other sensitive subpopulation facilities (such as hospitals and nursing homes, are located beyond the 8 km (5 mi) radius from the center of RFETS. There are 93 schools, 8 nursing homes, and 4 hospitals within a 16 km (10 mi) radius of RFETS (DOE, 1990).

Standley Lake Park, a recreational area and a drinking water supply for the cities of Thornton, Northglenn, Westminster, and Federal Heights, is located 5.6 km (3.5 mi) to the southeast of RFETS. From the reservoir, water is piped to each city's water treatment facility. Boating, picnicking, and limited overnight camping is permitted at Standley Lake Park.

5.1.2 Land Use

Current off-site land use in the area surrounding RFETS is shown in the Jefferson County Land Use Inventory. Table 5-1 is a summary of land use corresponding to the Jefferson County Land Use Inventory. Current land use surrounding RFETS includes recreational, open space, agricultural, residential, and commercial/industrial. The northeastern Jefferson County and the RFETS area is currently one of the most concentrated areas of industrial development in the Denver metropolitan area (Jefferson County, 1989).

**Table 5-1
RFETS
Current Land Use in Jefferson County Surrounding RFETS**

Parcel #	Current Use/ Project Name	Zoning ^a	Land Use Type
22009	NA	NA	NA
44001	Vacant	A-2	Vacant
44002	NA	NA	NA
44003	Vacant	I-1	Industrial
44004	Vacant	A-2	Vacant
44005	NA	NA	NA
44006	Vacant	I-3	Industrial
44007	Vacant	A-2	Vacant
45001	NA	NA	NA
45002	Walnut Creek Unit 1	P-D	Single Family - Detached
45002	Walnut Creek Unit 1	P-D	Retail
45003	Vacant	A-2	Vacant
45004	Single Family - Detached	A-2	Single Family - Detached
45005	Single Family - Detached	A-2	Vacant
45006	Water	A-2	Water
45007	Single Family - Detached	A-2	Single Family - Detached
45007	SF-D	A-2	Farm/Ranching
46005	Vacant	A-2	Single Family - Detached
46006	Triple C Quarter Horses	A-2	Retail
46007	Horse Barn-Boarding & Breeding	A-2	Retail
46008	Single Family - Detached	A-1	Single Family - Detached
46009	Single Family - Detached	SR-2	Single Family - Detached
46011	Mountain View Tech Center	P-D	Industrial
46012	Jefcope	P-D	Industrial
46017	Water	A-2	Water
46019	Single Family - Detached	A-2	Single Family - Detached
47036	Vacant	SR-2	Single Family - Detached

Table 5-1
(continued)

Parcel #	Current Use/ Project Name	Zoning ^a	Land Use Type
47040	NA	NA	NA
71001	Rocky Flats	A-2	Industrial
72001	Vacant	I-2	Industrial
72002	Vacant	A-2	Vacant
72003	Single Family - Detached	A-2	Single Family - Detached
72004	Vacant	I-2	Vacant
72004	Vacant	I-2	Industrial
72005	Tosco Flg 1	I-2	Industrial
72006	Rocky Flats Ind Park Flg 2	I-2	Industrial
72007	Rocky Flats Ind District Flg 1	I-2	Industrial
72008	Water Tank Ralston Val Stn 2	I-2	Utilities
72009	Vacant - Rocky Flats	A-2	Industrial
72010	Vacant	I-2	Industrial
72011	Northwest Industrial	I-2	Industrial
72012	Vacant	A-2	Vacant
72013	NA	NA	NA
73001	Vacant	A-2	Vacant
73005	Wheat Ridge Gardens	A-2	Vacant
73019	Vacant	A-1	Vacant
73020	Single Family - Detached	SR-2	Single Family - Detached
73021	Vacant	RC	Office/Retail
73022	Westminster Gardens	A-2	Single Family - Detached
99001	Great Western Aggregate Quarry	I-1	Industrial
99005	Sawmill Operation	I-2	Industrial
99006	Great Western Aggregates	I-2	Industrial
99007	Vacant	I-2	Industrial
99008	Colorado Brick Comp Clay Mine	M-C	Mining
99009	Vacant	I-2	Industrial

**Table 5-1
(continued)**

Parcel #	Current Use/ Project Name	Zoning ^a	Land Use Type
100001	Rock Creek Ind Park Vacant	P-D	Industrial
100002	Vacant	I-1	Industrial
100003	Rocky Flats - Vacant	I-1	Industrial
100004	Rocky Flats - Clay Extraction	M-C	Industrial
100005	Rocky Flats - Vacant	I-2	Industrial
100006	Electric Substation	M-C	Utilities
100006	Gravel Mine	M-C	Industrial
101001	Vacant	A-2	Vacant
101002	Vacant	M-C	Industrial
101003	Vacant	I-2	Industrial
101004	Mine and Water	I-2	Industrial
101005	Northwest Industrial	I-2	Industrial
101006	Vacant	M-C	Industrial
101007	Sanitary Landfill and Gravel	P-DA	Industrial
101008	Rocky Flats Lake	M-C	Water

NA = Data not available

a. Zoning Abbreviations are:

- A-1 Agricultural 1
- A-2 Agricultural 2
- I-1 Industrial 1
- I-2 Industrial 2
- I-3 Industrial 3
- P-D Planned Development
- SR-2 Suburban Residential 2
- RC Restricted Commercial
- P-DA Planned Development Amended.

Source: Jefferson County, 1989

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The predominant current off-site land use in the immediate area of the RFETS is open space, single-family detached dwellings, and horse-boarding facilities. Two small cattle herds (approximately 10 to 20 cattle in each herd) existed in the area in 1993: one to the southeast, where 96th Avenue turns into Alkire and crosses Woman Creek; and one to the east of RFETS, between Alkire and Simms Streets and north of 100th Avenue. Industrial facilities include the TOSCO laboratory, Great Western Inorganics Plant, and Frontier Forest Products (EG&G, 1992a).

Future off-site land use is generally expected to follow existing land-use patterns. Jefferson County, in its *Northeast Jefferson, County Community Profile Report* (Jefferson County, 1989), a socio-economic study of its northeastern area, developed a baseline profile of growth and land use in the area. Using the baseline profile and historic trends, future land-use scenarios were developed. At the time of this study, Jefferson County expected that industrial land uses would continue to dominate the northeastern portion of the county. Along with the increase in industrial development, the county income and employment growth is expected to increase dramatically, while household and population growth is expected to increase only moderately. Although the changing RFETS mission may eventually influence growth in the area, this is not likely to be significant until decontamination and decommissioning and environmental restoration are completed.

Industrial and commercial development of the area is attractive to businesses and developers for several reasons:

- The availability of undeveloped and lower-cost lands
- The lower taxes in an unincorporated portion of the county
- The possible future alignment of W-470, a segment of proposed highway providing access to the area.

The proposed W-470 would complete a loop encircling the entire Denver metropolitan area and would significantly impact growth in the area. The highway, in its proposed alignment, will skirt the southern and eastern boundaries of the RFETS. Commercial growth, particularly light

industrial and office development, is expected to occur along the highway (Jefferson County, 1989).

Residential development may not be as attractive as industrial development of the area for several reasons including the proposed alignment of W-470, the proximity to and possible expansion of Jefferson County Airport, the current industry in the area, and proposed business park/retail/commercial/ residential/open space development by the Jefferson Center Metropolitan District. The decreased desirability of living near a major highway or an airport, for traffic and noise reasons, is a deterrent to residential development. The proximity of RFETS and the general industrial nature of the area also decreases the desirability of housing in the area.

Future land use in the area is the topic of *The North Plains Community Plan* (Jefferson County, 1990). The plan is intended to guide the county and cities to achieve compatible land use and development decisions, regardless of the jurisdiction in which they are proposed. Representatives of Jefferson County and 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, cooperatively developed this plan. The plan identifies RFETS and the Jefferson County Airport as constraints to future residential development in the area, and recommends office and light industrial development. The plan further identifies the acquisition of lands 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).

The North Plains Community Development Plan (Jefferson County, 1990) shows that the predominant future land uses to the south and southeast of the RFETS 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 RFETS are planned for industrial, commercial, or office space, with the areas farther from RFETS designated for residential development. This planning is consistent with the projected residential growth rate of zero in the next 20 years for areas immediately adjacent to the RFETS (DOE, 1990).

To the north of RFETS, in Boulder County, the predominant land uses include open-space, park land, and industrial development. Two areas adjacent to RFETS 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).

Future land use east, southeast, and south of the RFETS is expected to consist mostly of open space and commercial/industrial, with smaller areas of mixed commercial/rural residential. Suburban residential developments are expected to occur farther east, probably at least 6.4 km (4 mi) from the center or 3.2 km (2 mi) from the boundary of RFETS. The timing for transition of some existing agricultural lands to open space is not known.

Currently the RFETS is in "transition", a process of converting the land from its historical mission to its current mission (DOE, 1993). Facility-wide on-site land use consists of many diverse activities including: commercial/industrial, maintenance, testing, characterization, environmental investigations, office work, and security surveillance. Specific current uses for specific areas or OUs may be identified through RFETS documents and interviews with knowledgeable site personnel. Future uses may be projected based on statements by the Secretary of Energy and various DOE planning documents.

According to a June 12, 1992, speech by Secretary of Energy James Watkins, there is the potential for occupation by private industry for the future use of the on-site production areas at RFETS. Secretary Watkins characterized RFETS as an attractive site for manufacturers and other businesses. After necessary decontamination is complete, private industry could relocate to existing buildings and use existing equipment at RFETS. One organization interested in the impacts of changes at the plant is the Rocky Flats Local Impacts Initiative (RFLII). This organization is a coalition of local governments, workers, community-based public-interest groups, private sector interests, surrounding landowners, and citizens working together to identify, assess, and mitigate impacts resulting from the change of mission at RFETS, and to plan for its future. The workplan of the organization is to formulate a strategy to transform future changes at RFETS into economic, socioeconomic, educational, land use, environmental,

and infrastructural advantages. One of this organization's goals is to convene and coordinate an inclusive planning process to determine long term land and facilities uses and policies desired by the community, and coordinate plans for implementation.

When the Atomic Energy Commission (AEC) acquired the undeveloped land surrounding the production area, it established plans to preserve the land as open space (AEC, 1972). The buffer zone is being considered as a potential ecological preserve or National Environmental Research Park.

There are at least three reasons why Rocky Flats would make an exceptional environmental research area. First, the site presents an excellent sample of a shortgrass prairie/montane ecotone.... Second, it also provides an almost unique opportunity to conduct environmental research in an area which abuts a major metropolitan area.... Third, ...the site has an abundance of wetlands and would be an excellent outdoor laboratory for a variety of wetland related ecological research (Knight, 1992).

Ecological surveys of the buffer zone, performed in compliance with the Threatened and Endangered Species Act, may indicate the presence of several listed species at RFETS. Additional surveys of threatened and endangered species are ongoing and, if necessary, may be performed in the future to identify and provide for the protection of any threatened or endangered species at the site (EG&G, 1992b). The buffer zone has not been impacted by commercial development for many years, thereby allowing progressive re-establishment of quality native habitats. Because of this history, the future use of this area as an ecological reserve is reasonable. Ecological reserve usage is consistent with DOE policy and plans (DOE, 1992). In addition, the ecological reserve site use is consistent with the Jefferson County Planning Department's recommendations for the provision of large amounts of undeveloped land in the area (Jefferson County, 1990).

The Board of County Commissioners of Jefferson County adopted Resolution CC94-654 on September 8, 1994 that states, "the Board is particularly concerned about any efforts to change the land use of the buffer zone from its current status as undeveloped open space" (Jefferson County, 1994). The resolution also states the following position of the board.

Maintaining, in perpetuity, the undeveloped buffer zone of "open space" around Rocky Flats is a critically important environmental, safety, and health constraint which must be required as part of any and all alternative actions proposed by the Department of Energy." (Jefferson County, 1994)

Extensive development of the RFETS would face the difficulties of steep topography and limited availability of water in parts of the drainages. The Denver Water Board controls most of the metropolitan water supply and currently provides much of the water for suburban areas. The Denver Water Board, however, is under no obligation to supply water to the suburbs, making the future supply questionable (Jefferson County, 1989). Existing facilities within the RFETS are already served by municipal water supplies from the City of Golden, increasing the likelihood that existing structures will be targeted for use by industry and businesses. 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).

In summary, residential development of the RFETS is unlikely due to the industrial nature of the area, the proximity of the proposed W-470 corridor, limited water supply, and potentially poor slope stability. Future residential land use is also inconsistent with current Jefferson County and DOE land-use plans for the area. Future land use generally follows existing land-use patterns and would likely involve industrial and office or open-space uses.

5.2 Selecting Exposure Scenarios

An exposure scenario generally includes facts, data, assumptions, inferences, and sometimes professional judgement about the following:

- Physical setting where exposure would take place
- Exposure pathway(s) from source(s) to exposed individual(s)
- Characterization of the chemical(s) such as amounts, locations, environmental pathways, fate of chemical in environment, etc.

- Identification of the exposed individual(s) or population(s), and the profile of contact with the chemical(s)
- Assumptions about the transfer of the chemical to the receptor.

Current and future human populations on and near the RFETS are potential candidates for evaluation based on their likelihood of exposure to site-related chemicals of concern. EPA guidance does not require an exhaustive assessment of every potential receptor and exposure scenario (EPA, 1992c). Rather, the highest potential exposures that are reasonably expected to occur should be evaluated, along with an assessment of any associated uncertainty (EPA, 1989a). However, potential receptors will be identified and evaluated to ensure that the important exposure pathways and receptors have been included.

5.3 Refining Conceptual Site Model and Pathway Analysis

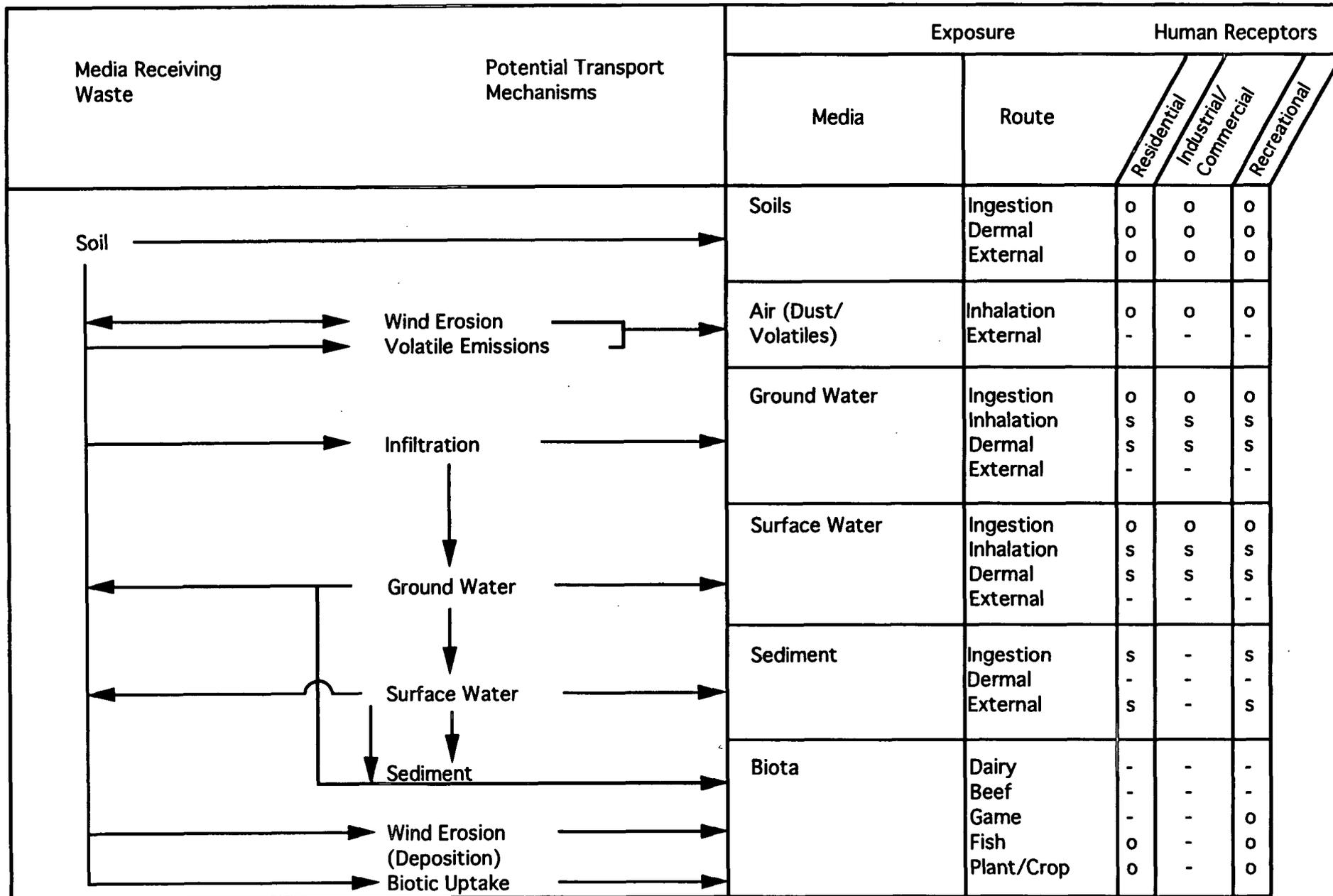
Information concerning waste sources, waste constituent release and transport mechanisms, and locations of potentially exposed receptors is used to develop a conceptual understanding of the site in terms of potential human exposure pathways.

The CSM is a schematic representation of the contaminant source areas, contaminant release mechanisms, environmental transport media, potential human intake routes, and potential human receptors. The purpose of the CSM is to:

- Provide a framework for problem definition
- Identify exposure pathways that may result in human health risks
- Aid in identifying data gaps
- Aid in identifying effective clean-up measures, if necessary, that are targeted at significant contaminant sources and exposure pathways.

Figure 5-1 shows a generalized CSM for potential human exposure pathways. As illustrated in this example, primary, secondary, and negligible or incomplete pathways are identified for

Figure 5-1 Generalized Conceptual Site Model for HHRA



o Primary Pathway
 s Secondary Pathway
 - Negligible/Insignificant Pathway

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each potential human receptor. Primary pathways can be defined as resulting in potentially complete and significant exposure, and secondary pathways as potentially complete and relatively insignificant exposure. Both primary and secondary pathways should be quantitatively addressed in the HHRA. Quantitatively addressing primary and secondary exposure pathways will provide for risk estimates that do not underestimate actual risks. Negligible or incomplete exposure pathways are designated in the example CSM, however, these pathways are not quantitatively addressed in the HHRA but should be qualitatively discussed.

Significant pathways are those that involve relatively direct exposure or only moderately reduced concentrations due to contaminant fate and transport. In contrast, insignificant pathways are those that are expected to result in exposure concentrations one or more orders of magnitude lower than significant exposure pathways. In addition, negligible or incomplete pathways are those where fate and transport are expected to reduce contaminant concentrations by several orders of magnitude or more in comparison to significant exposure pathways.

5.3.1 Identifying Sources and Release Mechanisms

As indicated in the CSM example in Figure 5-1, the contamination is traced from primary source to potential human receptor. First, the primary release mechanisms are identified for the primary source(s), then the resulting secondary sources are identified, and finally, the secondary release mechanisms (as appropriate) are described. Subsequent sources and release mechanisms are identified until the exposure route for the contaminant is reached. Potential human receptors are identified, and the probable significance of the potential exposure for each receptor and exposure route is determined.

5.3.2 Identifying Complete Pathways

As previously discussed, the CSM aids in identifying potentially complete pathways for the HHRA. An exposure pathway describes a specific environmental pathway by which an individual receptor could be exposed to contaminants present at or originating from a site. An exposure pathway includes five necessary elements:

- Source of chemical(s)
- Mechanism of chemical release
- Environmental transport medium
- Exposure point
- A human intake route.

Each of these five elements must be present for an exposure pathway to be complete. Then all potentially complete pathways will be discussed, by scenario, in the HHRA. An incomplete pathway means that no human exposure can occur. Only potentially complete and relevant pathways need be addressed in HHRAs for the RFETS.

5.4 Identifying Exposure Area and Exposure Point Concentrations

After AOCs and COCs have been identified, exposure point concentrations are estimated for each COC in each environmental medium. All COC data within the AOC will be aggregated over the appropriate exposure area. Steps in the exposure area procedure follow.

- Determine the size of the exposure area for each scenario by considering the receptors, the toxicity of the COC, and exposure pathways. Default exposure areas for RFETS are 50 acres for ecological researcher or recreational users, 30 acres for commercial/industrial workers, and 10 acres for residential receptors.
- Plot all COC data, including data below background or detection limit, on a map of the OU.
- Consult with toxicologists and health physicists from DOE, EPA, and CDPHE to properly place a grid of exposure areas over the AOC.
- Identify the exposure area representing the highest risk by considering COC concentrations, contaminated environmental media, and potential exposure pathways. If the exposure area associated with the highest risk within the OU cannot be readily defined, several exposure areas may need to be analyzed. Analyze data within the exposure area using the following procedure:
 - Using the complete OU data set, determine the statistical distribution for each COC in each environmental media.
 - Plot the data in a histogram plot showing frequency of detection versus concentration.

- Use EPA's *Supplemental Guidance to RAGS: Calculating the Concentration Term* (EPA, 1992d) to calculate the 95th percent upper confidence limit (95% UCL) of the arithmetic mean over each exposure area for each COC. Guidance for treatment of data sets with non-detects is presented in Section 5.3.3 of RAGS. If the COC data are lognormally distributed, use Supplemental Guidance to RAGS (EPA, 1992d) highlight 5. If the COC data are normally distributed or are determined to be non-parametric, use highlight 6. The guidance states that calculation of the 95% UCL using data sets with fewer than 10 samples per exposure area provides a poor estimate of the mean concentration. Data sets with 20 to 30 samples per exposure area provide a fairly consistent estimate of the mean. For limited amounts of data, the 95% UCL can be greater than the highest measured concentration. In these cases, the highest measured value should be used as the concentration term. A professional statistician should be consulted regarding the treatment of non-detects in the data set and calculation of the exposure point concentration. Uncertainties in the estimates of the mean concentrations will be addressed in the uncertainty analysis. On a case-by-case basis, with the approval of the regulators, geostatistics may be utilized to evaluate spatial continuity of data.

5.5 Identifying Exposure Equations and Parameters

Identify exposure equations and parameters for the complete pathways discussed in Section 5.3. Use the exposure point concentrations of chemicals in the various media (discussed in Section 4) to estimate the potential human intake of those chemicals via each exposure pathway. Intakes are expressed in terms of milligrams of chemical ingested, inhaled or dermally absorbed per kilogram of body weight per day (mg/kg-day). Intakes are calculated following guidance in RAGS (EPA, 1989a), the *Exposure Factors Handbook* (EPA, 1989b), other EPA guidance documents as appropriate, and using professional judgment regarding likely site-specific exposure conditions. Intakes are estimated using estimates of body weight, inhalation volume, ingestion rates, soil or food matrix effects, and frequency and duration of exposure.

Calculations are conducted to identify the central tendency value for intake and the reasonable maximum exposure (RME) value for intake. The central tendency value for intake is estimated by using control tendency values (e.g., mean and median) for exposure variables. 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. Both calculations use the 95% UCL exposure point concentration (EPA, 1992d).

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

$$\text{Intake} = \frac{\text{chemical conc.} \times \text{contact rate} \times \text{exposure frequency} \times \text{exposure duration}}{\text{body weight} \times \text{averaging time}} \quad (5.1)$$

with corresponding units of:

$$\text{mg/kg-day} = \frac{\text{mg/vol} \times \text{vol/day} \times \text{day/year} \times \text{year}}{\text{kg} \times \text{day}} \quad (5.2)$$

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 cumulative 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 current scientific opinion that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime. Therefore, regardless of exposure duration, the intake of a carcinogen is averaged over a 70-year lifetime (EPA, 1989a). Equation 5.1 is used to calculate intakes of radionuclides excludes the denominator (body weight x averaging time). Intakes of noncarcinogens are averaged over the period of exposure because potential effects would be expected to occur during the period of exposure. The following are generalized pathway-specific equations in use at RFETS.

Ingestion of Water

$$\text{Intake (mg/kg/day)} = \frac{\text{CW} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (5.3)$$

where:

- CW = Chemical concentration in water (mg/liter)
- IR = Ingestion rate (liter/day)
- EF = Exposure frequency (days/year)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (period over which exposure is averaged - days)

For calculation of radionuclide intakes, the concentration is expressed in pCi/l, and the expression is not divided by body weight and averaging time. The intake for radionuclides is expressed in pCi.

Dermal Contact with Water

The equation used for dermal contact with contaminants in water is presented below. This equation calculates the actual absorbed dose (i.e., intake, not the amount of chemical that comes in contact with the skin).

$$\text{Absorbed Dose (mg/kg/day)} = \frac{\text{CW} \times \text{SA} \times \text{PC} \times \text{ET} \times \text{EF} \times \text{ED} \times \text{CF}}{\text{BW} \times \text{AT}} \quad (5.4)$$

where:

- CW = Chemical concentration in water (mg/liter)
- SA = Skin surface area available for contact (cm²)
- PC = Exposure frequency (days/year)
- ET = Exposure duration (years)
- EF = Body weight (kg)
- ED = Averaging time (period over which exposure is averaged - days)
- CF = Volumetric conversion factor for water (1 liter/1000 cm³)
- BW = Body weight (kg)
- AT = Averaging time (period over which exposure is averaged - days)

Inhalation of Airborne Contaminants

Airborne contaminants may be either in the vapor phase or, in the case of metals and radionuclides, in particulates. Dermal absorption of vapor-phase contaminants is considered to be negligible portion of inhalation intakes and, therefore, is disregarded in accordance with Risk Assessment Guidance for Superfund (RAGS) EPA, 1991b). The following equation is used:

$$\text{Intake (mg/kg/day)} = \frac{\text{CA} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (5.5)$$

where:

- CA = Contaminant concentration in air (mg/m³ or pCi/m³)
- IR = Ingestion rate (m³/day)
- EF = Exposure frequency (days/year)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (period over which exposure is averaged - days)

For calculation of intakes from inhalation of particulates, only the fraction of the particulate concentration in air that is considered to be respirable (< 10 μm) is evaluated. The respiratory model developed by the International Commission on Radiological Protection indicates that particles with sizes above 10 μm are relatively unimportant contributors to internal dose (NCRP, 1985). For calculation of radionuclide intakes, the concentration is expressed in pCi/m³ and the expression is not divided by body weight and averaging time. The intake for radionuclides is expressed in pCi.

Inhalation of Volatiles From Indoor Water Use

$$\text{Intake (mg/kg/day)} = \frac{\text{CA} \times \text{IR} \times \text{EF} \times \text{ED} \times \text{VF}}{\text{BW} \times \text{AT}} \quad (5.6)$$

where:

- CA = Contaminant concentration in air (mg/m³ or pCi/m³)
- IR = Ingestion rate (m³/day)
- EF = Exposure frequency (days/year)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (period over which exposure is averaged - days)
- VF = Volatilization Factor (L/m³)

Incidental Ingestion of Soil or Sediments

The following equation is used in calculating the intake from incidental ingestion of contaminants in soil or sediments.

$$\text{Intake (mg/kg/day)} = \frac{\text{CS} \times \text{IR} \times \text{CF} \times \text{FI} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (5.7)$$

where:

- CS = Chemical concentrations in soil (mg/kg or pCi/kg)
- IR = Ingestion rate (mg soil/day)
- CF = Conversion factor (10^{-6} kg/mg)
- FI = Fraction ingested from contaminated source (unitless)
- EF = Exposure frequency (days/years)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (period over which exposure is averaged - days)

For calculation of radionuclide intakes, the concentration is expressed in pCi/kg, and the expression is not divided by body weight and averaging time. The intake for radionuclides is expressed in pCi.

Dermal Contact With Soil or Sediments

The exposure from dermal contact with contaminants in soil and sediments is calculated using the following equation which results in an estimate of the absorbed dose, not the amount of chemical in contact with the skin (i.e., intake):

$$\text{Absorbed Dose (mg/kg/day)} = \frac{\text{CS} \times \text{CF} \times \text{SA} \times \text{AF} \times \text{ABS} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (5.8)$$

where:

- CS = Chemical concentration in soil or sediments (mg/kg)
- CF = Conversion factor (10^{-6} kg/mg)
- SA = Skin surface area available for contact (cm^2/event)
- AF = Soil to skin adherence factor (mg/cm^2)
- ABS = Absorption factor (unitless)
- EF = Exposure frequency (events/year)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (period over which exposure is averaged - days)

Ingestion of Garden Fruits and Vegetables

The contaminant intakes for ingestion of garden produce are calculated using the following equation:

$$\text{Intake (mg/kg/day)} = \frac{\text{CF} \times \text{IR} \times \text{FI} \times \text{EF} \times \text{ED}}{\text{BW} \times \text{AT}} \quad (5.9)$$

where:

- CF = Contaminant concentration in food (mg/kg)
- IR = Ingestion rate (kg/day)
- FI = Fraction ingested from contaminated source (unitless)
- EF = Exposure frequency (days/year)
- ED = Exposure duration (years)
- BW = Body weight (kg)
- AT = Averaging time (period over which exposure is averaged - days)

For calculation of radionuclide intakes, the concentration is expressed in pCi/kg, and the expression is not divided by body weight and averaging time. The intake for radionuclides is expressed in pCi.

Omitting chemical concentrations or dose from the intake equation yields an "intake factor" that is constant for the respective exposure pathway and receptor. The intake factor can then be multiplied by the concentration or dose of each chemical to obtain the pathway and receptor-specific intake of that chemical. Intake factors are calculated separately for each applicable exposed receptor and exposure pathway. Contact rates, such as dermal contact, caloric intake and inhalation (but not soil ingestion) are approximately proportional to body weight. Body weight is not exactly proportional to surface area and age-specific body weight/inhalation rates differ by factors of two or less. However, these differences are assumed to be negligible when compared to the other uncertainties associated with risk assessment.

5.6 Developing an Exposure Assessment Technical Memorandum

The EATM describes present, future, potential, and reasonable use exposure scenarios to be evaluated and identifies reasonable maximum intake parameters for estimating contaminant

intake via these pathways. The EATM is normally submitted prior to initiating the exposure assessment calculations.

The contents of the EATM include:

- Population, land use, and current and future human exposure scenarios
- Complete exposure pathways identified by the CSM
- The route(s) of contaminant intake
- Maps of AOCs and grid placement
- Intake equations and parameters for each potentially contaminated medium, such as soil, water, and air.

The EATM does not quantify contaminant intake. The magnitude of exposure is dependent on the contaminant concentration at the exposure points, which will be estimated based on the analytical results of the OU Phase I Site Investigation and fate and transport modeling, as appropriate.

5.7 Using Fate and Transport Modeling

If concentrations in the media cannot be measured, they can frequently be estimated indirectly by using fate and transport modeling. To accomplish this, fate and transport models use a combination of general relationships and situation-specific information to estimate concentrations of chemicals in different environmental media, the distribution of concentrations over space and time, indoor air levels of chemicals, concentrations in foods, etc. Because models rely on indirect measurements and data remote from the point of contact, statistically valid analytical measurements take precedence if discrepancies arise.

The term model refers to computer codes or a set of equations that can be used to represent site conditions and the transport of contaminants through soil gas, groundwater, surface water, and air. The models incorporate site-specific data and interpretations of and estimates derived

from site-specific data. The combination of a computer code and site-specific data is generally referred to as a site-specific model.

Models selected should be capable of incorporating key contaminant transport and transformation processes and simulating the important domain characteristics and material/fluid properties. The following five categories should be considered when selecting models for use:

- Ability to adequately simulate RFETS conditions
- Ability to satisfy the objectives of the study
- Verification of the model using published analytical equations
- Documentation, peer-review, and availability
- Practicality and cost-effectiveness.

Considerations for implementing a model include:

- Availability of and confidence in input data that will support the model
- Availability of the model
- Degree and nature of documentation
- Extent of peer review of the model
- Nature of model verification and validation and testing
- Computer systems on which the model has been used
- User familiarity with the model.

The following subsections describe models used in HHRA.

5.7.1 Using the CSM to Determine Modeling Needs and Objectives

The CSM evaluates exposure pathways by their potential contribution to exposure and classifies them as significant, insignificant, and negligible or incomplete. Significant pathways should be examined to identify the need for modeling. Pathways involving direct exposure to sources may use measured source data directly and do not require modeling. Pathways with multiple release mechanisms may require fate and transport modeling (e.g., resuspension of subsequent airborne contaminant soil and transport offsite).

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Many fate and transport models are available for use and the listed categories and considerations discussed in section 5.7 should be consulted prior to the final selection of a specific model(s). The goal of fate and transport modeling is to simulate contaminant migration from source areas in soils, groundwater, surface water, sediments, and air to potential on-site and off-site receptors. The results of the modeling are then used in the HHRA of the BRA, and may also be used for the EE.

5.7.2 Overview of Models and Data Needs

The following sections provide an overview of the modeling specific to contaminants in soil gas, groundwater, surface water, and air. This document does not discuss specific models, however, when specific models are selected for use at RFETS it is important to identify and document the assumptions and limitations associated with each model and its application. The following four sections discuss soil gas transport, groundwater, surface water, and air modeling.

5.7.2.1 Soil-Gas Transport - The objective of soil-gas modeling is to predict the transport and resulting concentrations in air of contaminants through the soil gas pathway. Such predictions will be formulated to provide the information necessary to perform an HHRA. Normally the highest concentrations of contaminants from the soil gas pathway are inside of a building, therefore, part of the modeling investigation should be directed at characterizing the geotechnical suitability of the site for construction of buildings associated with future human receptors. Examples of the data needed for a soil gas model(s) that may or may not require assumptions include:

- Properties of the site such as soil porosity, water content, and hydraulic conductivity
- Environmental properties such as relative humidity
- Building characteristics such as pressurization and ventilation rate
- Chemical-specific properties such as vadose zone concentration, groundwater concentration, solubility, Henry's law constant, and biodegradation rate.

5.7.2.2 Groundwater – A hydrogeological conceptual model provides a description of the primary processes that control the movement of solutes in the subsurface. Such processes include groundwater flow rates and directions, solute release rates and timing, recharge and discharge rates, dispersion, degradation rates, and adsorption. Vadose zone and groundwater modeling should consider site-specific conditions, the location(s) of the groundwater flow, recharge and discharge, the primary source(s) of contamination, the distribution of boundary conditions, and material types. Examples of data required for the modeling effort include:

- Horizontal and vertical hydraulic conductivity
- Specific storativity
- Porosity
- Molecular dispersion
- Residual and saturated moisture content.

5.7.2.3 Surface Water – The purpose of surface water modeling is to estimate the potential concentration of contaminants in associated surface water locations at RFETS. The potential for future transport of contaminants by surface water erosion can be evaluated using empirical mathematical models. Because of the dispersed nature of drainage patterns associated with overland flow, nonpoint sources associated with overland flow are very difficult to monitor using conventional methods. Nonpoint source models consist of equations to predict surface water runoff supplemented with methods to calculate sediment movement. Combined, the two components describe contaminant transport associated with overland flow and nonpoint sources. The equations describe total contaminant concentrations in overland flow, (dissolved, adsorbed and solid components), and total contaminant mass loading. Assumptions associated with surface water modeling include:

- Area of site that affects surface water
- Area of contaminated soils
- Contaminant concentrations in soil
- Soil erodibility factor
- Cover/management factor
- Length-slope factor
- Rainfall factor
- Seasonal water flow.

5.7.2.4 Air – The objective of air modeling is to provide estimates of emissions, dispersion, surface deposition, and fate of contaminants released from the site. Both near-field and far-field scenarios should be developed for the site. Far-field models are more complex and include most of the requirements of near-field models, with the addition of transport, dispersion and deposition of contaminants. Site characteristics that require simulation include:

- Meteorological conditions
- Dispersion assumptions
- Special conditions
- Time domain
- Terrain characteristics.

Conditions at the receptor which must also be represented by the model include:

- Height
- Location
- Exposure pathways
- Occupancy factors
- Consumption or usage.

5.8 Documenting Fate and Transport Modeling

The fate and transport modeling TM is prepared as part of the HHRA process. The TM provides a description of the RFETS conditions, emphasizing those conditions that have greater impact on the modeling results. It documents the specific criteria that were used to select the models, and as appropriate, why the criteria are critical. The TM then describes the specific model(s) selected for use, and to which media and pathways the model(s) are applicable. Specific data requirements for each model should be identified, and finally, a data summary of the model(s) parameters should be included.

5.9 Documenting the Exposure Assessment

After the appropriate modeling has been completed, the results need to be documented in the exposure assessment. The following subsections discuss how modeling results are incorporated.

5.9.1 Documenting Fate and Transport Modeling Results

The results of fate and transport modeling for the associated media should be documented along with critical assumptions that are made. Modeling is generally necessary to derive contaminant concentrations in groundwater, surface water, and air. The results are usually summarized in a format consistent with the selected RME values and that can be directly incorporated into the intake equations; or, a 95% UCL value can be calculated.

5.9.2 Documenting Biouptake Results

Modeling results applicable to biouptake of contaminants through ingestion of fruits, vegetables, meat, milk, fish, and shellfish should also be documented in the exposure assessment. As discussed in RAGS, the primary items of concern for exposure by ingestion of contaminants that have accumulated in food are:

- Fish and shellfish
- Vegetables and other produce
- Meat, eggs, and dairy products (domestic and game species).

To incorporate modeling results and determine pathway-specific and contaminant-specific biouptake, the equations in RAGS should be consulted.

5.10 Calculating Intakes

As discussed in Section 5.5, calculations are conducted for central tendency and RME values for intake (EPA, 1992d). The RME is estimated by selecting various input values for

exposure variables so that the combination of all variables in the intake equations results in the RME that can be expected to occur. This approach usually results in individual intake variables that are not at their maximum, however, when combined with other variables, yields estimates of RME. All parameters for each receptor, pathway, and respective intake equation should be identified in the exposure assessment. The parameters can be summarized in tables to make the correlation between pathway-specific intake equations and the correct parameters obvious. During the exposure assessment, specific probability distributions for each exposure parameter may also be identified for use in the quantitative uncertainty analysis.

Table 5-2 provides as an example of an intake factor equation, along with the respective parameters for inhalation of particulates. Exposure parameters specific to RFETS are being developed to provide information necessary to calculate a central tendency value for intake and an RME value for intake. These values should be used unless alternate values can be justified and are approved by DOE.

Combining situation-specific input parameters and contaminant concentrations in respective intake equations, yields values for receptor intakes that can then be used to determine potential health risk. After the intake values are calculated, they may be presented in tabular form, such as in Table 5-3. In Table 5-3, pathways are presented in column headers and the rows contain COCs. Thus, each intake presented is identified with a specific pathway and a specific COC. Organize intake tables and associated risk tables in the same manner to facilitate reading and checking.

**Table 5-2
Inhalation of Particulates
Current Off-Site Resident (Adult)**

Intake Factor = $\frac{IR \times ET \times EF \times ED \times DF}{BW \times AT}$		
Parameter	Central Tendency	RME
IR = Inhalation rate (m ³ /hr)		
ET = Exposure time (hr/day)		
EF = Exposure frequency (day/yr)		
ED = Exposure duration (yr)		
DF = Deposition factor		
BW = Body weight (kg)		
AT = Averaging time (days) Noncarcinogenic Carcinogenic		

**Table 5-3
COC Intakes**

COC	Pathway A (mg/kg-d) ^a	Pathway B (mg/kg-d) ^a	Pathway C (mg/kg-d) ^a	Pathway N (mg/kg-d) ^a	TOTAL (mg/kg-d) ^a
COC 1					
COC 2					
COC 3					
COC n					

^a Units equal mg/kg-day, radionuclide units equal pCi

6.0 TOXICITY ASSESSMENT

Toxicity values are used to characterize risk and toxicity profiles summarize toxicological information for radioactive and nonradioactive COCs. Consistent with EPA's RAGS (EPA, 1989a), the toxicity information is summarized for two categories of potential effects: noncarcinogenic and carcinogenic effects. These two categories are selected because of the slightly differing methodologies for estimating potential health risks associated with exposures to carcinogens and noncarcinogens. The toxicity assessment section of this HHRA methodology discusses obtaining toxicity values, developing toxicity profiles, and preparing a toxicity assessment TM.

6.1 Obtaining Toxicity Values

The toxicity values used quantitatively in HHRA are obtained from two sources. The primary source of information is EPA's *Integrated Risk Information System (IRIS)* (EPA, 1994b). IRIS contains only those toxicity values that have been verified by EPA's Reference Dose or Carcinogen Risk Assessment Verification Endeavor (CRAVE) Work Groups. The IRIS database is updated monthly and, per RAGS, supersedes all other sources of toxicity information. If the necessary data are not available in IRIS, EPA's most recent issue of *Health Effects Assessment Summary Tables (HEAST)* (for example EPA, 1994c) is used. The tables are published annually and updated approximately two times per year. HEAST contains a comprehensive listing of provisional risk assessment information that has undergone review and has the concurrence of individual EPA Program Offices, but has not had enough review to be recognized as high-quality, agency-wide consensus information (EPA, 1993). Values that are pending or that have been withdrawn should not be used quantitatively unless EPA Region VIII toxicologist approve their use for RFETS risk assessment.

Secondary sources of information may be used qualitatively in HHRA. Previous years of IRIS and HEAST may be reviewed to track changing values. EPA toxicologists, both regional and national, may also serve as information sources.

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6.1.1 Toxicity Assessment for Noncarcinogenic Effects

Potential noncarcinogenic effects will be evaluated in the risk characterization by comparing daily intakes (calculated in the exposure assessment) with chronic RfDs developed by EPA. This section provides a definition of an RfD and discusses how it will be applied in the risk assessment.

A chronic RfD is an estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure that can be incurred during a lifetime, without an appreciable risk of a noncancer effect being incurred in human populations, including sensitive subgroups (EPA, 1989a). The RfD is based on the assumption that thresholds exist for noncarcinogenic toxic effects (e.g., liver or kidney damage). It is a benchmark dose derived by applying of one or more order-of-magnitude uncertainty factors to doses thought to represent the lowest observed adverse effect level or no observed adverse effect level in humans. Thus, there should be no adverse effects associated with chronic daily intakes below the RfD value. Conversely, if chronic daily intakes exceed this threshold level, there is a potential that some adverse noncarcinogenic health effects might be observed in exposed individuals.

RfDs are typically calculated by dividing a benchmark dose, at which there are no significant measurable effects produced, by an uncertainty or safety factor that typically ranges from 10 to 10,000. The RfD is rounded to one significant figure and is presented in units of mg/kg-day.

RfDs have been derived by EPA for both oral and inhalation exposures. However, in January 1991, EPA decided to replace inhalation RfDs with Reference Concentrations (RfCs). RfCs are expressed in terms of concentrations in air (mg/m^3), not in terms of "dose" ($\text{mg}/\text{kg}\text{-day}$). This decision was based on two factors: 1) EPA believed that it was technically more accurate to base toxicity values directly on measured air concentrations instead of making the metabolic, pharmacokinetic, and/or other adjustments required to estimate an internal dose; and 2) for compounds that elicit route-of-entry effects (e.g., sensitizers and irritants), where the toxic effect is to the respiratory system or exchange boundary, EPA believed that a measure of

internal dose might inappropriately imply effects to other organ systems or effects from other exposure routes (EPA, 1993).

The chronic oral and inhalation RfDs and RfCs for the COCs should be compiled in a table for the HHRA report. The table should also provide information on the uncertainty factors used to derive the RfDs, the overall confidence in the RfD (as provided in IRIS), and the target organs and critical effects that are the basis of the RfD. The table should also indicate how specific inhalation RfDs are derived, (e.g., through a route-to-route extrapolation from the oral RfD or through extrapolation from the RfC). An example of a table for presentation of noncarcinogenic toxicity values and supporting information is provided as Table 6-1.

6.1.2 Toxicity Assessment for Carcinogenic Effects

Potential carcinogenic risks will be expressed as an estimated probability that an individual might develop cancer from lifetime exposure. This probability is based on projected intakes and chemical-specific dose-response data called CSFs. CSFs and the estimated daily intake of a compound, averaged over a lifetime of exposure, are used to estimate the incremental risk that an individual exposed to that compound may develop cancer. There are two classes of potential carcinogens: chemical carcinogens and radionuclides. For the purposes of toxicity assessment, each of these two classes of elements or compounds are discussed separately.

6.1.2.1 Toxicity Assessment for Chemical Carcinogens - Evidence of chemical carcinogenicity originates primarily from two sources: lifetime studies with laboratory animals, and human (epidemiological) studies. For most chemical carcinogens, animal data from laboratory experiments represent the primary basis for the extrapolation. Assumptions relevant to the following issues arise from extrapolating experimental results:

- Across species (i.e., from laboratory animals to humans)
- From high-dose regions (i.e., levels to which laboratory animals are exposed) to low-dose regions (i.e., levels to which humans are likely to be exposed in the environment)
- Across routes of administration (e.g., inhalation versus ingestion).

**Table 6-1
Toxicity Constants for COCs
(for chronic noncarcinogenic effects)**

COC	Oral RfD (mg/kg-day)	Inhalation RfC (mg/m³)	Inhalation RfD (mg/kg-day)	Uncertainty Factor	Overall Confidence in RfD	Target Organ/ Critical Effect	Reference
COC 1	xxxxx	Pending	Pending	1,000	Medium	Liver/Heptatic Lesions	Most current applicable reference
COC 2	xxxxx	No Data	No Data	1,000	Medium	Liver/Heptatic Lesions	Most current applicable reference
COC N	Withdrawn	xxxxx	No Data	10	High	Liver/Heptatic Lesions	Most current applicable reference

Federal regulatory agencies have traditionally estimated human cancer risks associated with exposure to chemical carcinogens on the administered-dose basis according to the following approach:

- The relationship between the administered dose and the incidence of cancer in animals is based on laboratory animal bioassay results.
- The relationship between the administered dose and the incidence of cancer in the low-dose range is based on mathematical models.
- The dose-response relationship is assumed to be the same for both humans and animals, if the administered dose is measured in the proper units.

Thus, effects from exposure to high (i.e., administered) doses are based on laboratory animal bioassay results, while effects associated with exposure to low doses of a chemical are generally estimated from mathematical models.

For chemical carcinogens, EPA assumes a small number of molecular events can evoke changes in a single cell that can lead to uncontrolled cellular proliferation and tumor induction. This mechanism for carcinogenesis is referred to as stochastic, which means that there is theoretically no level of exposure to a given chemical carcinogen that does not pose a small, but finite, probability of generating a carcinogenic response. Since risk at low exposure levels cannot be measured directly either in laboratory animals or human epidemiology studies, various mathematical models have been proposed to extrapolate from high to low doses (i.e., to estimate the dose-response relationship at low doses).

Currently, regulatory decisions are based on the output of the linearized multistage model (EPA, 1989a). The basis of the linearized multistage model is that multiple events may be needed to yield tumor induction (Crump et al., 1977). The linearized multistage model reflects the biological variability in tumor frequencies observed in animal or human studies. The dose-response relationship predicted by this model at low doses is essentially linear. CSFs calculated for nonradiological carcinogens using the multistage model represent the 95% UCL on the probability of a carcinogenic response. Consequently, risk estimates based on these CSFs are

conservative estimates representing upper-bound estimates of risk where there is only a 5-percent probability that the actual risk is greater than the estimated risk.

Uncertainties in the toxicity assessment for chemical carcinogens are dealt with by classifying each chemical into one of several groups, according to the weight-of-evidence from epidemiological studies and animal studies. These Groups are shown in Table 6-2.

**Table 6-2
Carcinogen Groups**

Group	Description
Group A	Human Carcinogen (sufficient evidence of carcinogenicity in humans)
Group B	Probable Human Carcinogen (B1-limited evidence of carcinogenicity in humans; B2-sufficient evidence of carcinogenicity in animals with inadequate or lack of evidence in humans)
Group C	Possible Human Carcinogen (limited evidence of carcinogenicity in animals and inadequate or lack of human data)
Group D	Not Classifiable as to Human Carcinogenicity (inadequate or no evidence)
Group E	Evidence of Noncarcinogenicity for Humans (no evidence of carcinogenicity in adequate studies)

The oral and inhalation CSFs for the COCs should be compiled in a table, including the weight-of-evidence, source reference, and date. In addition, as with RfDs, the CRAVE Work Group believes that a unit conversion is required to present inhalation CSFs in the units of $(\text{mg}/\text{kg}\text{-day})^{-1}$. Consequently, CSFs should also be provided for the inhalation route as unit risks in units of "per microgram per cubic meter" $(\mu\text{g}/\text{m}^3)^{-1}$. An example of a table for carcinogenic toxicity values and supporting information is provided as Table 6-3.

6.1.2.2 Toxicity Constants for Radionuclides - Extensive literature exists that describes the health effects of radionuclides on humans and animals. Intensive research by national and international commissions has established universally accepted limits to which workers and the public may be exposed without clinically detectable effects. This literature has

Table 6-3

Toxicity Constants for COCs
(for carcinogenic effects)

COC	CSF oral (mg/kg-day) ⁻¹	CSF inh. (μg/m ³) ⁻¹	CSF inh. (mg/kg-day) ⁻¹	Weight of Evidence	Reference	Notes
Non-Radionuclides						
COC 1	xxxxx	xxxxx	xxxxx	A	Most current applicable reference	
COC 2	xxxxx	xxxxx	xxxxx	B2	Most current applicable reference	
COC n	Pending	Pending	Pending	—	Most current applicable reference	
Radionuclides						
	Oral CSF Risk/pCi	Inhalation CSF Risk/pCi		Weight of Evidence	Reference	Notes
COC 1	xxxxx	xxxxx		A	Most current applicable reference	
COC n	xxxxx	xxxxx		A	Most current applicable reference	

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resulted in EPA classifying all radionuclides as Group A carcinogens because they emit ionizing radiation, which, at high doses, has been associated with increased cancer incidence in humans. For radionuclides, human epidemiological data collected from the survivors of the Hiroshima and Nagasaki bomb attacks form the basis for the most recent extrapolation by the National Academy of Sciences (1980). Conversely, for most nonradiological carcinogens, animal data from laboratory studies provide the primary basis for the extrapolation. Another fundamental difference between the assessment of potential toxicity associated with exposure to radionuclide and nonradionuclide carcinogens is that CSFs for radionuclides are typically best estimates (mean or median values rather than upper 95th percentile values). Furthermore, in the past, risk factors for radionuclides have generally been based on fatalities (i.e., the number of laboratory animals or people who actually died from cancer), while CSFs for nonradiological carcinogens are based on incidence (i.e., the number of lab animals or people who developed cancer). Finally, the CSFs for radionuclides are expressed in different units, i.e., risk per pCi (pCi)⁻¹ rather than (mg/kg-day)⁻¹.

Radionuclide CSFs may be included in the same table as chemical carcinogens, however they should be grouped separately due to the differences in units. Example Table 6-3 also provides example presentation of radionuclide CSFs. The nonthreshold radionuclide CSFs account for:

- The amount of radionuclide transported into the bloodstream
- The decay of radioactive progeny within the body
- The distribution and retention of the radionuclide and its progeny (if any) in the body
- The radiation dose delivered to specific organs and tissues
- The age and sex of the exposed individuals (EPA, 1993).

6.2 Developing Toxicity Profiles

Toxicity profiles will be developed only for COCs that do not have toxicity values in the current IRIS or HEAST. The profiles should be coordinated with EPA and CDPHE toxicologists prior to presentation in the toxicity assessment TM and the HHRA report.

The profiles should be developed by a toxicologist to present general and contaminant-specific information on health effects relating to the HHRA COCs. General information should be provided on the class of chemical and its uses. Specific information should be presented on the effects reported in different studies, including exposure levels, biological endpoints, and dose-response. The strength of the studies should also be discussed, along with toxicity values and supporting information on how EPA derived them.

The following is an example toxicity profile for carbon tetrachloride, however, this example does not cite specific references.

Carbon tetrachloride is an organic solvent which was, until recently, widely used as an industrial and household cleaning fluid. Recently, its household and industrial use has been severely restricted. Carbon tetrachloride, like chloroform, has anesthetic properties, which may lead to confusion and coma. Liver damage may result from either acute or chronic exposure. Fatty liver and centrilobular necrosis readily develop at low levels of chronic exposure, and in humans this is followed by kidney failure, which may be the ultimate cause of death.

This compound has been more extensively studied regarding its toxic effects than any other aliphatic hydrocarbon. Carbon tetrachloride may cause damage to the heart, liver, kidneys, and the central nervous system (CNS) after high oral or inhalation exposures. At lower exposures, it may cause biochemical alterations (e.g., liquid peroxidation), nausea, and headaches. The chronic oral RfD for carbon tetrachloride is 7×10^{-4} mg/kg-day with an uncertainty factor of 1,000 (to account for interspecies and intrahuman variability). At the lowest observed adverse effect level, exposures

to carbon tetrachloride produced liver lesions in rats. Although the principal study from which the RfD was derived was well done, and good dose-response data were available from a variety of other studies, confidence in the RfD was judged to be medium since supporting studies on possible reproductive and teratogenic effects are not available. An inhalation reference concentration is not available in IRIS.

The carcinogenicity of carbon tetrachloride, through both the inhalation and ingestion pathway, has been established with a variety of test animals and a number of gavage studies. Carbon tetrachloride has produced hepatocellular carcinomas in rats, mice, and hamsters. It is classified as a Group B2 carcinogen with an oral CSF of 0.13 (mg/kg-day)⁻¹. Since risk estimates generated from oral cancer studies varied by two orders of magnitude, EPA calculated the CSF using the geometric mean of the available data to account for deficiencies in several of the studies. The inhalation unit risk is 1.5×10^{-5} ($\mu\text{g}/\text{m}^3$)⁻¹ or 0.052 (mg/kg-day)⁻¹. The inhalation unit risk is based on the oral exposure data and assumes a 40% absorption rate by humans. Several studies of workers who may have used carbon tetrachloride have suggested that these individuals may have an excess cancer risk.

A toxicity profile should not be limited to the type and depth of information provided in this example. The depth of the toxicity profile should depend on the information available and the professional judgement of the toxicologist.

6.3 Preparing a Toxicity Assessment Technical Memorandum

According to the agreement between DOE, EPA, and CDPHE the TM on toxicity assessment will contain only information on COCs that do not have toxicity information in IRIS or HEAST. If toxicity information is available in IRIS or HEAST for all COCs, no TM is required. If toxicity values have been derived, or when withdrawn or pending values are used, then a TM on toxicity assessment is required to present information. For these COCs, the TM on toxicity assessment should include tables of COC toxicity values for noncarcinogenic and

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carcinogenic effects similar to example Tables 6-1 and 6-3. The toxicologist should include text with the tables explaining the derivation of the toxicity values along with toxicity profiles.

7.0 RISK CHARACTERIZATION

Risk characterization involves estimating the magnitude of the potential adverse effects of COCs under study, and summarizing risks to public health. Risk characterization considers the nature and weight of evidence supporting these risk estimates and the magnitude of uncertainty surrounding those estimates. Risk characterization combines the results of the exposure and toxicity assessments to provide numerical estimates of health risk. These estimates are comparisons of exposure levels with RfDs or estimates of the lifetime cancer risk for a given intake. The process of characterizing risk includes the following:

- Calculating and characterizing cancer risk and noncarcinogenic effects
- Conducting qualitative uncertainty analysis
- Conducting quantitative uncertainty analysis.

7.1 Calculating and Characterizing Cancer Risk and Noncarcinogenic Effects

To quantify the health risks, the intakes are first calculated for each COC for each applicable scenario. The central tendency and RME intakes are calculated based on measured or modeled concentrations, and use the methodology documented in the EPA's RAGS (1989a) and discussed in Section 5. The specific intakes are then compared to the applicable chemical-specific toxicological data, discussed in Section 6, to determine the central tendency and RME health risks.

The health risks from each potential contaminant are calculated to first determine potential carcinogenic effects and secondly to determine potential noncarcinogenic effects. Each of these calculations are discussed in the following sections.

7.1.1 Determining Carcinogenic Effects

The following calculations are used to determine carcinogenic effects by obtaining numerical estimates, (i.e., unitless probability) of lifetime cancer risks:

$$\text{RISK} = \text{INTAKE} \times \text{CSF} \quad (7.1)$$

where:

Risk = Potential lifetime excess cancer risk (unitless)

CSF = Slope factor, for chemicals (mg/kg-day)⁻¹, or radionuclides (pCi)⁻¹

Intake = Chemical intake (mg/kg-day), or radionuclide intake (pCi)

Inhalation and oral ingestion CSFs are used with respective inhalation and ingestion intakes to estimate risks. Chemical CSFs are extrapolated from animal experiments and based on the 95th percentile value, while radionuclide slope factors are best estimates derived from human epidemiological studies.

Cancer risks are summed separately across all potential chemical carcinogens and across all radionuclides considered in the risk assessment using the following equation:

$$\text{RISK}_T = \sum \text{RISK}_i \quad (7.2)$$

where:

RISK_T = Total cancer risk, expressed as a unitless probability

RISK_i = Risk estimate for the i^{th} contaminant

This equation is an approximation of the precise equation for combining risks to account for the probability of the same individual developing cancer as a consequence of exposure to two or more carcinogens. As stated in RAGS (EPA, 1989a), the difference between the precise equation and this approximation is negligible for total cancer risks less than 0.1. This risk summation assumes independence of action by the compounds involved. Some limitations are posed by using this approach, and they are discussed in RAGS (EPA, 1989a). For example, limitations apply when adding potential carcinogenic risk across the pertinent weight-of-evidence cancer classes.

The software used to calculate the carcinogenic risks may be configured to print a table of risks for each scenario. Each table can show contaminant and pathway-specific risk if

contaminants are presented in rows and pathways are presented by column. After reasonable exposure pathway combinations are identified, the likelihood that the same individuals would consistently be exposed by more than one pathway is evaluated. In most situations a receptor could be exposed by several pathways in combination. For these situations, risks may be subtotaled across pathways for each contaminant.

Carcinogenic risks should be summed separately for each weight-of-evidence classification. A total carcinogenic risk may also be summed across weight-of-evidence classifications as an additional point of reference. In accordance with EPA guidance, only one significant digit is retained when summarizing calculated risks (EPA, 1989a). Table 7-1 provides an example table shell to document carcinogenic risks. Table 7-2 sums carcinogenic risk by cancer group.

The HHRA text should reference each table and discuss risks that exceed the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) risk range of 10^4 to 10^6 (EPA, 1990). Specifically, the pathways and contaminants driving the risk, should be noted and accompanied by any necessary qualifying statements. The text should not repeat the entire table, but should summarize more notable results.

In addition to presenting the incremental cancer risks due to contaminants at the site, perspective may be provided by giving examples of typical background sources of risk such as arsenic or radon and progeny. Because the public is often unaware of the numerous conservative assumptions involved in an HHRA, the text should note the assumptions associated with the calculations and reference the reader to the uncertainty section.

A summary table presenting risk subtotals for all scenarios should also be created for the HHRA risk summary section. This table may be presented by placing the results for each scenario in rows, and allowing weight-of-evidence Group A, B, and C subtotals in the columns. Table 7-3 provides an example table shell to document the risk summaries.

**Table 7-1
RME Carcinogenic Risk**

Chemical	Pathway 1	Pathway 2	Pathway 3	Pathway n	Total
COC 1					
COC 2					
COC 3					
COC n					

**Table 7-2
Summed Carcinogenic Risks by Cancer Group**

Cancer Group	Risk
A	
B2	
C	
Total Risk	

**Table 7-3
Summary of Point Estimates of Carcinogenic Risk**

Scenario	Total Risk (Groups)				Dominant COC	Dominant Pathway
	A	B2	C	Total		
Current						
On-Site Worker						
Future						
Future On-Site Worker						

7.1.2 Determining Noncarcinogenic Effects

Health risks associated with exposure to individual noncarcinogenic compounds are determined by calculating hazard quotients (HQs) and hazard indices (HIs). The noncarcinogen HQ is the ratio of the intake rate to the RfD, as follows:

$$HQ = \text{INTAKE}/\text{RfD} \quad (7.3)$$

where:

HQ = Noncarcinogen hazard quotient
 Intake = Chemical intake (mg/kg-day)
 RfD = Reference dose (mg/kg-day)

Chronic RfDs are extracted from IRIS and HEAST. Similar to CSFs, RfDs for inhalation and oral ingestion are used for inhalation and oral intakes, respectively.

HIs are the summed hazard quotients for each chemical across the exposure pathways. If the HI for any chemical exceeds unity there may be concern for potential health effects. The HI is calculated using the following equation:

$$HI = \sum \frac{E_i}{\text{RfD}_i} \quad (7.4)$$

where:

HI = Hazard index
 E_i = Exposure level (intake) for the i^{th} toxicant
 RfD_i = Reference dose for the i^{th} toxicant

E and RfD are expressed in the same units and represent the same exposure period.

These HI values should not be interpreted as statistical probabilities of an effect occurring, however, if the HI exceeds unity there may be a concern for potential noncancer effects. In

general, the greater the HI above unity, the greater the level of concern. However, the level of concern does not increase linearly as the HI approaches or exceeds unity. Further discussions and limitations on the application of this procedure are contained in RAGS (EPA, 1989a).

Noncarcinogenic effects are presented in the HHRA text and tables similar to those used in the presentation of carcinogenic risk. Each table can show contaminant and pathway-specific effects if contaminants are presented in rows and pathways are presented by column. After reasonable exposure pathway combinations are identified, the likelihood that the same individuals would consistently be exposed by more than one pathway is evaluated. In most situations, a receptor could be exposed by several pathways in combination. For these situations, HQs may be subtotaled across pathways for each contaminant.

HQs approaching or exceeding one are summed according to target organ to calculate the total HI by target organ. For a specific receptor scenario, a total HI may also be summed across all pathways and contaminants as an additional point of reference, but is subject to limitations. As is the convention with carcinogenic risk, only one significant digit is retained when summarizing calculated effects (EPA, 1989a). Table 7-4 provides an example table shell for presentation of HIs. Table 7-5 sums noncarcinogenic HIs by target organ.

The HHRA text should reference each table and discuss hazard quotients that exceed unity. Specifically, the pathways and contaminants driving the risk should be noted and accompanied by any necessary qualifying statements. The HHRA text should not repeat the entire table, but should summarize more notable results.

A summary table presenting HI subtotaals for all scenarios should also be created for presentation in the HHRA risk summary section. This may be presented by placing the results for each scenario in rows, and providing information on hazard indices, dominant COC, and dominant pathway in columns. Table 7-6 provides an example table shell that can be used for presentation of noncarcinogenic hazard.

Table 7-4
RME Noncarcinogenic HI

Chemical	Pathway 1	Pathway 2	Pathway 3	Pathway n	Total
Contaminant 1					
Contaminant 2					
Contaminant 3					
Contaminant n					

Table 7-5
Summed Noncarcinogenic HIs by Target Organ

Organ	HI
Blood	
Hepatic	
Kidney	
Lung	
CNS	
Total HI:	

Table 7-6
 Summary of Point Estimates of Noncarcinogenic Risk

Scenario	Total HI		Dominant COC	Target Organ	Dominant Pathway
	Child	Adult			
Current					
On-Site Worker	N/A				
Future					
Future On-Site Worker (Office)	N/A	xx			

7.2 Conducting Qualitative Uncertainty Analysis

The quantification of uncertainty is an important component of the risk assessment process. According to the EPA *Guidance on Risk Characterization for Risk Managers and Risk Assessors*, point estimates of risk "do not fully convey the range of information considered and used in developing the assessment" (EPA, 1992c). To provide information about the uncertainties associated with the RME estimate, uncertainties are identified during the HHRA process and are presented in qualitative and, where appropriate, quantitative terms.

There are four stages of analysis applied in the risk assessment process that can introduce uncertainties:

- Data Collection and Evaluation
- Exposure Assessment
- Toxicity Assessment
- Risk Characterization.

The uncertainty analysis characterizes the various sources and their contributions to uncertainty in the HHRA. These uncertainties are driven by uncertainty in the site investigation data, the likelihood of hypothetical exposure scenarios, the transport models used to estimate concentrations at receptor locations, receptor intake parameters, and the toxicity values used to characterize risk. Additionally, uncertainties are introduced in the risk assessment when exposures to several substances across multiple pathways are summed.

The concept of uncertainty can be more fully defined by distinguishing between variability and knowledge uncertainty. Variable parameters are those that reflect heterogeneity in a well-characterized population, for which the distributions would not generally be narrowed through further measurement or study. Uncertain parameters reflect a lack of information about properties that are invariant and whose single, true value could be known exactly by the use of a perfect measuring device. Where appropriate, qualitative uncertainty analysis may distinguish between variability and uncertainty.

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Qualitative uncertainty analysis should identify each key source of uncertainty, present an estimate of the relative impact of the uncertainty on the HHRA, and include any clarifying remarks. For many of the contributors, presenting uncertainty in a tabular format is sufficient. Table 7-7 provides an example format for summarizing the uncertainties and limitations

Table 7-7
Human Health Risk Assessment Uncertainty Factors

Uncertainty Factor	Effect of Uncertainty	Comment
Sampling and Analysis		
Use of invalidated data	May slightly underestimate risk	
Identification of OU1 contaminants	May slightly over- or underestimate risk	
Detection limits/COC screening	May slightly over- or underestimate risk	
Concentration-toxicity screen	May slightly over- or underestimate risk	
Data set completeness	May slightly over- or underestimate risk	
Fate and Transport Estimation		
Soil-gas source term assumptions	May over- or underestimate risk	
Natural infiltration rate	May overestimate risk	
Moisture content	May over- or underestimate risk	
Water table fluctuations	May slightly over- or underestimate risk	
Effect of micrometeorology on air dispersion	May slightly over or under estimate risk	
Variability in annual meteorological data	May slightly over or under estimate risk	
Plant uptake estimation	May slightly under or over estimate risk	
Exposure Estimation		
Exposure scenario assumptions	May overestimate risk	
Exposure parameter assumptions	May overestimate risk	
Receptor locations	May overestimate risk	
Exposure duration	May over- or underestimate risk	
Non chemical-specific constants (not dependent on chemical properties)	May overestimate risk	

**Table 7-7
(continued)**

Uncertainty Factor	Effect of Uncertainty	Comment
Exposure Estimation (continued)		
Exclusion of some hypothetical pathways from the exposure scenarios	May underestimate risk	
External radiation	May slightly underestimate risk	
Permeability coefficients	May slightly over- or underestimate risk	
Plant ingestion rate	May slightly over- or underestimate risk	
Model does not consider biotic decay	May overestimate risk	
Exclusion of transformation products	May underestimate risk	
Toxicological data		
Use of cancer slope factors	May overestimate risk	
Critical toxicity values derived primarily from animal studies	May over- or underestimate risk	
Critical toxicity values derived primarily from high doses, most exposures are at low doses	May over- or underestimate risk	
Critical toxicity values and classification of carcinogens	May over- or underestimate risk	
Lack of inhalation slope factors	May underestimate risk	
Use of oral slope factors to evaluate dermal absorption	May over- or underestimate risk	
Addition of risks across weight-of-evidence classifications	May overestimate risk	
Lack of RfDs or RfCs	May underestimate risk	
Lack of dermal absorption or direct action toxicity values	May slightly underestimate risk	

in an HHRA. For sources of uncertainty requiring more discussion than is convenient in a table, additional clarification may be provided in accompanying text.

7.3 Conducting Quantitative Uncertainty Analysis

In some cases, quantitative uncertainty analysis may be conducted in addition to the qualitative uncertainty analysis. Quantitative uncertainty analysis will be performed on chemicals and/or sets of chemicals that have a carcinogenic risk greater than 1×10^{-4} or a noncarcinogenic HQ or HI greater than 1. To quantify the uncertainty in the final risk characterization estimates, Monte Carlo simulations may be used for the pathways dominating the risk.

The Monte Carlo simulation is a technique that can be used to provide a probability function of estimated risk using random values of exposure factors and toxicity values in an exposure scenario. A Monte Carlo simulation involves assigning a joint probability distribution to the input variables (i.e., exposure factors) of an exposure scenario. Next, a large number of independent samples from the assigned joint distribution are taken and the corresponding outputs calculated. This is accomplished by repeated computer iterations using random numbers to assign values to the exposure factors. The simulated output represents a sample from the true output distribution. Methods of statistical inference are used to estimate, from the output sample, key parameters of the output distribution (e.g., percentiles).

The risk distributions produced by Monte Carlo simulations present significantly more information than do point estimates. However, the level of effort involved in conducting a quantitative uncertainty analysis should be weighed against the importance of this information to risk managers.

8.0 SUGGESTED HHRA REPORT ORGANIZATION

After the four TMs and the CDPHE letter report are submitted, and after the risk calculations are completed, the HHRA report is written. HHRA reports are generally written as "stand alone" documents for RFETS and are written for members of the public with a college education. The reports typically contain the following sections:

- Section 1. Introduction
- Section 2. Site Description
- Section 3. COC Identification
- Section 4. Scenario and Pathway Identification
- Section 5. Exposure Assessment
- Section 6. Toxicity Assessment
- Section 7. Risk Characterization
- Section 8. Summary
- Section 9. References
- Appendices.

TMs submitted before the HHRA report address information on COC identification, exposure assessment, fate and transport models, and toxicity assessment. Because the HHRA is a stand alone document, information from TMs that are used in the HHRA report is restated in the HHRA.

The following subsections describe the contents of each section of an HHRA report. These subsections discuss only minimum information for the HHRA, additional information can be included that would better describe the methodologies, approaches, and results to the reader.

8.1 Section 1. Introduction

Section 1. Introduction of the HHRA should provide the HHRA's purpose, scope, objectives, and the report organization. IAG requirements should be discussed in the Introduction. The Introduction can also include a chronology of the previous investigations.

8.2 Section 2. Site Description

Section 2. Site Description presents a brief summary of the presentations and findings of the RI report that include a description of IHSSs, meteorology and climate, hydrogeology, flora and fauna, demographics and local land use, determination of contaminants, nature and extent of contamination, and contaminant migration pathways. Tables, figures, and maps can be used to summarize contaminants and media at the site, general and specific site areas and locations, and contaminant detection locations.

The reader of the HHRA report can be referred to the source documents (e.g., RFI/RI report sections) for further detail.

8.3 Section 3. COC Identification

Section 3. COC Identification presents the methodology and its application in the identification and selection of COCs. A background comparison is presented that discusses applicable statistical tests and resulting potential COCs. If lengthy, this background comparison may be presented as an attachment. The COC screening methodology is presented and applied to derive a list of COCs to be used in the remainder of the risk assessment. Tables 3-1 through 3-8 provide examples of: summary statistics, the COC screening process, the concentration-toxicity screen, and the resulting COCs.

8.4 Section 4. Scenario and Pathway Identification

Section 4. Scenario of Pathway Identification discusses potential scenarios and pathways applicable to the existing and potential land use. A discussion is provided for each current and potential on-site and off-site land use. Potential receptors that could be exposed to COCs in the context of land uses discussed in Section 2 of the HHRA are then presented. Finally, justification of the selection of exposure pathways according to the CSM is provided.

8.5 Section 5. Exposure Assessment

Section 5. Exposure Assessment first presents pathway-specific information such as intake equations and modeling data, followed by information that is both scenario-specific and pathway-specific such as exposure parameters and exposure concentrations. Where modeling was used to provide the exposure concentrations, a brief summary of the model is provided. Finally, the resulting calculated are presented for each scenario. Tables and figures can include model applications, chemical-specific constants, intake equations and parameters, and resulting receptor intakes. Tables 5-2 and 5-3 in this HHRA methodology provide some presentation examples.

8.6 Section 6. Toxicity Assessment

Section 6. Toxicity Assessment provides COC toxicity information including carcinogenic and noncarcinogenic effects. Tables are used to summarize toxicity values for each COC, with toxicity profiles presented as text. Tables 6-1 and 6-3 in this HHRA methodology provide examples of summary toxicity information.

8.7 Section 7. Risk Characterization

Section 7. Risk Characterization presents the methodology and results of combining the results of the exposure and toxicity assessments. These results provide numerical estimates of potential health risk. Considered in the approach are the nature and weight of evidence supporting the risk estimates and the magnitude of uncertainty. Tables and figures include presentations of specific and summarized carcinogenic risk and noncarcinogenic HIs, summaries of sources of uncertainty, and the potential impact on the assessment. Tables 7-1 through 7-7 of this HHRA methodology provide examples of these risk characterization calculations and observations, and qualitative uncertainty analysis.

8.8 Section 8. Summary

Section 8. Summary summarizes the methodology implemented for each section of the HHRA and the overall results. Text, tables, and figures should summarize the entire HHRA into one section.

Section 8 can be written to be used for the HHRA portion of Section 6 of the RI/RFI report. This section of the RFI/RI report presents the BRA, which is comprised of the HHRA and the EE. In addition, portions of the summary of the HHRA can be used for the executive summary of the RFI/RI Report. Section 8 may include summary tables of risk and discussion of risk drivers and associated uncertainties.

8.9 Section 9. References

Section 9. References includes all references used throughout the HHRA.

8.10 Appendices

Appendices include additional information that would be helpful to the reader about the background, assumptions, or approach to any aspect of the HHRA. The following list section briefly describes suggested contents for appendices to the HHRA. Additional appendices can be added.

- **Background Comparison** - This appendix discusses the background analysis process and results. Using statistical analysis, inorganic chemicals or radionuclides that are at or below background levels are eliminated from further consideration. Specific criterion for the background analysis is that none of the statistical tests indicate a statistically significant difference between background and site-specific populations.
- **Fate and Transport Model Descriptions and Applications** - This appendix provides a detailed description of the models used in the HHRA including methodologies and assumptions. Applications of each model are described and discussed. Examples of models include ground-water modeling, soil-gas modeling, and atmospheric modeling.

- **Calculating of 95% UCLs for COCs** - This appendix provides a brief description of the methodologies and assumptions used to determine the 95% UCLs for the COCs. It can also include tables to summarize the results of the calculations for each COC.

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APPENDIX A
DATA CLEAN-UP AND TREATMENT GUIDELINES

APPENDIX A

DATA CLEAN-UP AND TREATMENT GUIDELINES

Upon receipt of RFEDS data, the user should verify the field positions of all variables in the RFEDS ASCII output file. After verification, the ASCII file may be transformed into data fields for a specific software (e.g., SAS, Lotus, Excel, SPSS, etc.) to be used in the data manipulation. It is recommended that the user create successive generations of the data files rather than just continually updating the original data file; this simplifies data analysis if back-tracking is required for any reason. To create successive generations of data files, the following procedure may be used.

1. Create original data files from RFEDS ASCII files; these files contain the entire RFEDS data pull, including QC samples, rejected data, etc.
2. In the second generation of data files, drop QC samples (except DUPs of DUP/REAL pairs), rejected data, blank form-generated records, tentatively identified compounds (TICs), etc.

In the RFEDS output format (i.e., for data extracted after February 21, 1994), the validated results, units, qualifiers, and detection limits will automatically replace the lab results, units, qualifiers, and detection limits. The validation code field ("Validation") indicates whether the datum is acceptable (Validation = A, V, or JA), or rejected (Validation = R), or other.

3. Treat results from samples requiring dilution individually. Treatment of DIL data requires the data analyst to find the analyte(s) that necessitated the dilution; these should have a qualifier of "E" (for exceedance of calibration range). The DIL results(s) for the E-qualified analyte(s) should be used in the data analysis; other analytes may have results reported for the DIL sample analysis, but these results should be deleted if these analytes in the original undiluted sample were NOT qualified as "E".
4. Standardize location names and soil units. Standardization of analyte names and units are automatic in the RFEDS data output.
5. From the second generation of data fields created in Steps 2, 3, and 4, create a third generation of data file with averaged DUP/REAL pairs (change REAL value to the mean value of the averaged DUP/REAL pair, then delete the DUP record). In the case of DUPs with no corresponding REAL record, change "DUP" to "REAL". (NOTE: Prior to averaging DUP/REAL pairs, sort the data by LOCATION, SAMPLE NUMBER, SAMPLE DATA, and ANALYTE. This should bring together all existing DUP/REAL pairs).
6. From the data files created in Step 1, create a separate field with QC data for analysis of data quality. Check the precision and accuracy parameters including RPD for DUP/REAL pairs and bias from field or laboratory blanks. Assess completeness by

calculating percent completeness of valid and invalid (validation code = R) data point.

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APPENDIX B

GUIDE FOR CONDUCTING STATISTICAL COMPARISONS OF
RFI/RI DATA AND BACKGROUND DATA
AT THE ROCKY FLATS PLANT

Best Available Copy

Guide for Conducting Statistical
Comparisons of RFI/RI Data and Background Data
At the Rocky Flats Plant

General

This document is intended to provide guidelines for OU-to-background comparisons of data, and to explicitly discuss approaches to the issue of determining OU-specific contamination. The OU-to-background comparison will be applied for inorganics and radionuclides. In addition, the comparison may occasionally be performed for organics on a limited, case-by-case basis, subject to EPA and CDH approval.

It is important to establish a common approach leading to a common list of possible contaminants for each OU. To this end, Figure 1, GENERAL APPROACH TO DETERMINING "CONTAMINANTS" was developed. In this general technique, a "Tool-Box" approach is employed to arrive at one common list of contaminants for each OU (or subdivision), for all functional aspects of the RFI/RI and CMS/FS.

As indicated, several disciplines such as the Human Health or Ecological Risk Assessors and Regulatory specialists may pare the list of contaminants to "Contaminants of Concern" (COCs) based on factors germane to their application (e.g., toxicity).

The text below follows Figure 2, FLOWCHART FOR COMPARING OU DATA TO BACKGROUND.

Start

Determine Background and OU Target Populations

Appropriate geographical, geological, and temporal data sets will be defined for comparison. This is essentially a matching exercise so that Site (OU) data sets are comparable to background sets. Consideration will be given to issues such as:

- Geologic materials
- Hydrostratigraphic unit
- Temporal comparability
- Sample size for statistical tests
- Confidence in geo/hydrologic regime determination

The background data sets will be taken from the 1993 Background Geochemistry Characterization Report (EG&G, September, 1993), except for surficial soils. Rock Creek surficial soil samples were used as background for OUs 1 and 2, and will be used until the FY94 surficial soil sampling data is available. Surficial soils are scheduled to be sampled in FY94 to supplement the Rock Creek data and the FY94 samples will be used subsequently as background surficial soil data. The following media have defined backgrounds: groundwater (Rocky Flats Alluvium, valley fill alluvium, colluvium, weathered sandstone, and unweathered Arapahoe/Laramie formation rocks), surface water (Rock Creek and Woman Creek), seeps, stream sediments (Rock Creek and Woman Creek), seep sediments, and soils (Rocky Flats Alluvium, colluvium, surficial, weathered claystone, and weathered Arapahoe, Laramie sandstone). Site media will be cross-referenced to one or more background media.

Set DQOs

DQOs are established to define data needs for each of the RFI/RI tasks, coordinate that collection activities support those needs, and ensure the quality and quantity of resultant data. Three stages are used in the development of DQOs:

Identify Decision Types:

- Identify and involve data users,
- Evaluate available data,
- Develop a conceptual model of the study site, and
- Specify RFI/RI objectives, and anticipate the decisions necessary to achieve the objectives.

Identify Data Uses and Needs:

- Identify data uses,
- Identify data types,
- Identify data-quality needs,
- Identify data-quantity needs,
- Evaluate sampling and analysis options, and
- Review data precision, accuracy, representativeness, completeness, and comparability (PARCC).

Design Data Collection Program:

- Assemble data-collection components, and
- Develop data-collection documentation.

Data Collection and Validation

Under current IAG schedule conditions, analytical data may not be 100% "validated" when the background comparisons are made in each draft report. However, non-validated data will be used only for draft RFI/RI's. Final RFI/RI reports will use only data that have undergone

validation. Data that have been rejected will not be used. The potential impacts of using non-validated data will be discussed on a case-by-case basis in the final reports.

Data Presentation

A "preliminary" exploratory data appraisal will be performed to obtain a "feel" for the data. This will involve techniques and identification of issues such as:

- Gross summary statistics
- Spatial arrays
- Temporal plots
- Sampling strategy comparability evaluation
- Affected media matrix
- Hit ratios
- Non-detect rates
- Detection limit/quantitation limit issues
- Extent of data qualifications "J", "B", etc.
- Histograms/boxplots/other visuals
- DQO adequacy/completeness assessment

This step will help guide the need for, and evaluate the appropriateness and applicability of further analysis, evaluate assumptions, and ascertain the impacts and limitations in light of the actual data as collected. Information generated during the exploratory data appraisal will be used in evaluating the appropriateness of the scope of the formal RFI/RI proposal. Results will be informationally discussed in a meeting with EPA, CDH, and DOE/RFO.

Several data-presentation techniques were identified by Dr. Gilbert as appropriate for different conditions. To perform them all for all compounds in a standard full suite is not necessary when it is clear from a preliminary review that the vast majority of data points for some compounds are entirely or almost entirely non-detects.

Accordingly, we have refined the methodology as follows:

Box plots will be used when the percentage of non-detects is 50% or less.

Histograms will also be used when the percentage of non-detects is 50% or less. Bars in the histogram will be shaded to indicate the percentage of detects and non-detects within each bar interval.

Probability plots, ordered listings, and other graphics will be used as appropriate.

As indicated by the OUI process, visual presentation of the data is important. Interpretable graphics will be produced to the extent that they facilitate analysis. In general, graphics will be a central feature of analysis.

BACKGROUND COMPARISON METHODOLOGY TOOL BOX APPROACH

Employing: Bounding-Benchmark Comparison (Hot Measurement), Inferential Statistics, and Professional Judgement

General

The tool-box approach employs a bounding-benchmark comparison, inferential statistics, and professional judgement. This approach was forwarded in the OUI comment-resolution process, endorsed by Dr. Gilbert, and is widely applied in the hazardous waste industry and environmental business across America. It employs a "weight-of-evidence" framework wherein all three aspects are factored into the determination of what is a Site (OU) contaminant. Statisticians will be used to verify that the methods used are correct.

Bounding-Benchmark Comparison ("Hot-Measurement Test" Component)

- o A hot-measurement test will be performed that will compare each analyte concentration to an upper-limit value for that analyte.
- o The upper-limit value will be the value at which there is a 99% probability that 99% of the background distribution will be below this value ($UTL_{99/99}$). If the $UTL_{99/99}$ cannot be calculated or reasonably estimated, then background values from technical literature and professional judgement will be used. The resulting geochemical interpretation of data will be subject to Agency review and approval.
- o The $UTL_{99/99}$ is required instead of a toxicity-based value because a single list of potential contaminants must be used by many disciplines (Human Health, Ecological, Regulatory, etc.,) to ensure consistency across the RFI/RI and CMS/FS Reports. The subjective nature of what is "hot", as well as toxicity and ARAR considerations, will be dealt with by the specialists who determine COC's specific to their discipline.
- o In addition to ensuring that high concentrations do not get overlooked, the $UTL_{99/99}$ is an important tool for identifying locations of suspected elevated concentration in the "nature and extent" section.

Background Comparison Using Inferential Statistical Methods

Based on Dr. Gilbert's work, the following inferential statistical tests will be used to compare background data sets to data sets compiled at the Operable Units (OUs). These data sets will be compiled and compared by analyte, and by the correct background data set (i.e., colluvium, alluvium, alluvium + colluvium, surface soils, etc. [See Determine Background and OU Target Populations]).

It should be noted that Dr. Gilbert's recommendations establish a framework that emphasizes using the most appropriate test available. Thus professional judgement will be necessary both in application of inferential tests, as well as their interpretation. Additionally, within the framework of a battery of tests drawn from a "tool box" of methods, it is requested that EPA and CDH remain open to consultation on the use of other tests as appropriate.

The results of all tests (hot-measurement, inferential) will then be evaluated in light of professional judgement. This process is depicted on Figure 3, BACKGROUND COMPARISONS METHODOLOGY.

If hot-measurement or inferential statistical tests show that the concentration of a given analyte in the OU data set is not greater than the concentration in the background data set, and if considerations in the professional-judgement arena do not override, then the analyte is considered not to be a contaminant.

If either the hot-measurement test or at least one inferential statistical test shows that the concentration of a given analyte in the OU data set may be greater than the concentration in the background data set, then professional judgement (using temporal and spatial analysis, as well as pattern-recognition concepts) is again applied to see if the analyte concentrations in the two data sets are actually different.

After the hot-measurement test and prior to the use of inferential statistical testing, the issue of non-detects must be dealt with for all tests except the Gehan test, which can be applied with non-detects present. For all other tests, non-detects should be replaced with a value of 0.5 times the applicable reported detection limit, following EPA guidance (Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance, July 1992), but realizing the performance of simple substitution decreases with an increasing proportion of non-detects.

The handling of non-detects, and the presence of multiple detection limits in the RFEDS data base, requires the use of good professional judgement along with the general guidance offered here. The use of graphical displays of data will assist in the handling of high-value non-detects.

Detection limits will be discussed in the FI report.

Gehan Test or Nonparametric ANOVA Test

- o The Gehan test is a nonparametric test and can be used when multiple detection limits are present. The Gehan test will be applied without replacing non-detects. These are the principal favorable attributes of the Gehan test.
- o Standard nonparametric ANOVA tests (Wilcoxon Rank Sum and Kruskal-Wallis) are widely used in environmental assessment, and are discussed in EPA guidance (Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Addendum to Interim Final Guidance, July 1992). These tests require replacement of non-detect values, either by simple substitution or maximum-likelihood methods.
- o For the Gehan or nonparametric ANOVA test, a p-value will be generated and p-values that are equal to or less than 0.05 will normally be considered indicative of a significant difference from background. Statements of the test and null hypotheses will be given, in both statistical and narrative terms.

Quantile Test

- o The quantile test is also a nonparametric test and can be considered as a rapid screening test.
- o Due to limitations in the quantile test, the test will only be used if the largest 20% of the combined background and site data are detects.
- o A p-value will be generated and p-values that are equal to or less than 0.05 will indicate a significant difference from background. Statements of the test and null hypotheses will be given, in both statistical and narrative terms.

Slippage Test

- o The slippage test is a nonparametric test and can be considered as a rapid screening test.
- o Due to limitations in the slippage test, the test will possibly not be used if the largest background value is a non-detect. If the largest background value is a non-detect, then professional judgement will be applied to determine whether or not the slippage test is applicable. For example, if the second largest background value is a detect and is similar in value to the largest background value, it could be used in place of the largest value (although the replacement must be taken into account when interpreting the test results).
- o A p-value will be generated and p-values that are equal to or less than 0.05 will indicate a significant difference from background. Statements of the test and null hypotheses will be given, in both statistical and narrative terms.

T-Test

- o The t-test is a parametric test and is very commonly used when testing the difference between means of two data sets.
- o Due to limitations in the t-test, the test will be applied in cases where both background and OU data are normally distributed and contain at least 20 data points, and less than 20% of the background and OU data are classified as non-detects.
- o A p-value will be generated and p-values that are equal to or less than 0.05 will indicate a significant difference from background. Statements of the test and null hypotheses will be given, in both statistical and narrative terms.

Professional Judgement

The following general guidelines will be used individually and collectively, in conjunction with the above comparison and statistical "tools" to ascertain if a reported analytical detection(s) constitutes contamination at the OU. When professional judgement is applied, documented and defensible evidence will be furnished, and DOE will bear the "burden of proof".

- o Spatial distribution of analytes above background are or are not indicative of contamination due to waste-related activities at the OU. Spatial plots, interpreted in a source-to-receptor conceptual model, in addition to compound-specific mobility considerations, generally assist in interpretation of inconclusive results.
- o Temporal distribution of analyte concentrations at a station indicates the "high" value(s) is(are) outlier(s). Time-series plots at wells or surface-water locations can generally be used to link apparently insignificant outlier reports to seasonal or hydrological phenomena, and vice versa.
- o Other associated analytes are determined not to be contaminants in the sample or at the station. Then this may be added to cumulative evidence ("burden of proof") that the analyte in question is not a potential contaminant of concern. Pattern-recognition concepts are useful in identifying anomalies as well as confirming "fingerprint" associations.

Flow Chart for Comparing OU Data to Background

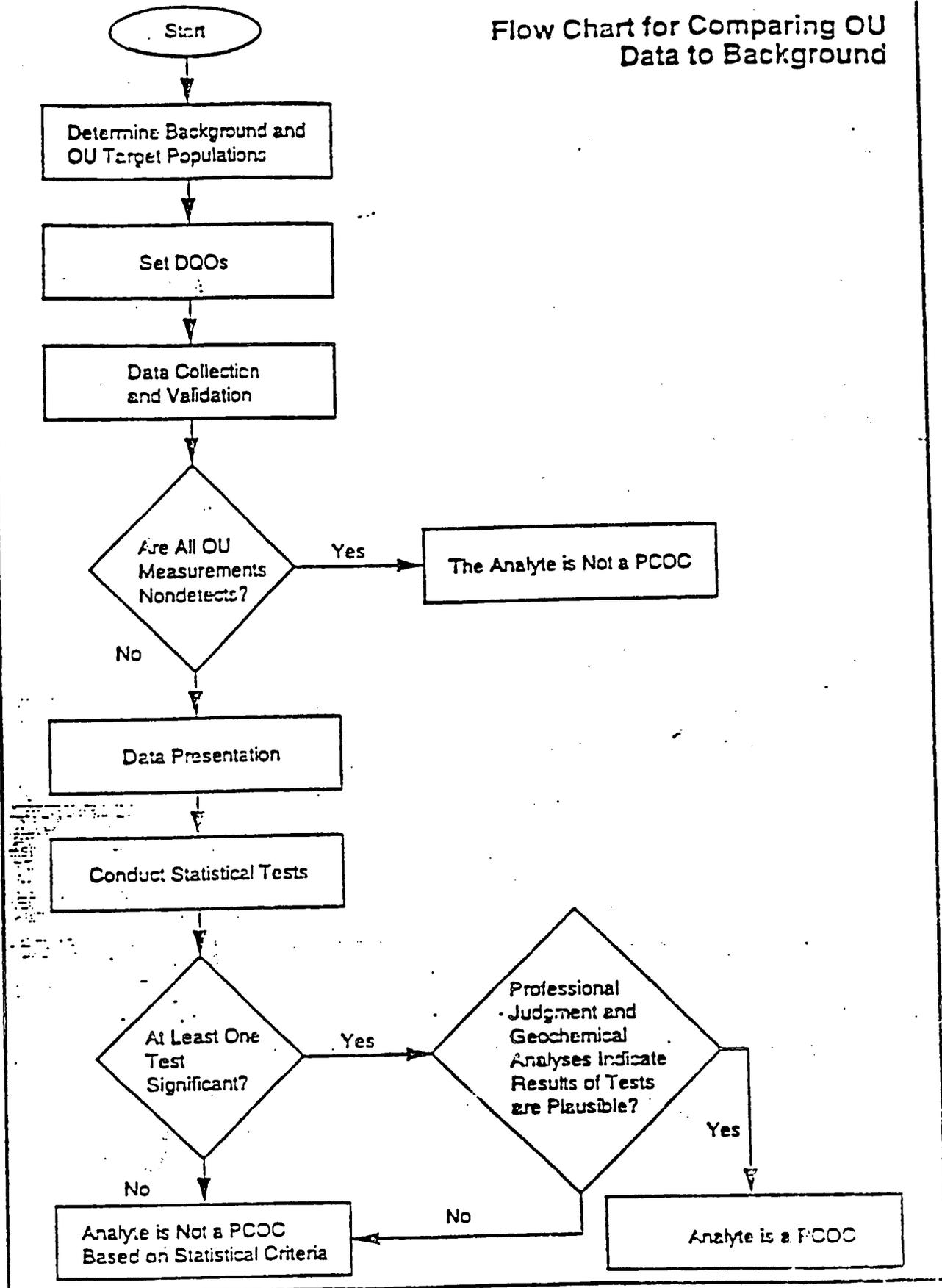


Figure 1
Flow Chart for Comparing
OU Data to Background

GENERAL APPROACH TO DETERMINING "CONTAMINANTS"

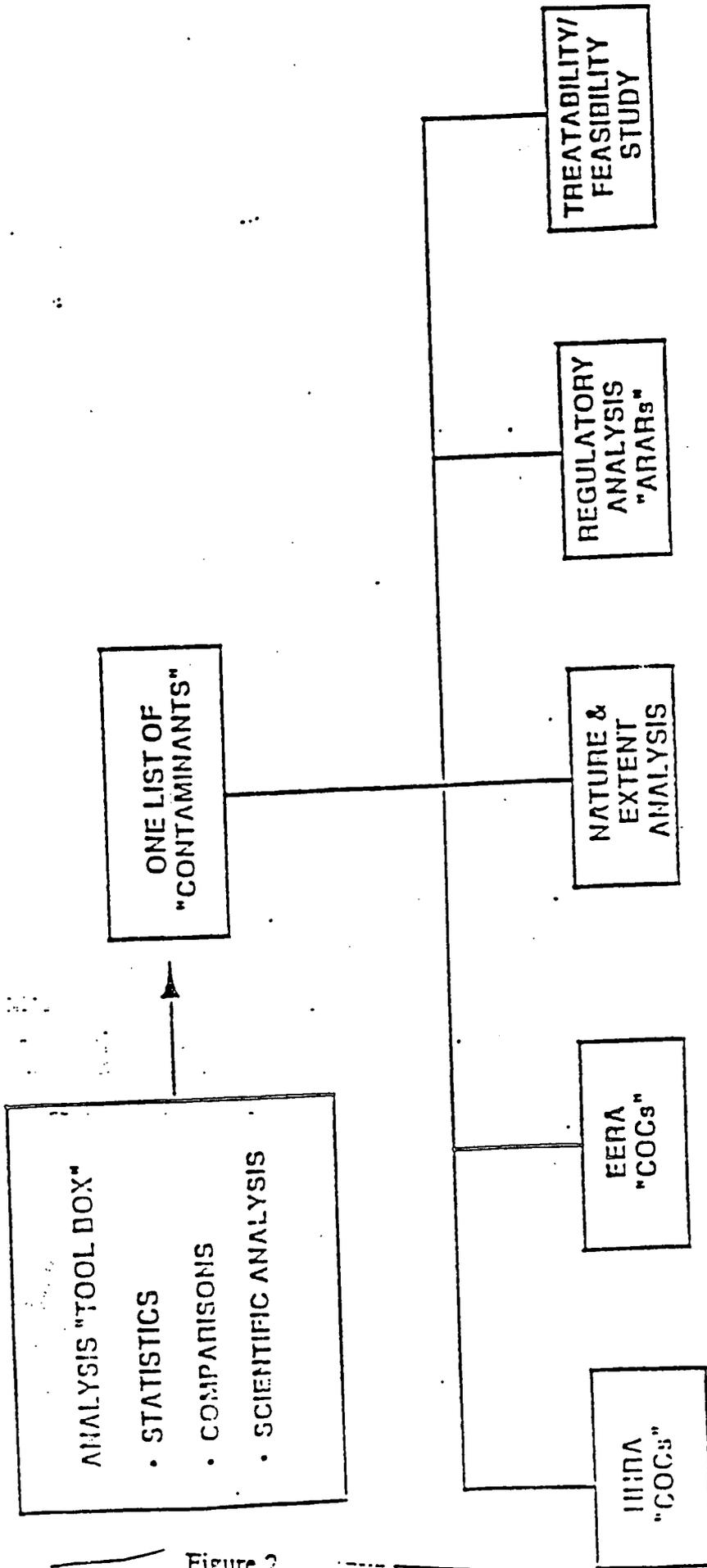


Figure 2
General Approach To Determining "Contaminants"

Background Comparison Methodology

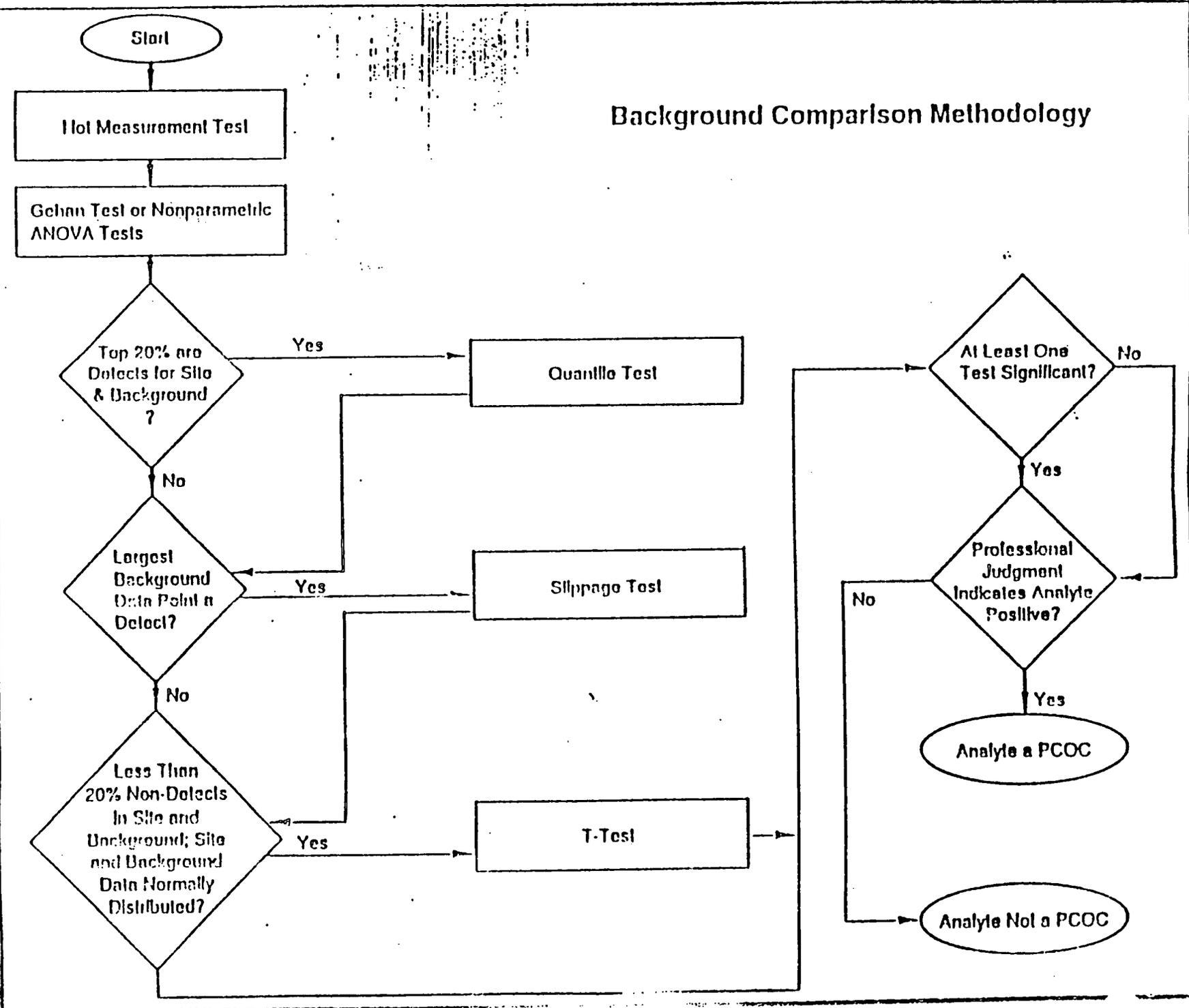


Figure 3
Background Comparison Methodology

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APPENDIX C
PROGRAMMATIC RISK-BASED
PRELIMINARY REMEDIATION GOALS

**PROGRAMMATIC RISK-BASED PRELIMINARY
REMEDATION GOALS**

**U.S. Department of Energy
Rocky Flats Plant
Golden, Colorado**

**Final
Revision 1**

October 1994

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LIST OF ACRONYMS

ACL	Alternative Concentration Limit
ARAR	Applicable or Relevant and Appropriate Requirement
BRA	Baseline Risk Assessment
CDPHE	Colorado Department of Public Health and the Environment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CHWA	Colorado Hazardous Waste Act
CMS/FS	Corrective Measures Study/Feasibility Study
COC	Contaminant of Concern
DOE	U.S. Department of Energy
IAG	Interagency Agreement
IHSS	Individual Hazardous Substance Site
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
NCP	National Oil and Hazardous Substances Pollution Contingency Plan
OU	Operable Unit
PPRG	Programmatic Preliminary Remediation Goal
RAGS	Risk Assessment Guidance for Superfund
RBC	Risk-Based Concentration
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFP	Rocky Flats Plant
RI/FS	Remedial Investigation/Feasibility Study
ROD	Record of Decision
TAL	Target Analyte List
TBC	To-Be-Considered
TCL	Target Compound List
USEPA	U.S. Environmental Protection Agency

1.0 INTRODUCTION

Various areas at the Rocky Flats Plant (RFP) are being closed and/or remediated in accordance with the provisions of the 1991 Interagency Agreement (IAG) signed between the U.S. Department of Energy (DOE), the U.S. Environmental Protection Agency (USEPA), and the State of Colorado (IAG 1991) to ensure protection of human health and the environment. The IAG integrates the closure and corrective action provisions of the Resource Conservation and Recovery Act (RCRA) and the Colorado Hazardous Waste Act (CHWA) with the hazardous substance response requirements contained in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The various areas to be closed or remediated, called Individual Hazardous Substance Sites (IHSSs), are divided into 16 Operable Units (OUs).

DOE is in the process of conducting a RCRA Facility Investigation/Remedial Investigation (RFI/RI) and Corrective Measures Study/Feasibility Study (CMS/FS) for each OU to select the most appropriate remedy for each OU. In order to identify, evaluate, and select a remedial alternative, the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) states that "Alternatives shall be developed that protect human health and the environment by recycling waste or by eliminating, reducing, and/or controlling risks posed through each pathway by a site." The number and type of alternatives to be analyzed shall be determined at each site, taking into account the scope, characteristics, and complexity of the site problem that is being addressed. In developing and, as appropriate, screening the alternatives, the lead agency shall establish remedial action objectives specifying contaminants and media of concern, potential exposure pathways, and remediation goals." [See 40 CFR 300.430(e)(2).]

This document addresses the establishment of programmatic remediation goals which are contaminant- and medium-specific levels of exposure that are protective of human health. The combination of the Baseline Risk Assessment (BRA) results, Applicable or Relevant and Appropriate Requirements (ARARs), and To-Be-Considered documents (TBCs) are used as the basis to establish the remediation goals approved by the regulatory agencies in the Record of Decision (ROD). CERCLA Section 121 and 40 CFR 300.430 allow the following factors to be considered when establishing remediation goals.

- Chemical-specific standards established pursuant to a Federal environmental law or any promulgated State standard which is more stringent than a Federal standard are to be used to establish remediation goals. These environmental laws include, but are not limited to, the Toxic Substances Control Act; the Safe Drinking Water Act; the Clean Air Act; the Clean Water Act; the Marine Protection, Research and Sanctuaries Act; and the Solid Waste Disposal Act. In addition to the promulgated standards, the following items should be considered:
 - For systemic toxicants, remediation goals are to be established so that the human population, including sensitive subgroups, may be exposed without adverse effect through a given lifetime (i.e., Hazard Index less than 1.0). Remediation goals are to incorporate an adequate margin of safety.

- For known or suspected carcinogens, remediation goals are to be established to represent an excess upper-bound lifetime cancer risk to an individual ranging from 10^{-4} to 10^{-6} using information on the relationship between dose and response. The 10^{-6} risk level shall be used as the point of departure for determining remediation goals for alternatives where specific ARARs are not available or protective due to multiple contaminants or exposure pathways. [NOTE: In cases where the chemical-specific ARARs result in a cumulative risk in excess of 10^{-4} , more restrictive remediation goals may be established in accordance with this provision.]
- Factors related to uncertainties, technical limitations (i.e., detection limits), and other pertinent information.
- Non-zero Maximum Contaminant Level Goals (MCLGs), where determined to be relevant and appropriate, are to be attained by remedial actions for ground or surface waters that are current or potential drinking water sources. For MCLGs set at zero, the corresponding Maximum Contaminant Level (MCL) is to be attained when determined to be relevant and appropriate.
- An Alternative Concentration Limit (ACL) can be established pursuant to CERCLA Section 121.
- Water quality standards established under the Clean Water Act Sections 303 and 304 are to be attained for releases to surface waters to be protective of aquatic life where determined to be relevant and appropriate.
- Fauna, flora, and aquatic habitats are to be considered during the establishment of the remediation goals. Environmental evaluations are to be conducted to assess threats to the environment, especially sensitive and critical habitats protected under the Endangered Species Act.

To the extent possible, chemical-specific ARARs are used to determine remediation goals. However, ARARs may not adequately consider the site-specific contamination or the cumulative effects associated with multiple contaminants and/or pathways. Therefore, chemical-specific ARARs are not always the sole determinant of protectiveness and are supplemented with risk assessments and consideration of other non-promulgated health-based criteria. The risk assessment process includes the evaluation of site-specific factors such as potential for exposure (e.g., future land use), the hazardous substances present, and the presence of sensitive populations and habitats. These factors will be considered during the development of the OU-specific BRA.

DOE proposes to develop Risk-Based Programmatic Preliminary Remediation Goals (PPRGs) which will establish initial sitewide clean up targets for each environmental medium.

The risk-based PPRGs incorporate BRA methodologies accepted on a sitewide basis. This report presents the purpose for risk-based PPRGs and methods used to calculate them. Section 2 provides information regarding the intended current and potential future uses of the risk-based PPRGs. Section 3.0 describes the exposure pathways and methodology used to calculate the risk-based PPRGs. Section 4.0 provides references for the toxicological information used for each specific contaminant. Section 5.0 gives a comprehensive list of risk-based PPRGs that are proposed to be used to develop and screen remedial technologies and alternatives.

2.0 PURPOSE OF RISK-BASED PROGRAMMATIC PRELIMINARY REMEDIAL GOALS

As stated in Section 1.0, the intended purpose for calculating risk-based PPRGs is to establish sitewide clean up targets for environmental contaminants. The calculation of risk-based PPRGs is possible through the standardization of exposure pathways and risk assessment methodologies. The benefits associated with developing risk-based PPRGs include:

- Support the CMS/FS process by allowing the development of remedial technologies and alternatives to proceed without an OU-specific BRA;
- Support the Contaminant of Concern (COC) selection process within the BRA by providing "Risk-Based Concentrations";
- Support the Colorado Department of Public Health and the Environment (CDPHE) conservative screen within the BRA; and
- Support the evaluation of sites where accelerated cleanup actions may be warranted.

In order to assure consistency with current risk assessment methodologies, Exposure Scenario Technical Memoranda were evaluated for use in the risk-based PPRG selection.

Although there is a certain level of risk associated with developing remedial technologies and alternatives prior to fully characterizing the risks associated with the OU contamination, the programmatic approach is consistent with the NCP. Specifically, 40 CFR 300.430(e)(2)(i) states that, "[I]nitially, preliminary remediation goals are developed based on readily available information, such as chemical-specific ARARs or other reliable information. Preliminary remediation goals should be modified, as necessary, as more information becomes available during the Remedial Investigation/Feasibility Study (RI/FS). Final remediation goals will be determined when the remedy is selected."

The "off-the-shelf" risk-based PPRGs will form the initial basis for identifying, screening, and evaluating potential remedial technologies and alternatives. However, the risk-based PPRGs are not intended to be the final justification for selecting a particular remedial alternative. Should the final BRA indicate that the risk-based PPRGs are not representative of

the actual risk posed by the contamination at the OU, the required changes will be incorporated as early as possible during the Development and Screening of Alternatives or Detailed Analysis of Alternatives.

The extensive amount of data at each OU warranted a process that would reduce the number of chemicals needing assessment in the BRA. USEPA, CDPHE, and DOE therefore approved a process by which COCs could be delineated at a site. One part of this process evaluates low detection frequency chemicals with respect to a Risk-Based Concentration (RBC) value. The value to be used for the RBC will be taken from the risk-based PPRG list using a residential scenario.

Data aggregation within an OU has been discussed between USEPA, CDPHE, and DOE, and an agreement has been reached on how this data aggregation is to be performed. To meet CDPHE requirements for data aggregation, the whole OU area is divided into sub-areas called "sources." Source area delineation is based on the environmental media data from the OU. After source areas are delineated, a risk-based screening process is performed for each source area. This screening process will use the residential exposure scenario values within the risk-based PPRG list.

As required by Section IX.A.1 of the IAG Statement of Work, DOE is to develop Corrective/Remedial Action objectives for each OU and document these objectives in OU-specific Technical Memoranda for submission to USEPA and/or the State for review. The objectives are to specify the contaminants and media of interest, exposure pathways and receptors, and USEPA and State accepted levels or ranges for each exposure route. The risk-based PPRGs will be used in conjunction with chemical-specific ARARs to establish acceptable PRGs for each OU. These acceptable levels or ranges (e.g., OU-specific PRGs) will be documented in the form of a Technical Memorandum.

It is projected that a risk-based evaluation will be needed to screen OUs for potential early actions. This screening evaluation will need to employ risk-based cleanup targets so that areas can be ranked with respect to human health risks. Also, high risk sites will need to be assessed with respect to the amount of cleanup required. It is projected that the risk-based PPRGs will be utilized for both of these exercises within an accelerated clean-up framework. Based on the CDPHE conservative screen, accelerated actions may be implemented at sites where the cumulative risk ratio is greater than 100.

3.0 EXPOSURE PATHWAYS

In order to standardize the risk-based PPRGs across all of the OUs, programmatic exposure pathways and receptors were established. Table 1 identifies the receptors and exposure pathways selected for each environmental media. A sand and gravel mining scenario is being examined for the possible incorporation into the risk-based PPRG document. If it is determined that this exposure scenario is required, the risk-based PPRG document will be revised accordingly. In addition, dermal exposure will be considered during the CDPHE conservative

TABLE 1
PROGRAMMATIC ENVIRONMENTAL MEDIA AND EXPOSURE PATHWAYS

Environmental Media Exposure Scenario	Residential	Commercial/Industrial	Ecological Researcher
Surface Soil	Direct Ingestion of Soils ^{a/} Inhalation of Particulates ^{b/} External Radiation Exposure ^{c/}	<u>Office Worker Scenario</u> Direct Ingestion of Soils ^{a/} Inhalation of Particulates ^{b/} External Radiation Exposure ^{c/}	Direct Ingestion of Soils ^{a/} Inhalation of Particulates ^{b/} External Radiation Exposure ^{c/}
Subsurface Soil	Not Applicable	<u>Construction Worker Scenario</u> Direct Ingestion of Soils ^{a/} Inhalation of Particulates ^{b/} External Radiation Exposure ^{c/} Inhalation of Volatiles	Not Applicable
Ground Water	Direct Ingestion of Ground Water ^{a/} Inhalation During Domestic Use ^{d/}	Not Applicable	Not Applicable
Surface Water	Direct Ingestion While Swimming ^{e/}	Not Applicable	Direct Ingestion While Wading ^{e/}

NOTES:

- ^{a/} Includes assessment of organics and inorganics.
- ^{b/} Includes assessment of non-volatile organics and inorganics.
- ^{c/} Includes assessment of radionuclides.
- ^{d/} Includes assessment of volatile organics.
- ^{e/} Includes assessment of organics and tritium.

5

for

screen in accordance with DOE/USEPA/CDPHE agreements. Should the results of the CDPHE conservative screen indicate that the cumulative risk ratio is less than one, dermal exposure will be assessed per USEPA dermal exposure assessment guidance (USEPA, 1992).

Standard assumptions given in Risk Assessment Guidance for Superfund (RAGS), Part B (USEPA, 1991) were used in developing risk-based PPRG equations where available. For situations not addressed by RAGS, Part B, standard assumptions given in RAGS, Part A (USEPA, 1989) were used. In addition, site-specific information from Exposure Scenario Technical Memoranda for OUs 1 through 7 was used where appropriate to supplement assumptions given in USEPA guidance. Best professional judgement was applied when default values differed from site-specific information.

In addition to USEPA and site-specific information, CDPHE guidance (*Interim Final Policy and Guidance on Risk Assessments for Corrective Action at RCRA Facilities*) was consulted for exposure pathways and parameters. While this guidance has not been finalized, it was reviewed and CDPHE was consulted on its use during development of the risk-based PPRG equations.

Due to the many programs that these risk-based PPRGs will support, elements from USEPA and CDPHE guidance, as well as site-specific information, were used to develop the risk-based PPRGs. This compromise approach will assure that all objectives of the document are met while maintaining the health protectiveness of the risk-based PPRGs.

4.0 METHODOLOGY, EQUATIONS, AND ASSUMPTIONS

This section presents the methodology, equations, and assumptions that were used to calculate the risk-based PPRGs. In general, the following USEPA guidance documents were used as the basis to derive the risk-based equations and exposure default values to calculate the risk-based PPRGs.

- *Human Health Evaluation Manual, Part B: Development of Risk-Based Preliminary Remediation Goals*, (USEPA 1991);
- *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part A)*, (USEPA 1989);
- *Changes to Equations in the Part B Guidance*, (Dinan 1992);
- *Revisions to Chapter 4: Risk-based PRGs for Radioactive Contaminants*, (USEPA 1993b); and
- *Human Health Evaluation Manual, Supplemental Guidance: Standard Default Exposure Factors, OSWER Directive 9285.6-03*, (USEPA, 1991b).

To ensure that all of the contaminants that may be encountered at the RFP are addressed, risk-based PPRGs were developed for all Target Analyte List (TAL) metals, Target Compound List (TCL) organics and 12 radionuclides for each receptor (i.e., resident, office worker, construction worker, and ecological researcher) and environmental media (i.e., surface soil, subsurface soil, ground water, and surface water) combination identified on Table 1. Separate risk-based equations were developed to account for the carcinogenic, noncarcinogenic, and/or radiological effects of the contaminant. Risk-based PPRGs for carcinogens (including radionuclides) were calculated by setting the carcinogenic target risk level at 10^{-6} . A target risk level of 10^{-6} means an individual has a one-in-one-million probability of developing cancer over a lifetime as a result of exposure to a specific contaminant. This risk is in addition to the probability of an individual developing cancer from other factors such as those associated with heredity or lifestyle. Similarly, risk-based PPRGs for toxicants (non-carcinogens) were calculated by setting the hazard index equal to 1 for each contaminant. A hazard index is the ratio between the contaminant concentration and a reference dose. The reference dose represents the exposure level to the contaminant below which adverse effects are not expected. For some of the contaminants both carcinogenic and noncarcinogenic toxicity information was available. For these contaminants, both a carcinogenic and noncarcinogenic risk-based concentration were calculated and the more restrictive value was used as the risk-based PPRG. The risk-based equations for radiological effects were used to calculate the risk-based PPRGs for the 12 radionuclides.

The risk-based PPRG equations include all of the exposure pathways (e.g., Direct Ingestion of Soils) listed in Table 1 for each exposure scenario/environmental media combination; separate risk-based PPRGs were not be calculated for each exposure pathway. When available, USEPA-specified default values were used to calculate the risk-based PPRGs. In the absence of USEPA guidance on specific parameters, site-specific default values were established based on previous DOE reports on specific operable units.

4.1 Surface Soils

Exposure pathways, equations, assumptions, and default values used to calculate the surface soil risk-based PPRGs for each receptor scenario are presented in this section. The receptors considered include residential use, office worker, and ecological researcher. The risk-based equations for all receptors included the following exposure pathways:

- Direct ingestion of soils contaminated with organic and inorganic (including radionuclides) contaminants;
- Inhalation of non-volatile organic and inorganic (including radionuclides) particulates; and
- External radiation exposure due to radionuclide contaminants.

4.1.1 Residential Exposure

For the residential exposure to surface soil, a combined adult and child exposure was assessed for the soil ingestion pathway. All other pathways were based on an adult exposure only.

The equations and assumptions used to derive risk-based PPRGs for surface soils with carcinogenic COCs are shown on Table 2, and the corresponding equation for COCs with noncarcinogenic effects is shown on Table 3. Table 4 shows the equation used to calculate risk-based PPRGs for radionuclides. All default values were based on USEPA guidance.

4.1.2 Commercial/Industrial Exposure

For the commercial/industrial exposure to surface soils, an office worker receptor was assessed. The equations and assumptions used to derive the risk-based PPRGs for surface soils are shown on Table 5 for COCs with carcinogenic effects, on Table 6 for COCs with noncarcinogenic effects, and on Table 7 for radionuclides. All default values were based on USEPA guidance.

4.1.3 Ecological Researcher Exposure

The risk-based PPRG equations and assumptions for exposure of an ecological researcher to surface soils are shown on Tables 8, 9, and 10 for potential carcinogens, noncarcinogens, and radionuclides, respectively. Because the ecological researcher is a site-specific receptor, site-specific exposure assumptions were developed. Specifically, the exposure frequency and duration were based on site-specific information. Other exposure assumptions were based on USEPA guidance pertaining to a commercial/industrial land use scenario.

4.2 Subsurface Soils

This section presents the exposure pathways, equations, assumptions, and default values used to calculate the subsurface soil risk-based PPRGs. Only a construction worker scenario was considered for this environmental media and the risk-based PPRGs were based on the following exposure pathways:

- Direct ingestion of soils contaminated with organic and inorganic (including radionuclides) contaminants;
- Inhalation of non-volatile organic and inorganic (including radionuclides) particulates;
- External radiation exposure due to radionuclide contaminants; and
- Inhalation of volatiles.

TABLE 2
SURFACE SOIL - RESIDENTIAL USE
CARCINOGENIC EFFECTS

$$PPRG_1 = \frac{TR \times AT \times 365 \text{ days/year}}{EF \times \left[(SFi \times IRa \times ED \times \frac{1}{BW} \times \frac{1}{PEF}) + (SFo \times 10^{-6} \text{ kg/mg} \times IF) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁	Risk-based PPRG for surface soil based on residential use (mg/kg)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
AT	averaging time (years)	70 years
EF	exposure frequency (days/year)	350 days/year
SFi	inhalation cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRa	daily inhalation rate (m ³ /day)	20 m ³ /day
ED	exposure duration (years)	30 years
BW	adult body weight (kg)	70 kg
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
SFo	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IF	age-adjusted soil ingestion factor (mg-yr/kg-day)	114 mg-yr/kg-day

Source: USEPA, 1991.

Note: Inhalation of particulates does not apply to volatile organics (i.e., Henry's Law Constant greater than 1x10⁵ atm-m³/mole and a molecular weight less than 200 g/mole).

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TABLE 3
SURFACE SOIL - RESIDENTIAL USE
NONCARCINOGENIC EFFECTS

$$PPRG_2 = \frac{THI \times AT \times 365 \text{ days/year}}{EF \times \left[(ED \times IRa \times \frac{1}{RfDi} \times \frac{1}{BW} \times \frac{1}{PEF}) + (\frac{1}{RfDo} \times 10^{-6} \text{ kg/mg} \times IF) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₂	Risk-based PPRG for surface soil based on residential use (mg/kg)	-
THI	target hazard index (unitless)	1
AT	averaging time (years)	30 years
EF	exposure frequency (days/year)	350 days/year
ED	exposure duration (years)	30 years
IRa	daily inhalation rate (m ³ /day)	20 m ³ /day
RfDi	inhalation chronic reference dose (mg/kg-day)	COC-Specific
BW	adult body weight (kg)	70 kg
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
RfDo	oral chronic reference dose (mg/kg-day)	COC-Specific
IF	age-adjusted soil ingestion rate (mg-yr/kg-day)	114 mg-yr/kg-day

Source: USEPA, 1991.

Note: Inhalation of particulates does not apply to volatile organics (i.e., Henry's Law Constant greater than 1x10⁵ atm-m³/mole and a molecular weight less than 200 g/mole).

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TABLE 4
SURFACE SOIL - RESIDENTIAL USE
RADIOLOGICAL EFFECTS

$$PPRG_3 = \frac{TR}{\left(EF \times IRa \times ED \times SFi \times 10^3 \text{ g/kg} \times \frac{1}{PEF} \right) + \left(EF \times SFo \times 10^{-3} \text{ g/mg} \times IF \right) + \left(SFe \times ED \times (1 - Se) \times Te \right)}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₃	Risk-based PPRG for surface soil based on residential use (pCi/g)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
EF	exposure frequency (days/year)	350 days/year
IRa	daily indoor inhalation rate (m ³ /day)	20 m ³ /day
ED	exposure duration (years)	30 years
SFi	inhalation cancer slope factor (risk/pCi)	COC-Specific
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
SFo	oral cancer slope factor (risk/pCi)	COC-Specific
IF	age-adjusted soil ingestion factor (mg-yr/day)	3600 mg-yr/day
SFe	external exposure slope factor (risk/yr per pCi/g)	COC-Specific
Se	gamma shielding factor (unitless)	0.2
Te	gamma exposure factor (unitless)	1

Source: USEPA, 1991; USEPA, 1993b.

TABLE 5
SURFACE SOIL - OFFICE WORKER
CARCINOGENIC EFFECTS

$$PPRG_4 = \frac{TR \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times \left[(SFi \times IRa \times \frac{1}{PEF}) + (SFo \times 10^{-6} \text{ kg/mg} \times IRs) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₄	Risk-based PPRG for surface soil based on office worker use (mg/kg)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	70 years
EF	exposure frequency (days/year)	250 days/year
ED	exposure duration (years)	25 years
SFi	inhalation cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRa	workday inhalation rate (m ³ /day)	6.64 m ³ /day ^{a/}
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
SFo	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRs	workday ingestion rate (mg/day)	50 mg/day

Source: USEPA, 1989; USEPA, 1991.

^{a/} Based on a total inhalation rate of 20 m³/day adjusted for an 8-hour workday.

Note: Inhalation of particulates does not apply to volatile organics (i.e., Henry's Law Constant greater than 1x10⁻⁵ atm-m³/mole and a molecular weight less than 200 g/mole).

TABLE 6
SURFACE SOIL - OFFICE WORKER
NONCARCINOGENIC EFFECTS

$$PPRG_5 = \frac{THI \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times \left[(IRa \times \frac{1}{RfDi} \times \frac{1}{PEF}) + (\frac{1}{RfDo} \times 10^{-6} \text{ kg/mg} \times IRs) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₅	Risk-based PPRG for surface soil based on office worker use (mg/kg)	-
THI	target hazard index (unitless)	1
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	25 years
EF	exposure frequency (days/year)	250 days/year
ED	exposure duration (years)	25 years
IRa	workday inhalation rate (m ³ /day)	6.64 m ³ /day ^{a/}
RfDi	inhalation chronic reference dose (mg/kg-day)	COC-Specific
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
RfDo	oral chronic reference dose (mg/kg-day)	COC-Specific
IRs	workday ingestion rate (mg/day)	50 mg/day

Source: USEPA, 1989; USEPA, 1991.

^{a/} Based on a total inhalation rate of 20 m³/day adjusted for an 8-hour workday.

Note: Inhalation of particulates does not apply to volatile organics (i.e., Henry's Law Constant greater than 1x10⁵ atm-m³/mole and molecular weight less than 200 g/mole.)

TABLE 7
SURFACE SOIL - OFFICE WORKER
RADIOLOGICAL EFFECTS

$$PPRG_6 = \frac{TR}{ED \times \left[(EF \times IRa \times SFi \times 10^3 \text{ g/kg} \times \frac{1}{PEF}) + (EF \times SFo \times 10^{-3} \text{ g/mg} \times IRs) + (SFe \times (1 - Se) \times Te) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₆	Risk-based PPRG for surface soil based on office worker use (pCi/g)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
ED	exposure duration (years)	25 years
EF	exposure frequency (days/year)	250 days/year
IRa	workday inhalation rate (m ³ /day)	6.64 m ³ /day ^{a/}
SFi	inhalation cancer slope factor (risk/pCi)	COC-Specific
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
SFo	oral cancer slope factor (risk/pCi)	COC-Specific
IRs	workday ingestion rate (mg/day)	50 mg/day
SFe	external exposure slope factor (risk/yr per pCi/g)	COC-Specific
Se	gamma shielding factor (unitless)	0.2
Te	gamma exposure factor (unitless)	0.3

Source: USEPA, 1989; USEPA, 1991.

^{a/} Based on a total inhalation rate of 20 m³/day adjusted for an 8-hour workday.

TABLE 8
SURFACE SOIL - ECOLOGICAL RESEARCHER
CARCINOGENIC EFFECTS

$$PPRG_7 = \frac{TR \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times \left[(SFi \times IRa \times \frac{1}{PEF}) + (SFo \times 10^{-6} \text{ kg/mg} \times IRs) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₇	Risk-based PPRG for surface soil based on ecological researcher use (mg/kg)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	70 years
EF	exposure frequency (days/year)	65 days/year ^{b/}
ED	exposure duration (years)	2.5 years ^{b/}
SFi	inhalation cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRa	workday inhalation rate (m ³ /day)	6.64 m ³ /day ^{a/}
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
SFo	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRs	workday ingestion rate (mg/day)	50 mg/day

Source: USEPA, 1991; DOE, 1993b, DOE, 1993c, DOE, 1993d.

^{a/} Based on a total inhalation rate of 20 m³/day adjusted for an 8-hour workday.

^{b/} Site-specific exposure factors for Rocky Flats Plant.

Note: Inhalation of particulates does not apply to volatile organics (i.e., Henry's Law Constant greater than 1x10⁵ atm-m³/mole and a molecular weight less than 200 g/mole).

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TABLE 9
SURFACE SOIL - ECOLOGICAL RESEARCHER
NONCARCINOGENIC EFFECTS

$$PPRG_8 = \frac{THI \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times \left[(IRa \times \frac{1}{RfDi} \times \frac{1}{PEF}) + (\frac{1}{RfDo} \times 10^{-6} \text{ kg/mg} \times IRs) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₈	Risk-based PPRG for surface soil based on ecological researcher use (mg/kg)	-
THI	target hazard index (unitless)	1
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	2.5 years
EF	exposure frequency (days/year)	65 days/year ^{b/}
ED	exposure duration (years)	2.5 years ^{b/}
IRa	workday inhalation rate (m ³ /day)	6.64 m ³ /day ^{a/}
RfDi	inhalation chronic reference dose (mg/kg-day)	COC-Specific
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
RfDo	oral chronic reference dose (mg/kg-day)	COC-Specific
IRs	workday ingestion rate (mg/day)	50 mg/day

Source: USEPA, 1991; DOE, 1993b; DOE, 1993c; DOE, 1993d.

^{a/} Based on a total inhalation rate of 20 m³/day adjusted for an 8-hour workday.

^{b/} Site-specific exposure factor for Rocky Flats Plant.

Note: Inhalation of particulates does not apply to volatile organics (i.e., Henry's Law Constant greater than 1x10⁵ atm-m³/mole and a molecular weight less than 200 g/mole).

TABLE 10
SURFACE SOIL - ECOLOGICAL RESEARCHER
RADIOLOGICAL EFFECTS

$$PPRG_9 = \frac{TR}{ED \times \left[(EF \times IRa \times SFi \times 10^3 \text{ g/kg} \times \frac{1}{PEF}) + (EF \times SFo \times 10^{-3} \text{ g/mg} \times IRs) + (SFe \times (1 - Se) \times Te) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₉	Risk-based PPRG for surface soil based on ecological researcher use (pCi/g)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
ED	exposure duration (years)	2.5 years ^{b/}
EF	exposure frequency (days/year)	65 days/year ^{b/}
IRa	workday inhalation rate (m ³ /day)	6.64 m ³ /day ^{a/}
SFi	inhalation cancer slope factor (risk/pCi)	COC-Specific
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
SFo	oral cancer slope factor (risk/pCi)	COC-Specific
IRs	workday ingestion rate (mg/day)	50 mg/day
SFe	external exposure slope factor (risk/yr per pCi/g)	COC-Specific
Se	gamma shielding factor (unitless)	0.2
Te	gamma exposure factor (unitless)	0.3

Source: USEPA, 1991; USEPA, 1993b; DOE, 1993b; DOE, 1993c; DOE, 1993d.

^{a/} Based on a total inhalation rate of 20 m³/day adjusted for an 8-hour workday.

^{b/} Site-specific exposure factor for Rocky Flats Plant.

4.2.1 Residential Exposure

A scenario involving residential exposure to subsurface soils was not considered to be credible and was therefore not included in the calculation of risk-based PPRGs.

4.2.2 Commercial/Industrial Exposure

The risk-based PPRG equations and assumptions are shown on Tables 11, 12, and 13 for potential carcinogens, noncarcinogens, and radionuclides, respectively. USEPA guidance does not specify exposure assumptions specific to a construction worker receptor. Therefore, site-specific information was used to develop assumptions for exposure frequency and exposure duration. All other exposure assumptions were based on USEPA guidance for a commercial/industrial land use scenario.

For the pathway involving inhalation of volatiles, a volatilization factor was calculated according to USEPA guidance as shown in Table 14. The volatilization model is applicable only if the soil concentration is at or below soil saturation. Thus, for those compounds for which the risk-based PPRG exceeds the soil saturation limit, the risk-based PPRG is set at the soil saturation limit. The soil saturation was calculated as shown on Table 15.

4.2.3 Ecological Researcher Exposure

The likelihood of having an ecological researcher exposed to subsurface soils was not considered to be credible and was therefore not included in the calculation of risk-based PPRGs.

4.3 Ground Water

This section presents the exposure pathways, equations, assumptions, and default values used to calculate the ground water risk-based PPRGs. Residential use of the ground water was the only receptor considered. The risk-based equations included the following exposure pathways:

- Direct ingestion of ground water contaminated with organic and inorganic (including radionuclides) contaminants; and
- Inhalation of volatile organics during domestic use.

4.3.1 Residential Exposure

The equations and assumptions used to derive risk-based PPRGs for residential use of ground water are shown on Table 16 for carcinogens, Table 17 for noncarcinogens, and Table 18 for radionuclides. All default exposure assumptions were based on USEPA guidance.

TABLE 11
SUBSURFACE SOIL - CONSTRUCTION WORKER
CARCINOGENIC EFFECTS

$$PPRG_{10} = \frac{TR \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times \left[(SFi \times IRa \times \left(\frac{1}{PEF} + \frac{1}{VF} \right)) + (SFo \times 10^{-6} \text{ kg/mg} \times IRs) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₀	Risk-based PPRG for subsurface soil based on construction worker use (mg/kg)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	70 years
EF	exposure frequency (days/year)	30 days/year ^{b/}
ED	exposure duration (years)	1 year ^{b/}
SFi	inhalation cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRa	workday inhalation rate (m ³ /day)	10 m ³ /day ^{a/}
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
VF	soil-to-air volatilization factor (m ³ /kg)	COC-Specific (See Table 14)
SFo	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRs	workday ingestion rate (mg/day)	480 mg/day

Source: USEPA, 1991; DOE, 1991; DOE, 1993a; DOE, 1993b; DOE, 1993c; DOE, 1993d.

^{a/} Based on an hourly inhalation rate of 1.25 m³/hour over an 8-hour workday.

^{b/} Site-specific exposure factor for Rocky Flats Plant.

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TABLE 12
SUBSURFACE SOIL - CONSTRUCTION WORKER
NONCARCINOGENIC EFFECTS

$$PPRG_{11} = \frac{THI \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times \left[(IRa \times \frac{1}{RfDi} \times (\frac{1}{PEF} + \frac{1}{VF})) + (\frac{1}{RfDo} \times 10^{-6} \text{ kg/mg} \times IRs) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₁	Risk-based PPRG for subsurface soil based on construction worker use (mg/kg)	-
THI	target hazard index (unitless)	1
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	1 year
EF	exposure frequency (days/year)	30 days/year ^{b/}
ED	exposure duration (years)	1 year ^{b/}
IRa	workday inhalation rate (m ³ /day)	10 m ³ /day ^{a/}
RfDi	inhalation chronic reference dose (mg/kg-day)	COC-Specific
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
VF	soil-to-air volatilization factor (m ³ /kg)	COC-Specific (See Table 14)
RfDo	oral chronic reference dose (mg/kg-day)	COC-Specific
IRs	workday ingestion rate (mg/day)	480 mg/day

Source: USEPA, 1991; DOE, 1991; DOE, 1993a; DOE, 1993b; DOE, 1993c; DOE, 1993d.

^{a/} Based on an hourly inhalation rate of 1.25 m³/hour over an 8-hour workday.

^{b/} Site-specific exposure factor for Rocky Flats Plant.

TABLE 13
SUBSURFACE SOIL - CONSTRUCTION WORKER
RADIOLOGICAL EFFECTS

$$PPRG_{12} = \frac{TR}{ED \times \left[(EF \times IRa \times SFi \times 10^3 \text{ g/kg} \times \frac{1}{PEF}) + (EF \times SFo \times 10^{-3} \text{ g/mg} \times IRs) + (SFe \times (1-Se) \times Te) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₂	Risk-based PPRG for subsurface soil based on construction worker use (pCi/g)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
ED	exposure duration (years)	1 year ^{b/}
EF	exposure frequency (days/year)	30 days/year ^{b/}
IRa	workday inhalation rate (m ³ /day)	10 m ³ /day ^{a/}
SFi	inhalation cancer slope factor (risk/pCi)	COC-Specific
PEF	particulate emission factor (m ³ /kg)	4.63 x 10 ⁹ m ³ /kg
SFo	oral cancer slope factor (risk/pCi)	COC-Specific
IRs	workday ingestion rate (mg/day)	480 mg/day
SFe	external exposure slope factor (risk/yr per pCi/g)	COC-Specific
Se	gamma shielding factor (unitless)	0.2
Te	gamma exposure factor (unitless)	0.3

Source: USEPA, 1991; DOE, 1991; DOE, 1993a; DOE, 1993b; DOE, 1993c; DOE, 1993d.

^{a/} Based on an hourly inhalation rate of 1.25 m³/hour over an 8-hour workday.

^{b/} Site-specific exposure factor for Rocky Flats Plant.

TABLE 14
SUBSURFACE SOIL - CONSTRUCTION WORKER
VOLATILIZATION FACTOR

$$VF = \frac{(LS \times V \times DH)}{A} \times \frac{(3.14 \times \alpha \times T)^{1/2}}{2 \times D_{ei} \times P_a \times K_{as}}$$

where,

$$\alpha = \frac{D_{ei} \times P_a}{P_a + \frac{(\rho_s)(1 - P_a)}{K_{as}}}$$

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
VF	volatilization factor (m ³ /kg)	--
LS	length of side area (m)	45
V	wind speed in mixing zone (m/s)	2
DH	diffusion height (m)	2
A	area of contamination (cm ²)	20,250,000
D _{ei}	effective diffusivity (cm ² /s)	D _i x (P _a ^{3.33} /P _t ²)
P _a	air-filled soil porosity (unitless)	P _t - Θβ
P _t	total soil porosity (unitless)	1-(β/ρ _s)
Θ	soil moisture content (cm ³ /water/g-soil)	10% or 0.1
β	soil bulk density (g/cm ³)	1.5
ρ _s	true soil density or particle density (g/cm ³)	2.65
K _{as}	soil-air partition coefficient (g-soil/cm ³ -air)	(H/K _d) x 41, (41 is a conversion factor)
T	exposure interval (s)	7.9 x 10 ⁸
D _i	diffusivity in air (cm ² /s)	COC-specific
H	Henry's Law constant (atm-m ³ /mole)	COC-specific
K _d	soil-water partition coefficient (cm ³ /g)	K _{oc} x OC
K _{oc}	organic carbon partition coefficient (cm ³)	COC-specific
OC	organic carbon content of soil (fraction)	2% or 0.02

Source: Dinan, 1992.

TABLE 15
SUBSURFACE SOIL - CONSTRUCTION WORKER
VOLATILIZATION FACTOR - SATURATED CONDITIONS

$$C_{sat} = \frac{(K_d \times C_w \times \beta) + (C_w \times P_w) + (C_w \times H^1 \times P_a)}{\beta}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
C_{sat}	soil saturation concentration (mg/kg)	--
K_d	soil-water partition coefficient (L/kg)	$K_{oc} \times OC$
K_{oc}	organic carbon partition coefficient (L/kg)	2% or 0.02
OC	organic carbon content of soil fraction	COC-specific
C_w	upper-limit of free moisture in soil (mg/L water)	$S \times \Theta_m$
Θ_m	soil moisture content (kg-water/kg-soil)	10% or 0.1
S	solubility in water (mg/L water)	COC-specific
β	soil bulk density (kg/L)	1.5
P_w	water filled soil porosity (unitless)	$P_t - P_a$
P_a	air-filled soil porosity (unitless)	$P_t - \Theta\beta$
Θ	soil moisture content (L water/kg soil)	10% or 0.1
P_t	total soil porosity (unitless)	$1 - (B/\rho_s)$
ρ_s	true soil density or particle density (kg/L)	2.65
H^1	Henry's Law constant (unitless)	$H \times 41$, (41 is a conversion factor)
H	Henry's Law constant (atm-m ³ /mole)	COC-specific

Source: Dinan, 1992.

TABLE 16
GROUND WATER - RESIDENTIAL USE
CARCINOGENIC EFFECTS

$$PPRG_{13} = \frac{TR \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times [(SFi \times IRa \times K) + (SFo \times IRw)]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₃	Risk-based PPRG for ground water based on residential use (mg/L)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	70 years
EF	exposure frequency (days/year)	350 days/year
ED	exposure duration (years)	30 years
SFi	inhalation cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRa	daily indoor inhalation rate (m ³ /day)	15 m ³ /day
K	volatilization factor (L/m ³)	0.0005 x 1000 L/m ³
SFo	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
IRw	daily water ingestion rate (L/day)	2 L/day

Source: USEPA, 1991.

Note: Inhalation component applies only to volatile organics (i.e., Henry's Law Constant greater than 1x10⁻⁵ atm-m³/mole and molecular weight less than 200 g/mole.)

TABLE 17
GROUND WATER - RESIDENTIAL USE
NONCARCINOGENIC EFFECTS

$$PPRG_{14} = \frac{THI \times BW \times AT \times 365 \text{ days/year}}{EF \times ED \times \left[(IRa \times \frac{1}{RfDi} \times K) + (\frac{1}{RfDo} \times IRw) \right]}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₄	Risk-based PPRG for ground water based on residential use (mg/L)	-
THI	target hazard index (unitless)	1
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	30 years
EF	exposure frequency (days/year)	350 days/year
ED	exposure duration (years)	30 years
IRa	daily indoor inhalation rate (m ³ /day)	15 m ³ /day
RfDi	inhalation chronic reference dose (mg/kg-day)	COC-Specific
K	volatilization factor (L/m ³)	0.0005 x 1000 L/m ³
RfDo	oral chronic reference dose (mg/kg-day)	COC-Specific
IRw	daily water ingestion rate (L/day)	2 L/day

Source: USEPA, 1991.

Note: Inhalation component applies only to volatile organics (i.e., Henry's Law Constant greater than 1x10⁵ atm-m³/mole and molecular weight less than 200 g/mole.)

TABLE 18
GROUND WATER - RESIDENTIAL USE
RADIOLOGICAL EFFECTS

$$PPRG_{15} = \frac{TR}{EF \times ED \times (SF_o \times IR_w)}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₅	Risk-based PPRG for ground water based on residential use (pCi/L)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
EF	exposure frequency (days/year)	350 days/year
ED	exposure duration (years)	30 years
SF _o	oral cancer slope factor (risk/pCi)	COC-Specific
IR _w	daily water ingestion rate (L/day)	2 L/day

Source: USEPA, 1991.

4.3.2 Commercial/Industrial Exposure

A scenario involving commercial/industrial exposure to ground water was not considered to be credible and was therefore not included in the calculation of risk-based PPRGs.

4.3.3 Ecological Researcher Exposure

A scenario involving exposure of an ecological researcher to ground water was not considered to be credible and was therefore not included in the calculation of risk-based PPRGs.

4.4 Surface Water

This section presents the exposure pathways, equations, assumptions, and default values used to calculate the surface water risk-based PPRGs for each receptor scenario. The receptors considered include residential use and ecological researcher. The risk-based equations for the residential receptor were based on exposure via swimming, while the risk-based equations for the ecological researcher were based on exposure via wading. For both receptors, the exposure pathways included direct ingestion of surface water.

4.4.1 Residential Exposure

The equations and assumptions used to derive risk-based PPRGs for residential exposure to surface water while swimming are shown on Tables 19 through 21 for carcinogens, noncarcinogens, and radionuclides, respectively. All assumptions were based on USEPA guidance.

4.4.2 Commercial/Industrial Exposure

The likelihood of having a commercial/industrial exposure to surface water was not considered to be credible and was therefore not included in the calculation of risk-based PPRGs.

4.4.3 Ecological Researcher Exposure

The risk-based PPRG equations and assumptions for exposure of an ecological researcher to surface water while wading are shown on Tables 22 through 24 for carcinogens, noncarcinogens, and radionuclides, respectively. USEPA guidance does not provide default values specific to this receptor. Therefore, site-specific information was used to determine exposure frequency and duration. All other exposure assumptions were based on USEPA guidance for swimming.

TABLE 19
SURFACE WATER - RESIDENTIAL USE
CARCINOGENIC EFFECTS

$$PPRG_{16} = \frac{TR \times BW \times AT \times 365 \text{ days/year}}{CR_w \times ET \times EF \times ED \times SF_o}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₆	Risk-based PPRG for surface water based on residential use (mg/L)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
SF _o	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	70 years
EF	exposure frequency (days/year)	7 days/year
ED	exposure duration (years)	30 years
CR _w	contact rate (L/hour)	0.05 L/hour
ET	exposure time (hours/day)	2.6 hours/day

Source: USEPA, 1989.

TABLE 20
SURFACE WATER - RESIDENTIAL USE
NONCARCINOGENIC EFFECTS

$$PPRG_{17} = \frac{THI \times BW \times AT \times 365 \text{ days/year} \times RfDo}{CRw \times ET \times EF \times ED}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₇	Risk-based PPRG for surface water based on residential use (mg/L)	-
THI	target hazard index (unitless)	1
RfDo	oral chronic reference dose (mg/kg-day)	COC-Specific
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	30 years
EF	exposure frequency (days/year)	7 days/year
ED	exposure duration (years)	30 years
CRw	contact rate (L/hour)	0.05 L/hour
ET	exposure time (hours/day)	2.6 hours/day

Source: USEPA, 1989.

TABLE 21
SURFACE WATER - RESIDENTIAL USE
RADIOLOGICAL EFFECTS

$$PPRG_{18} = \frac{TR}{SFO \times EF \times ED \times CRw \times ET}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₈	Risk-based PPRG for surface water based on residential use (pCi/L)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
SFO	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
EF	exposure frequency (days/year)	7 days/year
ED	exposure duration (years)	30 years
CRw	contact rate (L/hour)	0.05 L/hour
ET	exposure time (hours/day)	2.6 hours/day

Source: USEPA, 1989; USEPA, 1991.

TABLE 22
SURFACE WATER - ECOLOGICAL RESEARCHER
CARCINOGENIC EFFECTS

$$PPRG_{19} = \frac{TR \times BW \times AT \times 365 \text{ days/year}}{IRw \times EF \times ED \times SFo}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₁₉	Risk-based PPRG for surface water based on ecological researcher use (mg/L)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
SF _o	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	70 years
EF	exposure frequency (events/year)	7 events/year ^{a/}
ED	exposure duration (years)	2.5 years ^{a/}
IRw	ingestion rate (L/event)	0.05 L/event

Source: USEPA, 1989; DOE, 1993c; DOE, 1993d.

^{a/} Site-specific exposure factor for Rocky Flats Plant.

TABLE 23
SURFACE WATER - ECOLOGICAL RESEARCHER
NONCARCINOGENIC EFFECTS

$$PPRG_{20} = \frac{THI \times BW \times AT \times 365 \text{ days/year} \times RfDo}{IRw \times EF \times ED}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₂₀	Risk-based PPRG for surface water based on ecological researcher use (mg/L)	-
THI	target hazard index (unitless)	1
RfDo	oral chronic reference dose (mg/kg-day)	COC-Specific
BW	adult body weight (kg)	70 kg
AT	averaging time (years)	2.5 years
EF	exposure frequency (events/year)	7 events/year ^{w/}
ED	exposure duration (years)	2.5 years ^{w/}
IRw	ingestion rate (L/event)	0.05 L/event

Source: USEPA, 1989; DOE, 1993c; DOE, 1993d.

^{w/} Site-specific exposure factor for Rocky Flats Plant.

TABLE 24
SURFACE WATER - ECOLOGICAL RESEARCHER
RADIOLOGICAL EFFECTS

$$PPRG_{21} = \frac{TR}{SFO \times EF \times ED \times IRw}$$

where:

<u>Variable</u>	<u>Explanation (Units)</u>	<u>Default Value</u>
PPRG ₂₁	Risk-based PPRG for surface water based on ecological researcher use (pCi/L)	-
TR	target excess lifetime cancer risk (unitless)	10 ⁻⁶
SFO	oral cancer slope factor (mg/kg-day) ⁻¹	COC-Specific
EF	exposure frequency (events/year)	7 events/year ^{a/}
ED	exposure duration (years)	2.5 years ^{a/}
IRw	ingestion rate (L/event)	0.05 L/event

Source: USEPA, 1991; DOE, 1993c; DOE, 1993d.

^{a/} Site-specific exposure factor for Rocky Flats Plant.

5.0 CONTAMINANT TOXICITY INFORMATION

The COC-specific toxicology values used for the calculation of the risk-based PPRGs are presented in Table 25. The toxicity information used to calculate the risk-based PPRGs included the slope factor and unit risk for evaluating carcinogenic effects and the reference dose (RfD) and the reference concentration (RfC) for evaluating noncarcinogenic effects. Toxicity values were obtained from the latest information contained on the Integrated Risk Information System (IRIS). If values were not available from IRIS, the *Health Effects Assessment Summary Tables Annual Update*, (USEPA 1994a) was consulted. Values for polycyclic aromatic hydrocarbons were calculated using USEPA guidance entitled *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons* (USEPA 1993c).

6.0 RISK-BASED PROGRAMMATIC PRELIMINARY REMEDIATION GOALS

For each potential COC, the calculated risk-based PPRG for the exposure scenario (i.e., receptor and environmental media combination identified on Table 1) are given on Table 26. Where a chemical has both carcinogenic and noncarcinogenic effects, the more stringent of the calculated risk-based levels was selected as the risk-based PPRG. The calculated risk-based PPRGs are generally pertinent to all of the OUs should the contaminant be identified as an OU-specific COC. However, OU-specific factors may disqualify some or all of the risk-based PPRGs should these factors preclude one or more of the exposure pathways which formed the basis of the risk-based equations. For example, the risk-based PPRGs for the ground water media may not be applicable at OUs where the ground water is not of sufficient quantity or quality to support domestic residential use. Also, residential use risk-based PPRGs may not be appropriate for areas where the future land use will be solely devoted to commercial and/or industrial facilities.

As stated early, the programmatic risk-based PRGs presented in Table 26 are not intended to be the final cleanup standards listed in the ROD. Other factors such as, but not limited to, background contaminant concentrations, results of the OU-specific BRA, technology limitations, detection methods, chemical-specific ARARs, cost-benefit evaluations, worker safety, and ecological effects will need to be considered when establishing the final cleanup standards. The risk-based PPRGs are to be used as a standardized set of limits to enable screening of potential remedial technologies and alternatives. As additional information is obtained through the RFI/RI and CMS/FS processes, it may be determined that the risk-based PPRGs are not representative of the actual risk posed by the contamination at the OU. If this situation occurs, the required changes will be incorporated as soon as possible during the Development and Screening of Alternatives or Detailed Analysis of Alternatives.

TABLE 25
COC--Specific Toxicity Values*

Target Analyte List Chemical	Oral RfD (mg/kg-day)	Oral Slope Factor (mg/kg-day) ⁻¹	Inhalation RfD (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	External Slope Factor (risk/yr per pCi/g)	Henry's Law Constant (atm-m ³ /mol)	Koc (ml/g)	Water Solubility (mg/L)	Diffusivity
Acenaphthene#	6.00E-02	-	-	-	-	9.20E-05 k	4600 k	3.42E+00 k	
Acenaphthylene#	-	-	-	-	-	1.48E-03 k	2500 k	3.93E+00 k	
Acetone#	1.00E-01	-	-	-	-	2.06E-05 k	2.2 k	1.00E+06 k	0.1093 l
Aldrin	3.00E-05	1.70E+01	-	1.70E+01 b	-	1.60E-05 k	96000 k		
Aluminum	-	-	-	-	-	-			
Anthracene#	3.00E-01	-	-	-	-	1.02E-03 k	14000 k	4.50E-02 k	
Antimony	4.00E-04	-	-	-	-	-			
Aroclor-1016	7.00E-05	-	-	-	-	1.07E-03 k	530000 k		0.05571
Aroclor-1221	-	7.70E+00	-	-	-	1.07E-03 k	530000 k		0.05571
Aroclor-1232	-	7.70E+00	-	-	-	1.07E-03 k	530000 k		0.05571
Aroclor-1242	-	7.70E+00	-	-	-	1.07E-03 k	530000 k		0.05571
Aroclor-1248	-	7.70E+00 c	-	-	-	1.07E-03 k	530000 k		0.05571
Aroclor-1254	-	7.70E+00	-	-	-	1.07E-03 k	530000 k		0.05571
Aroclor-1260	-	7.70E+00	-	-	-	1.07E-03 k	530000 k		0.05571
Arsenic	3.00E-04	1.75E+00 g	-	1.51E+01	-	-			
Barium	7.00E-02	-	1.43E-04 b	-	-	-			
Benzene#	-	2.90E-02	-	2.90E-02	-	5.59E-03 k	83 k	1.75E+03 k	0.09234 l
alpha-BHC	-	6.30E+00	-	6.30E+00	-	5.87E-06 k	3800 k		
beta-BHC	-	1.80E+00	-	1.86E+00	-	4.47E-07 k	3800 k		
delta-BHC	-	-	-	-	-	2.07E-07 k	6600 k		
gamma-BHC (Lindane)	3.00E-04	1.30E+00 b	-	-	-	7.85E-06 k	1080 k		
Benzo(a)anthracene	-	7.30E-01 i	-	-	-	1.16E-06 k	1380000 k		
Benzo(a)pyrene	-	7.30E+00	-	-	-	1.55E-06 k	5500000 k		
Benzo(b)fluoranthene	-	7.30E-01 i	-	-	-	1.19E-05 k	550000 k		
Benzo(g,h,i)perylene	-	-	-	-	-	5.34E-08 k	1600000 k		
Benzo(k)fluoranthene	-	7.30E-02 i	-	-	-	3.94E-05 k	550000 k		
Benzoic Acid	4.00E+00	-	-	-	-	-			
Benzyl Alcohol	3.00E-01 b	-	-	-	-	-			
Beryllium	5.00E-03	4.30E+00	-	8.40E+00 b	-	-			
bis(2-Chloroethoxy)methane#	-	-	-	-	-	1.70E-07	7		
bis(2-Chloroethyl)ether#	-	1.10E+00	-	1.10E+00	-	1.31E-05 k	13.9 k	1.02E+04 k	
bis(2-Chloroisopropyl)ether#	4.00E-02	7.00E-02 b	-	3.50E-02 b	-	1.13E-04 k	61 k	1.70E+03 k	
bis(2-Ethylhexyl)phthalate	2.00E-02	1.40E-02	-	-	-	1.00E-04	10000		
Bromodichloromethane#	2.00E-02	6.20E-02	-	-	-	1.60E-03	53		
Bromoform#	2.00E-02	7.90E-03	-	3.90E-03	-	6.60E-04	98		0.1088 l
Bromomethane#	1.40E-03	-	1.43E-03	-	-	6.24E-03	126		
4-Bromophenyl phenyl ether	-	-	-	-	-	-			
2-Butanone#	6.00E-01	-	2.86E-01	-	-	-			0.09485 l
Butylbenzylphthalate	2.00E-01	-	-	-	-	-			
Cadmium	5.00E-04	-	-	6.30E+00	-	-			
Calcium	-	-	-	-	-	-			
Carbon disulfide#	1.00E-01	-	-	-	-	1.23E-02 k	54 k	2.94E+03 k	
Carbon tetrachloride#	7.00E-04	1.30E-01	-	5.25E-02	-	2.41E-02 k	110 k	7.57E+02 k	0.08451 l
Cesium	-	-	-	-	-	-			

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TABLE 25
COC-Specific Toxicity Values*

Target Analyte List Chemical	Oral RfD (mg/kg-day)	Oral Slope Factor (mg/kg-day) ⁻¹	Inhalation RfD (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	External Slope Factor (risk/yr per pCi/g)	Henry's Law Constant (atm-m ³ /mol)	Koc (ml/g)	Water Solubility (mg/L)	Diffusivity
alpha-Chlordane	6.00E-05 d	1.30E+00 d	-	1.30E+00 d	-	9.63E-06 k	140000 k		
beta-Chlordane	6.00E-05 d	1.30E+00 d	-	1.30E+00 d	-	9.63E-06 k	140000 k		
gamma-Chlordane	6.00E-05 d	1.30E+00 d	-	1.30E+00 d	-	9.63E-06 k	140000 k		
4-Chloroaniline	4.00E-03	-	-	-	-	-	-		
Chlorobenzene#	2.00E-02	-	5.71E-03 b	-	-	3.72E-03 k	330 k	4.66E+02 k	0.07627 l
Chloroethane#	-	-	2.86E+00	-	-	8.48E-03	33		0.11031 l
Chloroform#	1.00E-02	6.10E-03	-	8.05E-02	-	2.87E-03 k	31 k	8.20E+03 k	0.09404 l
Chloromethane#	-	1.30E-02 b	-	6.30E-03 b	-	8.82E-02	-		0.11827 l
4-Chloro-3-methylphenol	-	-	-	-	-	-	-		
2-Chloronaphthalene#	8.00E-02	-	-	-	-	-	-		
2-Chlorophenol#	5.00E-03	-	-	-	-	1.30E-05	15		
4-Chlorophenyl phenyl ether	-	-	-	-	-	-	-		
Chromium III	1.00E+00	-	-	-	-	-	-		
Chromium VI	5.00E-03	-	-	4.20E+01	-	-	-		
Chrysene	-	7.30E-03 i	-	-	-	1.05E-06 k	200000 k		
Cobalt	-	-	-	-	-	-	-		
Copper	4.00E-02 b	-	-	-	-	-	-		
Cyanide	2.00E-02	-	-	-	-	-	-		
4,4- DDD	-	2.40E-01	-	-	-	7.96E-06 k	770000 k		
4,4- DDE	-	3.40E-01	-	-	-	6.80E-05 k	4400000 k		
4,4- DDT	5.00E-04	3.40E-01	-	3.40E-01	-	5.13E-04 k	243000 k		
Dibenz(a,h)anthracene	-	7.30E+00 i	-	-	-	7.33E-08 k	3300000 k		
Dibenzofuran	-	-	-	-	-	-	-		
Dibromochloromethane	2.00E-02	8.40E-02	-	-	-	-	-		
Di-n-butylphthalate	1.00E-01	-	-	-	-	2.82E-07 k	170000 k		
1,2-Dichlorobenzene#	9.00E-02	-	5.60E-02 b	-	-	1.93E-03 k	1700 k	1.00E+02 k	
1,3-Dichlorobenzene#	-	-	-	-	-	3.59E-03 k	1700 k	1.23E+02 k	
1,4-Dichlorobenzene#	-	2.40E-02 b	8.00E-01	-	-	2.89E-03 k	1700 k	7.90E+01 k	
3,3-Dichlorobenzidine	-	4.50E-01	-	-	-	8.33E-07 k	1553 k		
1,1-Dichloroethane#	1.00E-01 b	-	1.43E-01	-	-	4.31E-03 k	30 k	5.50E+03 k	0.09643 l
1,2-Dichloroethane#	-	9.10E-02	-	9.10E-02	-	9.78E-04 k	14 k	8.52E+03 k	0.09643 l
1,1-Dichloroethene#	9.00E-03	6.00E-01	-	1.75E-01	-	3.40E-02 k	65 k	2.25E+03 k	0.08386 l
1,2-Dichloroethene (total)#	9.00E-03 b	-	-	-	-	-	36		0.08386 l
2,4-Dichlorophenol	3.00E-03	-	-	-	-	2.75E-06 k	380 k		
1,2-Dichloropropane#	-	6.80E-02 b	1.14E-03	-	-	2.31E-03 k	51 k	2.70E+03 k	
cis-1,3-Dichloropropene#	3.00E-04	1.80E-01 b,e	5.71E-03	1.30E-01 b,e	-	2.40E-03	23		
trans-1,3-Dichloropropene#	3.00E-04	1.80E-01 b,e	5.71E-03	1.30E-01 b,e	-	1.80E-03	26		
Dieldrin	5.00E-05	1.60E+01	-	1.60E+01	-	4.58E-07 k	1700 k		
Diethylphthalate	8.00E-01	-	-	-	-	1.14E-06 k	142 k		
2,4-Dimethylphenol#	2.00E-02	-	-	-	-	6.00E-07	425		
Dimethylphthalate	1.00E+01	-	-	-	-	-	-		
4,6-Dinitro-2-methylphenol#	-	-	-	-	-	4.80E-11	225		
2,4-Dinitrophenol	2.00E-03	-	-	-	-	6.45E-10 k	16.6 k		
2,4-Dinitrotoluene	2.00E-03	-	-	-	-	5.09E-06 k	45 k		
2,6-Dinitrotoluene	1.00E-03 b	6.80E-01	-	-	-	3.27E-06 k	92 k		

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TABLE 25
COC-Specific Toxicity Values*

Target Analyte List Chemical	Oral RfD (mg/kg-day)	Oral Slope Factor (mg/kg-day) ⁻¹	Inhalation RfD (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	External Slope Factor (risk/yr per pCi/g)	Henry's Law Constant (atm-m ³ /mol)	Koc (ml/g)	Water Solubility (mg/L)	Diffusivity
Di-n-octylphthalate	2.00E-02	1.40E-02	-	-	-	-	-	-	-
Endosulfan I	6.00E-03 b,f	-	-	-	-	-	-	-	-
Endosulfan II	6.00E-03 b,f	-	-	-	-	-	-	-	-
Endosulfan sulfate	6.00E-03 b,f	-	-	-	-	-	-	-	-
Endosulfan (technical)	6.00E-03 b	-	-	-	-	-	-	-	-
Endrin ketone	-	-	-	-	-	-	-	-	-
Endrin (technical)	3.00E-04	-	-	-	-	-	-	-	-
Ethylbenzene#	1.00E-01	-	2.86E-01	-	-	6.43E-03 k	1100 k	1.52E+02 k	0.0707 l
Fluoranthene	4.00E-02	-	-	-	-	6.46E-06 k	38000 k	-	-
Fluorene#	4.00E-02	-	-	-	-	6.42E-05 k	7300 k	1.69E+00 k	-
Heptachlor	5.00E-04	4.50E+00	-	4.50E+00	-	8.19E-04 k	12000 k	-	-
Heptachlor epoxide	1.30E-05	9.10E+00	-	9.10E+00	-	4.39E-04 k	220 k	-	-
Hexachlorobenzene	8.00E-04	1.60E+00	-	1.60E+00	-	6.81E-04 k	3900 k	-	-
Hexachlorobutadiene	2.00E-04 b	7.80E-02	-	7.70E-02	-	4.57E+00 k	29000 k	-	-
Hexachlorocyclopentadiene	7.00E-03	-	2.00E-05 b	-	-	1.37E-02 k	4800 k	-	-
Hexachloroethane	1.00E-03	1.40E-02	-	1.40E-02	-	2.49E-03 k	20000 k	-	-
2-Hexanone#	-	-	-	-	-	3.39E-05	134	-	-
Indeno(1,2,3-cd)pyrene	-	7.30E-01 i	-	-	-	6.86E-08 k	1600000 k	-	-
Iron	-	-	-	-	-	-	-	-	-
Isophorone	2.00E-01	9.50E-04	-	-	-	-	-	-	-
Lead	-	-	-	-	-	-	-	-	-
Lithium	-	-	-	-	-	-	-	-	-
Magnesium	-	-	-	-	-	-	-	-	-
Manganese	5.00E-03	-	1.43E-05	-	-	-	-	-	-
Mercury	3.00E-04 b	-	8.40E-05 h	-	-	-	-	-	-
Methoxychlor	5.00E-03	-	-	-	-	-	-	-	-
Methylene chloride#	6.00E-02	7.50E-03	-	1.64E-03	-	-	48	-	-
2-Methylnaphthalene#	-	-	-	-	-	5.18E-04	8500	-	-
4-Methyl-2-pentanone#	8.00E-02 b	-	2.24E-02 h	-	-	9.40E-05	19	-	-
2-Methylphenol	5.00E-02	-	-	-	-	-	-	-	-
4-Methylphenol	-	-	-	-	-	-	-	-	-
Molybdenum	5.00E-03	-	-	-	-	-	-	-	-
Naphthalene#	-	-	-	-	-	-	594	-	-
Nickel	2.00E-02	-	-	-	-	-	-	-	-
2-Nitroaniline	-	-	-	-	-	-	-	-	-
3-Nitroaniline	-	-	-	-	-	-	-	-	-
4-Nitroaniline	-	-	-	-	-	-	-	-	-
Nitrobenzene#	5.00E-04	-	5.60E-04 h	-	-	2.20E-05	36 k	1.90E+03 k	-
2-Nitrophenol	-	-	-	-	-	-	-	-	-
4-Nitrophenol#	-	-	-	-	-	-	21	-	-
n-Nitrosodiphenylamine#	-	4.90E-03	-	-	-	6.40E-04	1200	-	-
n-Nitrosodipropylamine	-	7.00E+00	-	-	-	6.92E-06 k	15 k	9.90E+03 k	-
Pentachlorophenol	3.00E-02	1.20E-01	-	-	-	2.75E-06 k	53000 k	-	-
Phenanthrene#	-	-	-	-	-	1.59E-04 k	14000 k	1.00E+00 k	-
Phenol	6.00E-01	-	-	-	-	4.54E-07 k	14.2 k	-	0.08924 l

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TABLE 25
COC-Specific Toxicity Values*

Chemical	Oral RfD (mg/kg-day)	Oral Slope Factor (mg/kg-day) ⁻¹	Inhalation RfD (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	External Slope Factor (risk/yr per µCi/g)	Henry's Law Constant (atm-m ³ /mol)	Koc (ml/g)	Water Solubility (mg/L)	Diffusivity	Target Analyte List
Potassium	-	-	-	-	-	-	-	-	-	
Pyrene	3.00E-02	-	-	-	-	5.04E-06 k	38000 k	-	-	
Selenium	5.00E-03	-	-	-	-	-	-	-	-	
Silver	5.00E-03	-	-	-	-	-	-	-	-	
Sodium	-	-	-	-	-	-	-	-	-	
Strontium	6.00E-01	-	-	-	-	-	-	-	-	
Styrene#	2.00E-01	-	2.86E-01	-	-	5.20E-03	270	0.0746 l	-	
1,1,2,2-Tetrachloroethane#	-	2.00E-01	-	2.00E-01	-	3.81E-04 k	118 k	2.90E+03 k	-	
Tetrachloroethene#	1.00E-02	5.20E-02 l	-	-	-	2.59E-02 k	364 k	-	0.07852 l	
Thallium	-	-	-	-	-	-	-	-	-	
Tin	6.00E-01 b	-	-	-	-	-	-	-	-	
Toluene#	2.00E-01	-	1.14E-01	-	-	6.37E-03 k	300 k	5.35E+02 k	0.08301 l	
Toxaphene	-	1.10E+00	-	1.10E+00	-	4.36E-01 k	964 k	-	-	
1,2,4-Trichlorobenzene#	1.00E-02	5.60E-02 h	-	-	-	2.31E-03 k	9200 k	3.00E+01 k	-	
1,1,1-Trichloroethane#	-	-	-	-	-	1.44E-02 k	152 k	-	-	
1,1,2-Trichloroethane#	4.00E-03	5.70E-02	-	5.60E-02	-	1.17E-03 k	56 k	4.50E+03 k	-	
Trichloroethene#	-	-	-	-	-	9.10E-03 k	126 k	1.10E+03 k	0.08606 l	
2,4,5-Trichlorophenol	1.00E-01	-	-	-	-	2.18E-04 k	89 k	-	-	
2,4,6-Trichlorophenol	-	1.10E-02	-	1.00E-02	-	3.90E-06 k	2000 k	-	-	
Vanadium	7.00E-03 b	-	-	-	-	-	-	-	-	
Vinyl acetate	1.00E+00 b	5.71E-02	-	-	-	-	-	-	-	
Vinyl chloride#	-	1.90E+00 b	-	3.00E-01 b	-	8.19E-02 k	57 k	2.67E+03 k	0.11375 l	
Xylene (total)#	2.00E+00	-	-	-	-	7.04E-03 k	240 k	1.98E+02 k	0.07597 l	
Zinc	3.00E-01	-	-	-	-	-	-	-	-	
Nitrate	1.60E+00	-	-	-	-	-	-	-	-	
Nitrite	1.00E-01	-	-	-	-	-	-	-	-	
pH	-	-	-	-	-	-	-	-	-	
Sulfide	-	-	-	-	-	-	-	-	-	
Ammonium	-	-	-	-	-	-	-	-	-	
Bicarbonate	-	-	-	-	-	-	-	-	-	
Bromide	-	-	-	-	-	-	-	-	-	
Carbonate	-	-	-	-	-	-	-	-	-	
Chloride	-	-	-	-	-	-	-	-	-	
Cyanide	-	-	-	-	-	-	-	-	-	
Fluoride	6.00E-02	-	-	-	-	-	-	-	-	
Orthophosphate	-	-	-	-	-	-	-	-	-	
Silica (as Si and SiO ₂)	-	-	-	-	-	-	-	-	-	
Sulfate	-	-	-	-	-	-	-	-	-	
Americium-241	-	2.40E-10 b*	-	3.20E-08 b*	4.90E-09 b	-	-	-	-	
Cesium-137	-	2.80E-11 b*	-	1.90E-11 b*	0.00E+00 b	-	-	-	-	
Plutonium-239	-	2.30E-10 b*	-	3.80E-08 b*	1.70E-11 b	-	-	-	-	

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TABLE 25
COC-Specific Toxicity Values*

Target Analyte List Chemical	Oral RfD (mg/kg-day)	Oral Slope Factor (mg/kg-day) ⁻¹	Inhalation RfD (mg/kg-day)	Inhalation Slope Factor (mg/kg-day) ⁻¹	External Slope Factor (risk/yr per pCi/g)	Henry's Law Constant (atm-m ³ /mol)	Koc (ml/g)	Water Solubility (mg/L)	Diffusivity
Plutonium-240	-	2.30E-10 b*	-	3.80E-08 b*	2.70E-11 b				
Radium-226	-	1.20E-10 b*	-	3.00E-09 b*	1.20E-08 b				
Radium-228	-	1.00E-10 b*	-	6.60E-10 b*	0.00E+00 b				
Strontium-89	-	3.00E-12 b*	-	2.90E-12 b*	4.70E-10 b				
Strontium-90	-	3.30E-11 b*	-	5.60E-11 b*	0.00E+00 b				
Tritium	-		-						
Uranium-233	-	1.60E-11 b*	-	2.70E-08 b*	4.20E-11 b				
Uranium-234	-	1.60E-11 b*	-	2.60E-08 b*	3.00E-11 b				
Uranium-235	-	1.60E-11 b*	-	2.50E-08 b*	2.40E-07 b				
Uranium-238	-	1.60E-11 b*	-	2.40E-08 b*	2.10E-11 b				

= Chemicals listed are volatile.

* = Values given are in units of risk/pCi.

a = All toxicity values are from IRIS, October 1994 unless otherwise noted.

b = Value from HEAST, 1994.

c = Values given are for PCBs.

d = Values given are for chlordane.

e = Values given are for 1,3-dichloropropene.

f = Values given are for endosulfan.

g = Value given for arsenic is calculated from an oral unit risk of 5E-5 (L/μg).

h = Values given for chemicals were calculated from HEAST.

i = Values given for PAHs were found in the EPA guidance document "Research and Development-Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons."

j = Values given for tetrachloroethene are from a U.S. EPA memo from the Office of Research and Development Environmental Criteria and Assessment Office.

k = Values given are found in the Superfund Public Health Evaluation Manual, 1986.

l = Values given are found in the Superfund Exposure Assessment Manual, 1988.

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TABLE 26
PROGRAMMATIC PRGs FOR ROCKY FLATS PLANT

Target Analyte List Chemical	Residential Groundwater (mg/L)	Residential Surface Water Swimming (mg/L)	Residential Soil (mg/kg)	Office Worker Soil (mg/kg)	Construction Worker Subsurface Soil (mg/kg)	Wading Ecological Worker (mg/L)	Soil Ecological Worker (mg/kg)
Acenaphthene#	2.19E+00	1.68E+03	1.65E+04	1.23E+05	1.06E+05	4.38E+03	1.48E+05
Acenaphthylene#	-	-	-	-	-	-	-
Acetone#	3.65E+00	2.81E+03	2.74E+04	2.04E+05	1.77E+05	7.30E+03	2.47E+05
Aldrin	5.00E-06	3.85E-03	3.77E-02	3.36E-01	7.30E+00	1.20E-01	4.07E-01
Aluminum	-	-	-	-	-	-	-
Anthracene#	1.09E+01	8.42E+03	8.23E+04	6.13E+05	5.32E+05	2.19E+04	7.41E+05
Antimony	1.46E-02	1.12E+01	1.10E+02	8.18E+02	7.10E+02	2.92E+01	9.87E+02
Aroclor-1016	2.55E-03	1.97E+00	1.92E+01	1.43E+02	1.24E+02	5.11E+00	1.73E+02
Aroclor-1221	1.10E-05	8.51E-03	8.32E-02	7.43E-01	1.61E+01	2.65E-01	8.98E-01
Aroclor-1232	1.10E-05	8.51E-03	8.32E-02	7.43E-01	1.61E+01	2.65E-01	8.98E-01
Aroclor-1242	1.10E-05	8.51E-03	8.32E-02	7.43E-01	1.61E+01	2.65E-01	8.98E-01
Aroclor-1248	1.10E-05	8.51E-03	8.32E-02	7.43E-01	1.61E+01	2.65E-01	8.98E-01
Aroclor-1254	1.10E-05	8.51E-03	8.32E-02	7.43E-01	1.61E+01	2.65E-01	8.98E-01
Aroclor-1260	1.10E-05	8.51E-03	8.32E-02	7.43E-01	1.61E+01	2.65E-01	8.98E-01
Arsenic	4.86E-05	3.74E-02	3.66E-01	3.27E+00	7.09E+01	1.17E+00	3.95E+00
Barium	2.56E+00	1.97E+03	1.91E+04	1.41E+05	1.24E+05	5.11E+03	1.73E+05
Benzene#	6.15E-04	2.26E+00	2.21E+01	1.66E-01	2.18E+00	7.05E+01	2.38E+02
alpha-BIIC	1.35E-05	1.04E-02	1.02E-01	9.08E-01	1.97E+01	3.24E-01	1.10E+00
beta-BIIC	4.72E-05	3.64E-02	3.56E-01	3.18E+00	6.90E+01	1.14E+00	3.84E+00
delta-BIIC	-	-	-	-	-	-	-
gamma-BIIC (Lindane)	6.54E-05	5.04E-02	4.93E-01	4.40E+00	9.55E+01	1.57E+00	5.32E+00
Benzo(a)anthracene	1.16E-04	8.97E-02	8.77E-01	7.84E+00	1.70E+02	2.80E+00	9.47E+00
Benzo(a)pyrene	1.16E-05	8.97E-03	8.77E-02	7.84E-01	1.70E+01	2.80E-01	9.47E-01
Benzo(b)fluoranthene	1.16E-04	8.97E-02	8.77E-01	7.84E+00	1.70E+02	2.80E+00	9.47E+00
Benzo(g,h,i)perylene	-	-	-	-	-	-	-
Benzo(k)fluoranthene	1.16E-03	8.97E-01	8.77E+00	7.84E+01	1.70E+03	2.80E+01	9.47E+01
Benzoic Acid	1.46E+02	1.12E+05	1.10E+06	8.18E+06	7.10E+06	2.92E+05	9.87E+06
Benzyl Alcohol	1.09E+01	8.42E+03	8.23E+04	6.13E+05	5.32E+05	2.19E+04	7.41E+05
Beryllium	1.98E-05	1.52E-02	1.49E-01	1.33E+00	2.89E+01	4.75E-01	1.61E+00
bis(2-Chloroethoxy)methane#	-	-	-	-	-	-	-
bis(2-Chloroethyl)ether#	1.63E-05	5.95E-02	5.82E-01	6.29E+00	1.13E+02	1.86E+00	6.28E+00
bis(2-Chloroisopropyl)ether#	4.22E-04	9.36E-01	9.15E+00	4.00E-01	1.77E+03	2.92E+01	9.87E+01
bis(2-Ethylhexyl)phthalate	6.07E-03	4.68E+00	4.57E+01	4.09E+02	8.87E+03	1.46E+02	4.94E+02
Bromodichloromethane#	1.37E-03	1.06E+00	1.03E+01	3.55E-01	3.55E+04	3.30E+01	1.11E+02
Bromoform#	3.77E-03	8.29E+00	8.11E+01	4.52E-02	4.75E+01	2.59E+02	8.75E+02
Bromomethane#	1.09E-02	3.93E+01	3.84E+02	2.86E+03	2.48E+03	1.02E+02	3.46E+03

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TABLE 26
PROGRAMMATIC PRGS FOR ROCKY PLATS PLANT

Chemical	Residential	Residential	Residential	Office	Construction	Wading	Soil
4-Bromophenyl phenyl ether	-	-	-	-	-	-	-
2-Butanone#	2.47E+00	1.68E+04	1.65E+05	1.23E+06	1.06E+06	4.38E+04	1.48E+06
Butylbenzylphthalate	7.30E+00	5.62E+03	5.49E+04	4.09E+05	3.55E+05	1.46E+04	4.94E+05
Cadmium	1.82E-02	1.40E+01	1.37E+02	1.02E+03	8.87E+02	3.65E+01	1.23E+03
Calcium	-	-	-	-	-	-	-
Carbon disulfide#	2.76E-02	2.81E+03	2.74E+04	2.04E+05	1.77E+06	7.30E+04	2.47E+06
Carbon tetrachloride#	2.60E-04	5.04E-01	4.93E+00	4.40E+01	6.82E-01	1.57E+01	5.32E+01
Cesium	-	-	-	-	-	-	-
alpha-Chlordane	6.54E-05	5.04E-02	4.93E-01	4.40E+00	9.55E+01	1.57E+00	5.32E+00
beta-Chlordane	6.54E-05	5.04E-02	4.93E-01	4.40E+00	9.55E+01	1.57E+00	5.32E+00
Gamma-Chlordane	6.54E-05	5.04E-02	4.93E-01	4.40E+00	9.55E+01	1.57E+00	5.32E+00
4-Chloroaniline	1.46E-01	1.12E+02	1.10E+03	8.18E+03	7.10E+03	2.92E+02	9.87E+03
Chlorobenzene#	5.16E-02	5.62E+02	5.49E+03	4.09E+04	3.55E+04	1.46E+03	4.94E+04
Chloroethane#	2.78E+01	-	-	-	1.18E+03	-	-
Chloroform#	2.76E-04	1.07E+01	1.05E+02	3.49E-02	6.61E-01	3.35E+02	1.13E+03
Chloromethane#	2.32E-03	5.04E+00	4.93E+01	7.44E-02	9.55E+03	1.57E+02	5.32E+02
4-Chloro-3-methylphenol	-	-	-	-	-	-	-
2-Chloronaphthalene#	2.92E+00	2.25E+03	2.20E+04	1.64E+05	1.42E+05	5.84E+03	1.97E+05
2-Chlorophenol#	1.82E-01	1.40E+02	1.37E+03	1.02E+04	8.87E+03	3.65E+02	1.23E+04
4-Chlorophenyl phenyl ether	-	-	-	-	-	-	-
Chromium III	3.65E+01	2.81E+04	2.74E+05	2.04E+06	1.77E+06	7.30E+04	2.47E+06
Chromium VI	1.82E-01	1.40E+02	1.37E+03	4.76E+03	8.87E+03	3.65E+02	1.23E+04
Chrysene	1.16E-02	8.97E+00	8.77E+01	7.84E+02	1.70E+04	2.80E+02	9.47E+02
Cobalt	-	-	-	-	-	-	-
Copper	1.46E+00	1.12E+03	1.10E+04	8.18E+04	7.10E+04	2.92E+03	9.87E+04
Cyanide	7.30E-01	5.62E+02	5.49E+03	4.09E+04	3.55E+04	1.46E+03	4.94E+04
4,4-DDD	3.54E-04	2.73E-01	2.67E+00	2.38E+01	5.17E+02	8.52E+00	2.88E+01
4,4-DDD#	2.50E-04	1.93E-01	1.88E+00	1.68E+01	3.65E+02	6.01E+00	2.03E+01
4,4-DDT	2.50E-04	1.93E-01	1.88E+00	1.68E+01	3.65E+02	6.01E+00	2.03E+01
Dibenz(a,h)anthracene	1.16E-05	8.97E-03	8.77E-02	7.84E-01	1.70E+01	2.80E-01	9.47E-01
Dibenzofuran	-	-	-	-	-	-	-
Dibromochloromethane	1.01E-03	7.80E-01	7.62E+00	6.81E+01	1.48E+03	2.43E+01	8.23E+01
D-n-butylphthalate	3.65E+00	2.81E+03	2.74E+04	2.04E+05	1.77E+06	7.30E+03	2.47E+05
1,2-Dichlorobenzene#	4.67E-01	2.53E+03	2.47E+04	1.84E+05	1.60E+05	6.57E+03	2.22E+05
1,3-Dichlorobenzene#	-	-	-	-	-	-	-
1,4-Dichlorobenzene#	3.54E-03	2.73E+00	2.67E+01	1.37E-01	5.17E+03	8.52E+01	2.88E+02
3,3-Dichlorobenzidine	1.89E-04	1.46E-01	1.42E+00	1.27E+01	2.76E+02	4.54E+00	1.54E+01

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TABLE 26
PROGRAMMATIC PRGs FOR ROCKY FLATS PLANT

Target Analyte List Chemical	Residential Groundwater (mg/L)	Residential Surface Water Swimming (mg/L)	Residential Soil (mg/kg)	Office Worker Soil (mg/kg)	Construction Worker Subsurface Soil (mg/kg)	Wading Ecological Worker (mg/L)	Soil Ecological Worker (mg/kg)
1,1-Dichloroethane#	1.01E+00	2.81E+03	2.74E+04	2.04E+05	8.54E+01	7.30E+03	2.47E+05
1,2-Dichloroethane#	1.97E-04	7.20E-01	7.04E+00	5.21E-01	6.67E-01	2.25E+01	7.60E+01
1,1-Dichloroethene#	6.77E-05	1.09E-01	1.07E+00	3.43E+00	1.27E-01	3.41E+00	1.15E+01
1,2-Dichloroethene (total)#	3.28E-01	2.53E+02	2.47E+03	1.84E+04	1.60E+04	6.57E+02	2.22E+04
2,4-Dichlorophenol	1.10E-01	8.42E+01	8.23E+02	6.13E+03	5.32E+03	2.19E+02	7.41E+03
1,2-Dichloropropane#	1.25E-03	9.63E-01	9.42E+00	3.89E-01	1.83E+03	3.01E+01	1.02E+02
cis-1,3-Dichloropropene#	1.27E-04	3.64E-01	3.56E+00	1.03E+00	5.32E+02	1.14E+01	3.84E+01
trans-1,3-Dichloropropene#	1.27E-04	3.64E-01	3.56E+00	1.03E+00	5.32E+02	1.14E+01	3.84E+01
Dieldrin	5.31E-06	4.09E-03	4.00E-02	3.57E-01	7.76E+00	1.28E-01	4.32E-01
Diethylphthalate	2.92E+01	2.25E+04	2.20E+05	1.64E+06	1.42E+06	5.84E+04	1.97E+06
2,4-Dimethylphenol#	7.30E-01	5.62E+02	5.49E+03	4.09E+04	3.55E+04	1.46E+03	4.94E+04
Dimethylphthalate	3.65E+02	2.81E+05	2.74E+06	2.04E+07	1.77E+07	7.30E+05	2.47E+07
4,6-Dinitro-2-methylphenol#	-	-	-	-	-	-	-
2,4-Dinitrophenol	7.30E-02	5.62E+01	5.49E+02	4.09E+03	3.55E+03	1.46E+02	4.94E+03
2,4-Dinitrotoluene	7.30E-02	5.62E+01	5.49E+02	4.09E+03	3.55E+03	1.46E+02	4.94E+03
2,6-Dinitrotoluene	3.65E-02	9.63E-02	9.42E-01	8.41E+00	1.83E+02	3.01E+00	1.02E+01
Di-n-octylphthalate	7.30E-01	4.68E+00	4.57E+01	4.09E+02	8.87E+03	1.46E+02	4.94E+02
Endosulfan I	2.19E-01	1.68E+02	1.65E+03	1.23E+04	1.06E+04	4.38E+02	1.48E+04
Endosulfan II	2.19E-01	1.68E+02	1.65E+03	1.23E+04	1.06E+04	4.38E+02	1.48E+04
Endosulfan sulfate	2.19E-01	1.68E+02	1.65E+03	1.23E+04	1.06E+04	4.38E+02	1.48E+04
Endosulfan (technical)	2.19E-01	1.68E+02	1.65E+03	1.23E+04	1.06E+04	4.38E+02	1.48E+04
Endrin ketone	-	-	-	-	-	-	-
Endrin (technical)	1.09E-02	8.42E+00	8.23E+01	6.13E+02	5.32E+02	2.19E+01	7.41E+02
Ethylbenzene#	1.58E+00	2.81E+03	2.74E+04	2.04E+05	1.00E+03	7.30E+03	2.47E+05
Fluoranthene	1.46E+00	1.12E+03	1.10E+04	8.18E+04	7.10E+04	2.92E+03	9.87E+04
Fluorene#	1.46E+00	1.12E+03	1.10E+04	8.18E+04	7.10E+04	2.92E+03	9.87E+04
Heptachlor	1.89E-05	1.46E-02	1.42E-01	1.27E+00	2.76E+01	4.54E-01	1.54E+00
Heptachlor epoxide	9.34E-06	7.20E-03	7.04E-02	6.29E-01	1.36E+01	2.25E-01	7.60E-01
Hexachlorobenzene	5.31E-05	4.09E-02	4.00E-01	3.57E+00	7.76E+01	1.28E+00	4.32E+00
Hexachlorobutadiene	-	-	-	7.33E+01	3.55E+02	-	-
Hexachlorocyclopentadiene	2.56E-01	1.97E+02	1.91E+03	1.42E+04	1.24E+04	5.11E+02	1.73E+04
Hexachloroethane	6.07E-03	4.68E+00	4.57E+01	4.09E+02	1.77E+03	7.30E+01	4.94E+02
2-Hexanone#	-	-	-	-	-	-	-
Indeno(1,2,3-cd)pyrene	1.16E-04	8.97E-02	8.77E-01	7.84E+00	1.70E+02	2.80E+00	9.47E+00
Iron	-	-	-	-	-	-	-
Isophorone	8.95E-02	6.89E+01	6.74E+02	6.02E+03	1.31E+05	2.15E+03	7.28E+03
Lead	-	-	-	-	-	-	-

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TABLE 26
PROGRAMMATIC PRGS FOR ROCKY FLATS PLANT

Chemical	Target Analyte List	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/L)	(mg/L)	(mg/kg)	(mg/kg)
Lithium		-	-	-	-	-	-	-	-	-	-	-	-
Magnesium		-	-	-	-	-	-	-	-	-	-	-	-
Manganese		1.82E-01	1.40E+02	1.36E+03	1.01E+04	8.86E+03	3.65E+02	1.23E+04	1.23E+04	1.09E-02	1.82E-01	1.40E+02	1.36E+03
Mercury		1.09E-02	8.42E+00	8.23E+01	6.13E+02	5.32E+02	2.19E+01	7.41E+02	7.41E+02	1.82E-01	1.40E+02	1.36E+03	1.09E-02
Methoxychlor		1.82E-01	1.40E+02	1.37E+03	1.02E+04	8.87E+03	3.65E+02	1.23E+04	1.23E+04	6.22E-03	1.82E-01	1.40E+02	1.36E+03
Methylene chloride#		6.22E-03	8.73E+00	8.54E+01	4.29E-02	1.66E+04	2.73E+02	9.22E+02	9.22E+02	2.03E-01	1.83E+00	1.40E+03	2.25E+03
2-Methylnaphthalene#		-	-	-	-	-	-	-	-	2.20E+04	1.37E+04	1.02E+05	1.64E+05
4-Methyl-2-pentanone#		2.03E-01	2.25E+03	2.20E+04	1.64E+05	1.42E+05	5.84E+03	1.97E+05	1.97E+05	1.40E+03	1.40E+03	1.40E+03	1.40E+03
2-Methylphenol		1.83E+00	1.40E+03	1.37E+04	1.02E+05	8.87E+04	3.65E+03	1.23E+05	1.23E+05	-	-	-	-
4-Methylphenol		-	-	-	-	-	-	-	-	1.40E+02	1.37E+03	1.02E+04	1.02E+05
Molybdenum		1.82E-01	1.40E+02	1.37E+03	1.02E+04	8.87E+03	3.65E+02	1.23E+04	1.23E+04	1.40E+03	1.40E+03	1.40E+03	1.40E+03
Naphthalene#		-	-	-	-	-	-	-	-	5.62E+02	5.49E+03	4.09E+04	3.55E+04
Nickel		7.30E-01	5.62E+02	5.49E+03	4.09E+04	3.55E+04	1.46E+03	4.94E+04	4.94E+04	-	-	-	-
2-Nitroaniline		-	-	-	-	-	-	-	-	-	-	-	-
3-Nitroaniline		-	-	-	-	-	-	-	-	-	-	-	-
4-Nitroaniline		-	-	-	-	-	-	-	-	-	-	-	-
Nitrobenzene#		4.20E-03	1.40E+01	1.37E+02	1.02E+03	8.87E+02	3.65E+01	1.23E+03	1.23E+03	1.37E+03	1.37E+03	1.37E+03	1.37E+03
2-Nitrophenol		-	-	-	-	-	-	-	-	-	-	-	-
4-Nitrophenol#		-	-	-	-	-	-	-	-	-	-	-	-
n-Nitrosodiphenylamine#		1.73E-02	1.34E+01	1.31E+02	2.80E-02	2.53E+04	4.17E+02	1.41E+03	1.41E+03	9.36E-03	1.21E-05	9.36E-03	9.36E-03
n-Nitrosodipropylamine		1.21E-05	9.36E-03	9.15E-02	8.17E-01	1.77E+01	2.92E-01	9.87E-01	9.87E-01	7.08E-04	5.46E-01	5.34E+00	5.34E+00
Pentachlorophenol		7.08E-04	5.46E-01	5.34E+00	4.77E+01	1.03E+03	1.70E+01	5.76E+01	5.76E+01	-	-	-	-
Phenanthrene#		-	-	-	-	-	-	-	-	-	-	-	-
Phenol		2.19E+01	1.68E+04	1.65E+05	1.23E+06	1.06E+06	4.38E+04	1.48E+06	1.48E+06	2.19E+01	1.68E+04	1.65E+05	1.23E+06
Potassium		-	-	-	-	-	-	-	-	-	-	-	-
Pyrene		1.09E+00	8.42E+02	8.23E+03	6.13E+04	5.32E+04	2.19E+03	7.41E+04	7.41E+04	1.82E-01	1.40E+02	1.36E+03	1.09E-02
Selenium		1.82E-01	1.40E+02	1.37E+03	1.02E+04	8.87E+03	3.65E+02	1.23E+04	1.23E+04	1.82E-01	1.40E+02	1.36E+03	1.09E-02
Silver		1.82E-01	1.40E+02	1.37E+03	1.02E+04	8.87E+03	3.65E+02	1.23E+04	1.23E+04	-	-	-	-
Sodium		-	-	-	-	-	-	-	-	-	-	-	-
Strontium		2.19E+01	1.68E+04	1.65E+05	1.23E+06	1.06E+06	4.38E+04	1.48E+06	1.48E+06	2.01E+00	5.62E+03	5.49E+04	4.09E+05
Styrene#		2.01E+00	5.62E+03	5.49E+04	4.09E+05	3.54E+04	1.46E+04	4.94E+05	4.94E+05	8.95E-05	3.28E-01	3.20E+00	3.20E+00
1,1,2,2-Tetrachloroethane#		8.95E-05	3.28E-01	3.20E+00	1.14E+00	1.14E+00	1.02E+02	3.46E+01	3.46E+01	1.63E-03	1.26E+00	1.23E+01	1.23E+01
Tetrachloroethene#		1.63E-03	1.26E+00	1.23E+01	2.97E-01	1.77E+04	3.93E+01	1.33E+02	1.33E+02	-	-	-	-
Thallium		-	-	-	-	-	-	-	-	-	-	-	-
Tin		2.19E+01	1.68E+04	1.65E+05	1.23E+06	1.06E+06	4.38E+04	1.48E+06	1.48E+06	9.65E-01	5.62E+03	5.49E+04	4.09E+05
Toluene#		9.65E-01	5.62E+03	5.49E+04	4.09E+05	3.54E+04	1.46E+04	4.94E+05	4.94E+05	7.73E-05	5.95E-02	5.82E-01	5.82E-01
Toxaphene		7.73E-05	5.95E-02	5.82E-01	5.20E+00	5.20E+00	1.13E+02	6.28E+00	6.28E+00	1.86E+00	1.46E+04	1.46E+04	1.46E+04

TABLE 26
PROGRAMMATIC PRGs FOR ROCKY FLATS PLANT

Target Analyte List Chemical	Residential Groundwater (mg/L)	Residential Surface Water Swimming (mg/L)	Residential Soil (mg/kg)	Office Worker Soil (mg/kg)	Construction Worker Subsurface Soil (mg/kg)	Wading Ecological Worker (mg/L)	Soil Ecological Worker (mg/kg)
1,2,4-Trichlorobenzene#	2.19E-01	2.81E+02	2.74E+03	2.04E+04	1.77E+04	7.30E+02	2.47E+04
1,1,1-Trichloroethane#	-	-	-	-	-	-	-
1,1,2-Trichloroethane#	3.18E-04	1.15E+00	1.12E+01	3.26E-01	2.18E+03	3.59E+01	1.21E+02
Trichloroethene#	-	-	-	-	-	-	-
2,4,5-Trichlorophenol	3.65E+00	2.81E+03	2.74E+04	2.04E+05	1.77E+05	7.30E+03	2.47E+05
2,4,6-Trichlorophenol	7.73E-03	5.95E+00	5.82E+01	5.20E+02	1.13E+04	1.86E+02	6.28E+02
Vanadium	2.56E-01	1.97E+02	1.92E+03	1.43E+04	1.24E+04	5.11E+02	1.73E+04
Vinyl acetate	3.65E+01	2.81E+04	2.74E+05	2.04E+06	1.77E+06	7.30E+04	2.47E+06
Vinyl chloride#	2.81E-05	3.45E-02	3.37E-01	1.09E+01	3.46E-02	1.08E+00	3.64E+00
Xylene (total)#	7.30E+01	5.62E+04	5.49E+05	4.09E+06	3.55E+06	1.46E+05	4.94E+06
Zinc	1.09E+01	8.42E+03	8.23E+04	6.13E+05	5.32E+05	2.19E+04	7.41E+05
Nitrate	5.84E+01	4.49E+04	4.39E+05	3.27E+06	2.84E+06	1.17E+05	3.95E+06
Nitrite	3.65E+00	2.81E+03	2.74E+04	2.04E+05	1.77E+05	7.30E+03	2.47E+05
pH	-	-	-	-	-	-	-
Sulfide	-	-	-	-	-	-	-
Ammonium	-	-	-	-	-	-	-
Bicarbonate	-	-	-	-	-	-	-
Bromide	-	-	-	-	-	-	-
Carbonate	-	-	-	-	-	-	-
Chloride	-	-	-	-	-	-	-
Cyanide	-	-	-	-	-	-	-
Fluoride	2.19E+00	1.68E+03	1.65E+04	1.23E+05	1.06E+05	4.38E+03	1.48E+05
Orthophosphate	-	-	-	-	-	-	-
Silica (as Si and SiO ₂)	-	-	-	-	-	-	-
Sulfate	-	-	-	-	-	-	-
Americium-241	1.98E-01 *	1.53E+02 *	2.37E+00 **	9.55E+00 **	2.16E+02 **	4.76E+03 *	1.09E+01 **
Cesium-137	1.70E+00 *	1.31E+03 *	2.83E+01 **	1.14E+02 **	2.48E+03 **	4.08E+04 *	1.38E+02 **
Plutonium-239	2.07E-01 *	1.59E+02 *	3.43E+00 **	1.38E+01 **	3.01E+02 **	4.97E+03 *	1.67E+01 **
Plutonium-240	2.07E-01 *	1.59E+02 *	3.42E+00 **	1.38E+01 **	3.01E+02 **	4.97E+03 *	1.67E+01 **
Radium-226	3.97E-01 *	3.05E+02 *	2.28E+00 **	9.13E+00 **	2.17E+02 **	9.52E+03 *	9.70E+00 **
Radium-228	4.76E-01 *	3.66E+02 *	7.93E+00 **	3.20E+01 **	6.94E+02 **	1.14E+04 *	3.86E+01 **
Strontium-89	1.59E+01 *	1.22E+04 *	6.64E+01 **	2.66E+02 **	6.41E+03 **	3.81E+05 *	2.78E+02 **
Strontium-90	1.44E+00 *	1.11E+03 *	2.40E+01 **	9.70E+01 **	2.10E+03 **	3.46E+04 *	1.17E+02 **

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TABLE 26
PROGRAMMATIC PRGs FOR ROCKY FLATS PLANT

Target Analyte List Chemical	Residential Groundwater (mg/L)	Residential Surface Water Swimming (mg/L)	Residential Soil (mg/kg)	Office Worker Soil (mg/kg)	Construction Worker Subsurface Soil (mg/kg)	Wading Ecological Worker (mg/L)	Soil Ecological Worker (mg/kg)
Tritium	-	-	-	-	-	-	-
Uranium-233	2.98E+00 *	2.29E+03 *	4.47E+01 **	1.82E+02 **	4.13E+03 **	7.14E+04 *	2.18E+02 **
Uranium-234	2.98E+00 *	2.29E+03 *	4.53E+01 **	1.85E+02 **	4.18E+03 **	7.14E+04 *	2.22E+02 **
Uranium-235	2.98E+00 *	2.29E+03 *	1.73E-01 **	6.92E-01 **	1.73E+01 **	7.14E+04 *	6.92E-01 **
Uranium-238	2.98E+00 *	2.29E+03 *	4.60E+01 **	1.87E+02 **	4.22E+03 **	7.14E+04 *	2.25E+02 **

NOTE: PPRGs listed are the minimum of the noncarcinogenic (RfD) and the carcinogenic (SF) PRG.

= Chemicals listed are volatile.

* = Values given are in units of pCi/L.

** = Values given are in units of pCi/g.

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