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**INTEROFFICE  
MEMORANDUM**

DATE: December 12, 1995

TO: Andy Ledford, OU4 Closure, X8673

FROM: Win Chromec, Ph.D., Technical Support, X4535

SUBJECT: HUMAN HEALTH RISK ASSESSMENT FOR OPERABLE UNIT 4  
(SOLAR PONDS), 95-FWC-016



000060753

*swl*

Draft A of the Human Health Risk Assessment for Operable Unit 4 (Solar Ponds) has been completed, as enclosed for your review and distribution. The risk estimates provided in the Memorandum dated October 9, 1995 (95-FWC-014) have not changed. For Area of Concern (AOC) No. 1, the cumulative hazard indices (HIs) were below 1 and reasonable maximum exposure (RME) cancer risk estimates were below or within the EPA's target acceptable risk range of 1E-06 to 1E-04 for all receptors. The highest cancer risk was for the future office worker with an RME risk of 2E-05; however, the average or central tendency (CT) risk was below 1E-06. The cancer risks for the future construction worker were 1E-06 and were driven by potential exposures to pond liner materials. These results indicate that no adverse noncarcinogenic health hazards and acceptable cancer risks are expected for all receptors evaluated in AOC No. 1.

For AOC No. 2, the cumulative HIs were below 1 and RME cancer risk estimates were well below the EPA's target acceptable risk range of 1E-06 to 1E-04 for both receptors. These results indicate that no adverse noncarcinogenic health hazards and negligible cancer risks are expected for all receptors evaluated in AOC No. 2. Estimated annual radiation doses for onsite receptors were 10 mrem/year or less, well below the DOE standard of 100 mrem/year for protection of the public. In addition, draft results of the Ecological Risk Assessment for AOC No. 2 indicate that risks to ecological receptors from the potential chemicals of concern detected in the surface and subsurface soils in this area would be minimal.

This risk assessment was prepared and formatted as a stand-alone document. However, if required, it can be incorporated into the OU 4 Interim Measure/Interim Remedial Action Decision Document with a few editorial adjustments as either a section or an appendix.

If you have any questions concerning this risk assessment or would like further assistance in this process, please call myself at X4535 or Rotha Randall at X4977.

Enclosure

cc w/o enclosure: Rotha Randall, Technical Support  
John Hopkins, Team Leader  
Susan Evans, Remediation Manager  
ERPD Records (2 copies)

**ADMIN RECCRD**

IA-A-000566

1/181

**Human Health Risk Assessment  
Operable Unit 4  
(Solar Ponds)**

**Rocky Mountain Remediation Services, L.L.C.**

**December 1995**

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## **ABBREVIATIONS, ACRONYMS, AND INITIALISMS**

AOC	Area of Concern
CDPHE	Colorado Department of Public Health and Environment
CEDE	Committed Effective Dose Equivalent
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	Chemical of Concern
CSM	Conceptual Site Model
CT	Central Tendency
DCF	Dose Conversion Factors
DOE	Department of Energy
ECAO	Environmental Criteria and Assessment Office
EDE	Effective Dose Equivalent
EPA	Environmental Protection Agency
FSUWG	Future Site Use Working Group
FWS	Fish and Wildlife Service
HHRA	Human Health Risk Assessment
HI	Hazard Index
HQ	Hazard Quotient
IAG	Interagency Agreement
ICRP	International Commission on Radiological Protection
IHSS	Individual Hazardous Substance Site
NCRP	National Commission on Radiological Protection
OU	Operable Unit
PA	Protected Area
PAH	Polyaromatic Hydrocarbon
PCB	Polychlorinated Hydrocarbon
PCOC	Potential Chemical of Concern
PEF	Particulate Emission Factor
PM <sub>10</sub>	Particulates 10 microns or less in diameter
RBC	Risk-based Concentration
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RFETS	Rocky Flats Environmental Technologies Site
RFI/RI	RCRA Facility Investigation/Remedial Investigation
RFLII	Rocky Flats Local Impact Initiative
RME	Reasonable Maximum Exposure
SEP	Solar Evaporation Pond
SF	Slope Factor
SVOC	Semivolatile Organic Compound
UCL	Upper Confidence Level
VOC	Volatile Organic Compound

## **1.0 INTRODUCTION AND OBJECTIVES**

### **1.1 PURPOSE AND AUTHORITY**

The Human Health Risk Assessment (HHRA) is presented as part of the Phase I Resource Conservation and Recovery Act (RCRA) Facility Investigation/Remedial Investigation (RFI/RI) Report for the Solar Ponds, Operable Unit 4 (OU 4) at the U.S. Department of Energy (DOE) Rocky Flats Environmental Technology Site (RFETS) in Golden, Colorado. The HHRA is required by the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) as part of the RI process. The HHRA is intended to estimate the level of health risk to humans from potential exposures to chemicals at or released from source areas within OU 4. The estimate of health risk is used to support the determination of appropriate cleanup levels or other risk management measures in keeping with current and future land uses. Health risks are estimated for both central tendency (CT) and reasonable maximum exposure (RME) conditions, in keeping with Environmental Protection Agency (EPA) guidance (EPA, 1989a; 1992a).

The Phase I RFI/RI is being conducted pursuant to the DOE Environmental Restoration Program; a Compliance Agreement among DOE, the EPA, and the Colorado Department of Public Health and Environment (CDPHE); and the Federal Facility Agreement and Consent Order (Interagency Agreement [IAG]) signed in 1991.

### **1.2 SITE DESCRIPTION**

RFETS consists of an industrialized area of about 400 acres surrounded by an undeveloped buffer zone of 6,150 acres. OU 4 is located in the central portion of RFETS (also known as "the Site") on the northeast side of the Protected Area (PA) and consists of five dry (empty) solar evaporation ponds (SEP 207-A, SEP 207-B North, SEP-B Center, SEP-B South, and SEP 207-C) and downgradient soils both within the PA and outside of the PA fence. The total area of OU 4 is 39 acres; the Solar Ponds cover 11 acres.

The Solar Ponds were constructed primarily to store and treat low-level radioactive wastes containing high nitrates, and neutralized acidic wastes containing aluminum hydroxide. In addition, these ponds have received wastes such as sanitary sewage sludge, lithium metal, sodium nitrate, ferric chloride, lithium chloride, sulfuric acid, ammonium persulfates, hydrochloric acid, nitric acid, hexavalent chromium, and cyanide solutions. A detailed description of the site location and general condition of the ponds is included in Sections 1.0 and 3.0 of the Phase I RFI/RI Report for OU 4.

### **1.3 GUIDANCE DOCUMENTS**

The HHRA was performed using EPA guidance provided in Risk Assessment Guidance for Superfund (EPA, 1989a; 1991), Dermal Exposure Assessment: Principles and Applications (EPA, 1992b), the Exposure Factors Handbook (EPA, 1989b), and Guidance for Data Useability in Risk Assessment (Parts A and B) (EPA, 1992c; 1992d). Other guidance documents and scientific literature were consulted as needed and cited where used. In addition, letters and memoranda from EPA Region VIII and CDPHE provided site-specific recommendations for identification of potential receptors, exposure areas, and chemicals of concern (COCs). Specific correspondence from EPA and CDPHE is cited in the relevant sections of the HHRA.

### **1.4 REPORT ORGANIZATION**

The following sections of this report compose the HHRA:

- 2.0 Selection of Chemicals of Concern. A description of the approach taken to identify COCs for quantitative evaluation in the HHRA, including a summary of the chemical analytical data used and how the data were aggregated.
- 3.0 Exposure Assessment. A discussion of the exposure scenarios evaluated in the HHRA, including the exposure point concentrations that were calculated for each COC in each exposure medium and exposure area, and the methodology and exposure parameters used to calculate chemical intake for each exposure pathway.
- 4.0 Toxicity Assessment. A description of the chemical-specific toxicity factors used in estimating noncarcinogenic and carcinogenic health risk from exposure to chemicals and radionuclides. The section also presents the radiation dose coefficients used in calculating annual radiation doses, and identifies detected chemicals without EPA toxicity factors.
- 5.0 Risk Characterization and Uncertainties. A presentation of the results of the quantitative risk assessment for each exposure scenario, including annual radiation dose calculations for each receptor. The section also identifies the primary sources of uncertainty in quantitative risk assessment.
- 6.0 Summary and Conclusions. This section includes summation and concluding remarks from the results of the risk assessment.
- 7.0 References.

In addition, the following appendices provide detailed information on various aspects of the HHRA:

- Appendix A Data Evaluation. A description of the chemical data used in the HHRA and the selection of potential COCs (PCOCs).

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Appendix B Estimating the Intake Factor. A discussion of the statistical procedures used to determine exposure point concentrations of COCs and the numerical values for all exposure parameters for each receptor and exposure pathway evaluated in the HHRA.

Appendix C Risk Characterization Calculations. A Listing of the detailed spreadsheets showing health risk calculations for all chemicals, receptors, and pathways and the calculation of annual radiation doses for each receptor.

## 2.0 SELECTION OF CHEMICALS OF CONCERN

This section describes the approach taken to identify COCs for quantitative evaluation in the HHRA, including a summary of the chemical analytical data used and how the data were aggregated. COCs in each sampled medium (surface soil, subsurface soil, and pond liner material) were selected on an OU-wide basis.

### 2.1 CHEMICAL ANALYTICAL DATABASE

Chemical analytical data from environmental samples collected during the OU 4 Phase I field investigations and from RFETS-wide sampling programs were used to characterize OU 4 chemical constituents and select COCs for risk assessment. The sampling and analytical programs followed approved work plans, and chemical analytical results were validated in accordance with EPA and RFETS data validation guidelines. Summaries of the work plans and the OU 4 field investigations are presented in Sections 1.0 and 2.0 of the OU 4 RFI/RI Report. Appendix A, *Data Evaluation*, describes the data preparation that occurred in establishing the final database used in the OU 4 HHRA. The data sets used for evaluation of surface soil, subsurface soil, and pond liner materials are presented in detail in the OU 4 RFI/RI report and briefly described in the following sections.

#### 2.1.1 Surface Soil

Surface soil samples were collected using the RFP method, in which the top 2 in. of soil are collected in several locations within a plot and then composited. Samples were collected from May through July 1994. The analytical parameters varied by location but generally included metals, radionuclides, nitrates, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), pesticides, and polychlorinated biphenyls (PCBs). Surface soil sampling locations are shown in Figure 2-1.

#### 2.1.2 Subsurface Soil

Subsurface soil samples were collected from October 1987 through November 1993. Subsurface soil samples were collected in 2- to 6-ft composites depending on sampling location. Laboratory analyses of subsurface soil samples generally included the following analytical groups: VOCs, SVOCs, metals, pesticides, PCBs, and radionuclides. Subsurface soil sampling locations are shown in Figure 2-2.

#### 2.1.3 Pond Liner Materials

A total of 12 pond liner material samples were collected in March 1993. Because the liners are made of asphalt, these sample data were analyzed for metals and radionuclides only. Sampling locations for the collection of pond liner materials are shown in Figures 2-1 and 2-2.

## **2.2 OU 4 CHEMICALS OF CONCERN**

COCs are (1) a subset of detected metals and radionuclides that had concentration distributions that differed significantly from background distributions and (2) detected organic chemicals. COCs are selected to be the constituents most likely to contribute significantly to overall risk. COCs are evaluated in the quantitative risk assessment and are the focus of transport modeling, risk assessment, and remedy selection (if warranted). This section describes the process for determining COCs in surface soil, subsurface soil, and pond liner materials.

COCs in each medium were selected on an OU-wide basis; that is, all sample results from each medium were pooled for the overall evaluation. Risk-based and other screening methods were used to identify COCs (i.e., the chemicals that are likely to pose the greatest risk to human health). The COC selection process is illustrated in Figure 2-3.

### **2.2.1 Background Comparison**

Analytical results for metals and radionuclides detected in surface soil and subsurface soil in OU 4 were compared to background levels (see description in Appendix A and illustration in Figure 2-4). Pond liner materials were compared to background surface soils for determination of PCOCs. All detected organic compounds were considered potential chemicals of concern (PCOCs) and were not compared to background data. The PCOCs derived for OU 4 are shown in Table 2-1.

### **2.2.2 Essential Nutrients/Major Cations and Anions**

Calcium, iron, magnesium, potassium, and sodium were eliminated from further consideration as COCs because they are essential nutrients, occur naturally in the environment, and are toxic only at very high doses. Nitrate was retained for further evaluation, but other major cations and anions measured as water quality parameters, such as carbonates, were not evaluated.

### **2.2.3 Frequency of Detection**

Metals with concentration distributions in OU 4 that were significantly different from background distributions and detected organic compounds were evaluated for frequency of detection. Chemicals that were detected at a frequency of 5 percent or greater were retained for further evaluation in concentration/toxicity screens to select OU-wide COCs. Organic chemicals and metals that were detected at less than 5 percent frequency were evaluated separately. Radionuclides were assumed to be detected at 100 percent frequency for statistical analysis (i.e., negative, zero, and positive results were retained in the data set); thus, the radionuclides were not screened based on frequency of detection.

In evaluating infrequently detected compounds, the maximum concentrations of chemical constituents with less than 5 percent detection frequency were compared to screening levels equivalent to 1,000 times risk-based concentrations (RBCs) to determine whether there was potential risk to human health on the basis of high concentration and toxicity even though the chemicals were rarely detected and exposure potential was low. RBCs were defined as chemical concentrations associated with an excess cancer risk of  $1E-6$  (1 in 1 million) or a hazard index of 1 for noncarcinogenic effects. RBCs for chemicals in surface soil were conservatively calculated assuming residential exposure via ingestion of soil and inhalation of airborne particulates. RBCs for chemicals in subsurface soil were calculated assuming construction worker exposure via soil ingestion and inhalation of particulates and VOCs. As shown in Table 2-2, there were no infrequently detected compounds with concentrations above the RBC in any of the OU 4 sampled media.

#### 2.2.4 Concentration/Toxicity Screens

Concentration/toxicity screens were conducted separately for noncarcinogens, carcinogens, and radionuclides that had been determined to be PCOCs within each medium (surface soil, subsurface soil, and pond liner materials). These screens were used to identify chemicals that, based on maximum concentration and toxicity criteria, are likely to contribute 1 percent or more of the total potential risk in each category (noncarcinogens, carcinogens, and radionuclides) in each medium. These chemicals were identified as COCs for evaluation in the quantitative risk assessment. Concentration/toxicity screens are shown in Tables 2-3 through 2-11. Analytes that contributed at least 1 percent of the total risk factor are presented in Table 2-12.

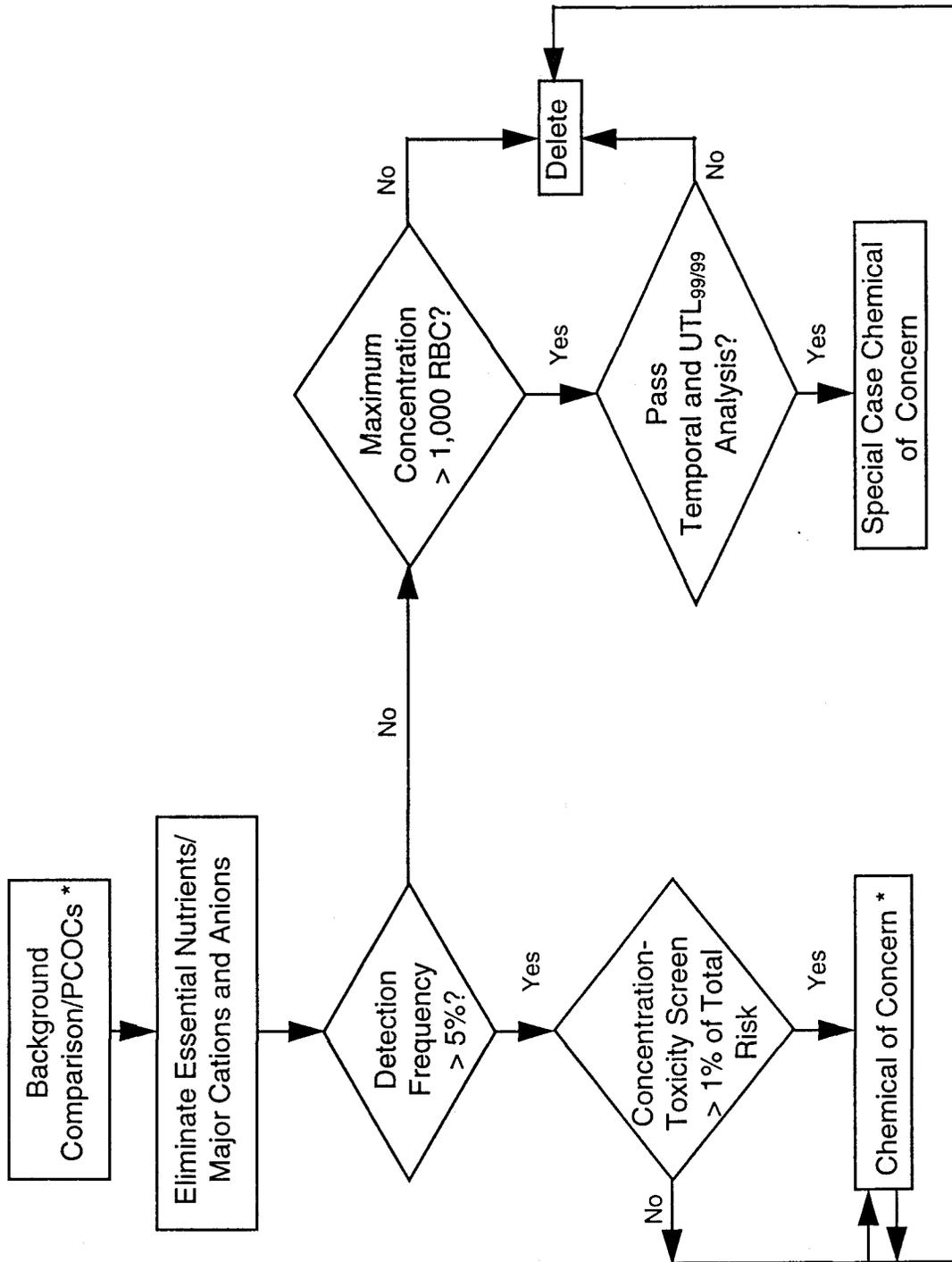
#### 2.2.5 Chemicals Without EPA Toxicity Values

Chemicals that were detected in OU 4 but do not have EPA-established toxicity values are listed in Table 2-13. These compounds cannot be evaluated in a toxicity or risk-based screen to select COCs. However, their potential contribution to overall risk was evaluated qualitatively in Section 5.0, *Risk Characterization and Uncertainty*.

### 2.3 DATA AGGREGATION FOR RISK ASSESSMENT

Data aggregation for risk assessment was performed in accordance with guidelines developed by CDPHE, EPA Region VIII, and DOE for application at RFETS. Areas of Concern (AOCs) were delineated on the basis of the spatial extent of potential contaminants and historical use. Two AOCs were identified in OU 4 (Figures 2-1 and 2-2). AOC No. 1 encompasses the Solar Evaporation Ponds, while AOC No. 2 includes the downgradient portion of OU 4 (both inside the PA and outside of the PA in the Buffer Zone) that may have received contaminants from the ponds.

Exposure concentrations used in the risk assessment were calculated for each medium in each AOC using the results from all samples collected in that AOC. More details on calculating the exposure concentrations are provided in Section 3.0.



\*Professional judgment applied to analytes at these points.

Figure 2-3 COC Selection Process

**Table 2-1 Summary of Potential Chemicals of Concern  
OU 4 Human Health Risk Assessment**

Analyte	Surface Soil	Subsurface Soil	Pond Liner <sup>a</sup>
<b>Organic Compounds:</b>			
1,1,1-Trichloroethane		X	
2-Butanone		X	
2-Hexanone		X	
4-Methyl-2-pentanone		X	
Acenaphthene	X		
Acetone		X	
Anthracene	X		
Aroclor-1254	X		
Benzo(a)anthracene	X		
Benzo(a)pyrene	X	X	
Benzo(b)fluoranthene	X	X	
Benzo(g,h,i)perylene	X		
Benzo(k)fluoranthene	X		
Benzoic Acid	X		
bis(2-Ethylhexyl)phthalate	X	X	
Bromodichloromethane		X	
Butylbenzylphthalate	X		
Chloroform		X	
Chrysene	X		
Di-n-butylphthalate	X	X	
Di-n-octylphthalate	X		
Dibenz(a,h)anthracene	X		
Dibenzofuran	X		
Fluoranthene	X	X	
Fluorene	X		
Indeno(1,2,3-cd)pyrene	X		
Methylene chloride		X	
n-Nitrosodiphenylamine		X	
Naphthalene	X		
Pentachlorophenol	X		
Phenanthrene	X	X	
Phenol		X	
Pyrene	X	X	
Tetrachloroethene		X	
Toluene		X	
Trichloroethene		X	
Xylene (total)		X	

a. No analyses were performed for organic chemicals.

Table 2-1 (continued)

Analyte	Surface Soil	Subsurface Soil	Pond Liner
<b>Metals (plus nitrate):</b>			
Barium	X		
Beryllium	X		
Cadmium	X	X	X
Chromium	X		X
Copper	X		
Lithium	X	X	
Mercury	X		
Nickel	X		
Nitrate	X	X	
Silver	X		
Strontium	X	X	
Tin	X		
Zinc	X	X	
<b>Radionuclides:</b>			
Americium-241	X	X	X
Plutonium-239/240	X	X	X
Radium-226	X	X	
Radium-228		X	
Strontium-89/90	X		
Tritium	X	X	
Uranium-233/234	X	X	X
Uranium-235	X	X	X
Uranium-238	X	X	X

Table 2-2 Rocky Flats OU 4 RBC Comparison for Infrequently Detected Compounds

Chemical	Range of Detected Concentrations (mg/kg)	Detection Frequency (%)	Reporting Limit (mg/kg)	Minimum Nondetect Value (mg/kg)	Maximum Nondetect Value (mg/kg)	Risk-based Concentration (mg/kg) <sup>a</sup>	Maximum Detected Concentration > RBC?	Maximum Detected Concentration > 1000 x RBC?	Maximum Nondetect > RBC?	Percent of Nondetects > RBC
<b>Surface Soils:</b>										
Benzoic Acid	0.052J	1.2	1.60-3.70	1.70	3.70	1.10E+06	No	No	No	None
Naphthalene	0.044J-0.180J	4.8	0.33-0.74	0.34	0.74	1.10E+04	No	No	No	None
Pentachlorophenol	0.050J	1.2	1.60-3.70	1.70	3.70	5.34E+00	No	No	No	None
<b>Subsurface Soils:</b>										
1,1,1-Trichloroethane	0.013	0.4	0.005-0.032	0.005	0.720	1.60E+05	No	No	No	None
4-Methyl-2-pentanone	0.002J-0.003J	1.2	0.006-0.065	0.006	1.400	1.42E+05	No	No	No	None
Benzo(a)pyrene	0.038J	2.5	0.330-0.440	0.330	0.440	1.70E+01	No	No	No	None
Benzo(b)fluoranthene	0.060J	2.5	0.330-0.440	0.330	0.440	1.70E+02	No	No	No	None
Bromodichloromethane	0.025	0.4	0.005-0.032	0.005	0.720	2.00E+03	No	No	No	None
Chloroform	0.005J-0.018J	3.5	0.005-0.032	0.005	0.720	5.68E+02	No	No	No	None
Fluoranthene	0.071J-0.120J	4.9	0.330-0.440	0.330	0.440	7.10E+04	No	No	No	None
n-Nitrosodiphenylamine	0.083J	2.4	0.330-0.440	0.350	0.440	2.53E+04	No	No	No	None
Phenol	0.059J	2.4	0.330-0.440	0.330	0.440	1.06E+06	No	No	No	None
Pyrene	0.051J-0.062J	4.9	0.330-0.440	0.330	0.440	5.32E+04	No	No	No	None
Tetrachloroethene	0.002J-0.023J	4.3	0.005-0.032	0.005	0.720	2.21E+03	No	No	No	None
Trichloroethene	0.002J-0.009J	0.8	0.005-0.032	0.005	0.720	2.18E+03	No	No	No	None
Xylene (total)	0.001J	0.4	0.005-0.032	0.005	0.720	3.55E+06	No	No	No	None

a. Risk-based concentrations (RBCs) used for comparison of surface soil data were calculated assuming a residential exposure scenario; for subsurface soil data comparisons, construction worker RBCs were used.

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Table 2-3 Concentration/Toxicity Screen OU 4 Surface Soils Nonradiological Carcinogens

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency (%)	Oral Slope Factor (1/[mg/kg-day])	Inhalation Slope Factor (1/[mg/kg-day])	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Cadmium	382	56.6	-	6.30E+00	2.41E+03	9.24E-01	92.43
Aroclor-1254	11.9	8	7.70E+00	-	9.16E+01	3.52E-02	3.52
Beryllium	9.6	24.1	4.30E+00	8.40E+00	8.06E+01	3.10E-02	3.10
Benzo(a)pyrene	2.1	62.6	7.30E+00	-	1.53E+01	5.89E-03	0.59
Dibenz(a,h)anthracene	0.56	16.9	7.30E+00	-	4.09E+00	1.57E-03	0.16
Benzo(b)fluoranthene	3.3	73.5	7.30E-01	-	2.41E+00	9.25E-04	0.09
Benzo(a)anthracene	1.9	62.6	7.30E-01	-	1.39E+00	5.33E-04	0.05
Indeno(1,2,3-cd)pyrene	1.6	54.2	7.30E-01	-	1.17E+00	4.49E-04	0.04
bis(2-Ethylhexyl)phthalate	21	55.4	1.40E-02	-	2.94E-01	1.13E-04	0.01
Benzo(k)fluoranthene	3.7	68.42	7.30E-02	-	2.70E-01	1.04E-04	0.01
Chrysene	2.2	67.5	7.30E-03	-	1.61E-02	6.17E-06	0.00
			TOTAL RISK FACTOR		2.60E+03		

a. Carcinogenic Risk Factor = Maximum Detected Concentration times highest Slope Factor value.

b. Risk Index = Risk Factor/Total Risk Factor.

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Table 2-4 Concentration/Toxicity Screen OU 4 Surface Soils Radionuclides

Chemical	Maximum Detected Concentration (pCi/g)	Detection Frequency (%)	Oral Slope Factor (1/pCi)	Inhalation Slope Factor (1/pCi)	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Americium-241	130	100	3.28E-10	3.85E-08	5E-06	6.67E-01	66.66
Plutonium-239/240	56	100	3.16E-10	2.78E-08	1.6E-06	2.07E-01	20.73
Uranium-233/234	41	100	1.60E-11	1.40E-08	5.7E-07	7.64E-02	7.64
Uranium-238	27	100	6.20E-11	1.24E-08	3.3E-07	4.46E-02	4.46
Uranium-235	2.3	100	4.70E-11	1.30E-08	3E-08	3.98E-03	0.40
Radium-226	2.9	100	2.96E-10	2.75E-09	8E-09	1.06E-03	0.11
Strontium-89/90	1.5	100	1.03E-11	3.68E-12	1.5E-11	2.06E-06	0.00
Tritium	8.4	100	7.15E-14	9.59E-14	8.1E-13	1.07E-07	0.00
TOTAL RISK FACTOR				7.5E-06			

a. Carcinogenic Risk Factor = Maximum Detected Concentration times highest Slope Factor value.

b. Risk Index = Risk Factor/Total Risk Factor.

Table 2-5 Concentration/Toxicity Screen OU 4 Surface Soils Noncarcinogens

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency (%)	Oral Slope Factor (mg/kg-day)	Inhalation Slope Factor (mg/kg-day)	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Cadmium	382	56.6	5.00E-04	-	7.64E+05	5.50E-01	54.96
Aroclor-1254	11.9	8	2.00E-05	-	5.95E+05	4.28E-01	42.80
Nickel	176	91.6	2.00E-02	-	8.80E+03	6.33E-03	0.63
Mercury	1.8	32.9	3.00E-04	8.40E-05	6.00E+03	4.32E-03	0.43
Barium	393	100	7.00E-02	1.43E-04	5.61E+03	4.04E-03	0.40
Copper	77.5	97.6	4.00E-02	-	1.94E+03	1.39E-03	0.14
Beryllium	9.6	24.1	5.00E-03	-	1.92E+03	1.38E-03	0.14
Lithium	34.9	98.8	2.00E-02	-	1.75E+03	1.26E-03	0.13
Zinc	460	100	3.00E-01	-	1.53E+03	1.10E-03	0.11
bis(2-Ethylhexyl)phthalate	21	55.4	2.00E-02	-	1.05E+03	7.55E-04	0.08
Strontium	510	100	6.00E-01	-	8.50E+02	6.11E-04	0.06
Silver	3.7	13.3	5.00E-03	-	7.40E+02	5.32E-04	0.05
Nitrate	765	100	1.60E+00	-	4.78E+02	3.44E-04	0.03
Pyrene	3.6	77.1	3.00E-02	-	1.20E+02	8.63E-05	0.01
Fluoranthene	4.7	83.1	4.00E-02	-	1.18E+02	8.45E-05	0.01
Tin	61.5	25.3	6.00E-01	-	1.03E+02	7.37E-05	0.01
Di-n-octylphthalate	1.3	9.6	2.00E-02	-	6.50E+01	4.68E-05	0.00
Dibenzofuran	0.21	7.2	4.00E-03	-	5.25E+01	3.78E-05	0.00
Chromium III*	48.4	100	1.00E+00	-	4.84E+01	3.48E-05	0.00
Di-n-butylphthalate	1.7	34.9	1.00E-01	-	1.70E+01	1.22E-05	0.00
Fluorene	0.44	15.7	4.00E-02	-	1.10E+01	7.91E-06	0.00
Acenaphthene	0.56	18.1	6.00E-02	-	9.33E+00	6.71E-06	0.00
Anthracene	0.77	21.7	3.00E-01	-	2.57E+00	1.85E-06	0.00
Butylbenzylphthalate	0.29	12	2.00E-01	-	1.45E+00	1.04E-06	0.00
			TOTAL RISK FACTOR		1.39E+06		

a. Noncarcinogenic Risk Factor = Maximum Detected Concentration times 1/RfD.

b. Risk Index = Risk Factor/Total Risk Factor.

\* Chromium III is assumed based on data from OU 2 chromium speciation work and documentation presented in OU 6 COC TM.

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Table 2-6 Concentration/Toxicity Screen OU 4 Subsurface Soils Nonradiological Carcinogens

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency (%)	Oral Slope Factor (1/[mg/kg-day])	Inhalation Slope Factor (1/[mg/kg-day])	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Cadmium	547	21.1	-	6.30E+00	3.45E+03	1.00E+00	100.00
bis(2-Ethylhexyl)phthalate	0.83	17.1	1.40E-02	-	1.16E-02	3.37E-06	0.00
Methylene chloride	0.071	32.5	7.50E-03	1.65E-03	5.33E-04	1.55E-07	0.00
			TOTAL RISK FACTOR	TOTAL RISK FACTOR	3.45E+03		

Table 2-7 Concentration/Toxicity Screen OU 4 Subsurface Soils Radionuclides

Chemical	Maximum Detected Concentration (pCi/g)	Detection Frequency (%)	Oral Slope Factor (1/pCi)	Inhalation Slope Factor (1/pCi)	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Plutonium-239/240	20	100	3.16E-10	2.78E-08	5.56E-07	4.41E-01	44.10
Uranium-233/234	21	100	1.60E-11	1.40E-08	2.94E-07	2.33E-01	23.32
Americium-241	6.1	100	3.28E-10	3.85E-08	2.35E-07	1.86E-01	18.63
Uranium-238	11.48	100	6.20E-11	1.24E-08	1.42E-07	1.13E-01	11.29
Radium-226	6.84	100	2.96E-10	2.75E-09	1.88E-08	1.49E-02	1.49
Uranium-235	0.87	100	4.70E-11	1.30E-08	1.13E-08	8.97E-03	0.90
Radium-228	3.5	100	2.48E-10	9.94E-10	3.48E-09	2.76E-03	0.28
Tritium	0.84	100	7.15E-14	9.59E-14	8.06E-14	6.39E-08	0.00
			TOTAL RISK FACTOR	TOTAL RISK FACTOR	1.26E+06		

a. Carcinogenic Risk Factor = Maximum Detected Concentration times highest Slope Factor value.

b. Risk Index = Risk Factor/Total Risk Factor.

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Table 2-8 Concentration/Toxicity Screen OU 4 Subsurface Soils Noncarcinogens

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency (%)	Oral Slope Factor (mg/kg-day)	Inhalation Slope Factor (mg/kg-day)	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Cadmium	547	21.1	5.00E-04	-	1.09E+06	9.91E-01	99.12
Lithium	79.9	87.7	2.00E-02	-	4.00E+03	3.62E-03	0.36
Nitrate	6100	97.6	1.60E+00	-	3.81E+03	3.45E-03	0.35
Zinc	340	100	3.00E-01	-	1.13E+03	1.03E-03	0.10
Strontium	398	91.4	6.00E-01	-	6.63E+02	6.01E-04	0.06
bis(2-Ethylhexyl)phthalate	0.83	17.1	2.00E-02	-	4.15E+01	3.76E-05	0.00
Toluene	1.2	67.1	2.00E-01	1.14E-01	6.00E+00	5.44E-06	0.00
2-Butanone	2	5.7	6.00E-01	2.86E-01	3.33E+00	3.02E-06	0.00
Acetone	0.11	23.8	1.00E-01	-	1.10E+00	9.97E-07	0.00
Di-n-butylphthalate	0.098	14.6	1.00E-01	-	9.80E-01	8.88E-07	0.00
Methylene chloride	0.071	32.5	6.00E-02	8.57E-01	8.28E-02	7.51E-08	0.00
			TOTAL RISK FACTOR		1.10E+06		

a. Noncarcinogenic Risk Factor = Maximum Detected Concentration times 1/RfD.

b. Risk Index = Risk Factor/Total Risk Factor.

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**Table 2-9 Concentration/Toxicity Screen Pond Liner Materials Nonradiological Carcinogens**

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency (%)	Oral Slope Factor (1/[mg/kg-day])	Inhalation Slope Factor (1/[mg/kg-day])	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Cadmium	69.7	100	-	6.30E+00	4.39E+02	1.00E+00	100
TOTAL RISK FACTOR					4.39E+02		

**Table 2-10 Concentration/Toxicity Screen Pond Liner Materials Radionuclides**

Chemical	Maximum Detected Concentration (pCi/g)	Detection Frequency (%)	Oral Slope Factor (1/pCi)	Inhalation Slope Factor (1/pCi)	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Americium-241	4.032	100	3.28E-10	3.85E-08	1.55E-07	4.54E-01	45.38
Plutonium-239/240	3.126	100	3.16E-10	2.78E-08	8.69E-08	2.54E-01	25.41
Uranium-233/234	4.66	100	1.60E-11	1.40E-08	6.52E-08	1.91E-01	19.07
Uranium-238	2.68	100	6.20E-11	1.24E-08	3.32E-08	9.72E-02	9.72
Uranium-235	0.11	100	4.70E-11	1.30E-08	1.43E-09	4.18E-03	0.42
TOTAL RISK FACTOR					3.42E-07		

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Table 2-11 Concentration/Toxicity Screen Pond Liner Materials Noncarcinogens

Chemical	Maximum Detected Concentration (mg/kg)	Detection Frequency (%)	Oral Slope Factor (mg/kg-day)	Inhalation Slope Factor (mg/kg-day)	Risk Factor <sup>a</sup>	Risk Index <sup>b</sup>	Percent of Total Risk Factor
Cadmium	382	56.6	5.00E-04	-	7.64E+05	1.00E+00	99.99
Chromium III <sup>c</sup>	48.4	100	1.00E+00	-	4.84E+01	6.33E-05	0.01
TOTAL RISK FACTOR					7.64E+05		

- a. Risk Factor = Maximum Detected Concentration times highest Slope Factor value (for carcinogenics) or 1/RfD (for noncarcinogenics).  
 b. Risk Index = Risk Factor/Total Risk Factor.  
 c. Chromium III is assumed based on data from OU 2 chromium speciation work and documentation presented in OU 6 COC TM.

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**Table 2-12 Summary of Chemicals of Concern  
 OU 4 Human Health Risk Assessment**

Analyte	Surface Soil	Subsurface Soil	Pond Liner
<b>Organic Compounds:</b>			
Aroclor-1254	X		
<b>Metals:</b>			
Beryllium	X		
Cadmium	X	X	X
<b>Radionuclides:</b>			
Americium-241	X	X	X
Plutonium-239/240	X	X	X
Radium-226		X	
Uranium-233/234	X	X	X
Uranium-238	X	X	X

**Table 2-13 Detected Chemicals with No Toxicity Values  
 OU 4 Human Health Risk Assessment**

Chemical	Maximum Detected Concentration (mg/kg)	Frequency of Detection (%)
<b>Surface Soil:</b>		
Benzo(g,h,i)perylene	1.3	43.4
Phenanthrene	3.7	74.7
<b>Subsurface Soil:</b>		
2-Hexanone	0.061	0.4
Phenanthrene	0.067	2.4

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### **3.0 EXPOSURE ASSESSMENT**

This section discusses the exposure scenarios evaluated in the HHRA, presents the exposure point concentrations that were calculated for each COC in each exposure medium and exposure area, and describes the methodology and exposure parameters used to calculate chemical intake for each exposure pathway.

#### **3.1 EXPOSURE SCENARIOS**

Exposure scenarios (receptors, exposure areas, and exposure pathways) were evaluated quantitatively in the OU 4 risk assessment and were identified for both current and possible future onsite uses. Current and future exposure scenarios in OU 4 were developed based on:

- Identification of current onsite land uses and characterization of future land-use scenarios
- Identification of potential receptors based on current and future land-use scenarios
- Development of a conceptual site model (CSM)

Current and future offsite receptors were not evaluated in the HHRA for OU 4 because estimating effects from individual OUs would not address potential cumulative impacts to offsite receptors from other sources at RFETS. However, exposure of offsite receptors should be evaluated in a future sitewide risk assessment.

##### **3.1.1 Current and Future Onsite Land Use**

As described in Section 1.2, RFETS consists of a 400-acre industrial area surrounded by an undeveloped buffer zone of approximately 6,150 acres. The OU 4 area, a portion of which is also designated as IHSS 101, includes the Solar Evaporation Ponds and surrounding land surface. Current activities in OU 4 consist of environmental investigations, monitoring, cleanup, and routine security surveillance. No industrial or commercial operations currently occur in OU 4. RFETS is fenced and guarded, and trespassing does not occur. Activities in the industrialized portion of the plant include maintenance, waste management, and environmental restoration activities.

Probable future onsite land use at RFETS includes environmental restoration, decontamination and decommissioning, economic development, waste management, and open space. The Rocky Flats Local Impact Initiative (RFLII, 1992) is working with DOE and local economic development agencies to encourage business development at RFETS, using new or existing facilities. The Rocky Flats

Future Site Uses Working Group (FSUWG) has also developed recommendations regarding future use of the RFETS property. Residential development at RFETS has not been recommended by this group or by other planning groups. Commercial and industrial uses of developed portions of the site are considered beneficial. Commercial development in undeveloped portions of the property has not been ruled out, although preservation as open space is consistent with DOE policy, the Jefferson County Planning Department's recommendations (Jefferson County, 1990), and the FSUWG recommendations (FSUWG, 1995). The Jefferson County Board of Commissioners has also adopted a resolution stating its support of maintaining, in perpetuity, the undeveloped buffer zone of open space around Rocky Flats for environmental and safety reasons (Jefferson County Board of Commissioners, 1994).

Ecological surveys performed in compliance with the Threatened and Endangered Species Act indicate the presence of habitat that is potentially suitable to four plant species and several wildlife species of concern. The plant species are the forktip threeawn, Colorado butterfly plant, toothcup, and Diluvium lady's tresses (EG&G, 1991). The wildlife species include the bald eagle, peregrine falcon, whooping crane, Prebles meadow jumping mouse, and the black-footed ferret (DOE, 1991; FWS, 1990; DOE, 1994). The Prebles meadow jumping mouse inhabits creek drainages and is a candidate for listing as an endangered species (DOE, 1994). Onsite commercial or other development in the buffer zone may be precluded because of the undisturbed nature of the buffer zone and the presence of a rare species such as the Prebles meadow jumping mouse.

Future onsite residential development at OU 4 is inconsistent with recommendations being considered for future onsite land use. The Future Site Use Working Group land use map (FSUWG, 1995) indicated that a residential scenario in OU 4 could be considered outside the range of what is reasonable for future land use at Rocky Flats (EPA, 1995a). Therefore, residential development in OU 4 is considered to be an improbable future land use scenario and was not evaluated in the HHRA. Onsite agricultural development is considered to be improbable because of the decline of agriculture in the Northeast Jefferson County area.

In summary, future onsite land use in OU 4 is most likely commercial/industrial use for that portion of OU 4 lying within the PA and open space for the down-gradient area outside of the PA.

### 3.1.2 Onsite Exposure Areas and Receptors

Current and future onsite exposures were evaluated in the two separate OU 4 AOCs identified in Section 2.2 and shown in Figure 2-1. The four receptors selected for quantitative evaluation in the HHRA are listed below:

1. *Current Onsite Security Worker*: A current onsite worker (RFETS plant security personnel) who is assumed to spend a portion of the time in OU 4 while conducting routine patrols within the

RFETS boundary. For the purposes of this HHRA, it was assumed that a security surveillance person spends one half hour in OU 4 during each work day. Current onsite workers were evaluated for exposures in both AOC No. 1 and in AOC No. 2.

2. *Future Onsite Office Worker:* The future office worker is assumed to work indoors in a building complex. Future office workers are evaluated for exposure in AOC No. 1.
3. *Future Onsite Construction Worker:* The future onsite construction worker is assumed to contact subsurface soil and pond liner materials during excavation activities associated with construction of commercial buildings in AOC No. 1.
4. *Future Open-Space Recreation User:* The open-space exposure scenario was developed to estimate potential risks from recreational use of open space at RFETS. Future open-space use by children and adults is assumed to include recreational activities such as hiking and biking. An open space use scenario was evaluated in AOC No. 2.

These receptors were selected to represent the potentially exposed populations based on current and probable future land use. Onsite industrial or office workers and open-space recreational users provide realistic, yet still conservative, estimates of potential risk under various land use scenarios.

### 3.1.3 Exposure Pathways

This section identifies potential exposure pathways by which receptors could be exposed to chemicals in or released from sources in OU 4. A complete exposure pathway requires a chemical source, chemical release mechanism, environmental transport medium, exposure point, and human intake route. If one of these elements is lacking, the pathway is incomplete and no human exposures can occur. Incomplete pathways were not evaluated in the HHRA.

Potentially complete pathways include all pathways for which human exposure is possible, no matter how trivial. A potentially complete pathway was not assessed when, based on professional judgement and logic, the contribution of the pathway to overall exposure is likely to be orders of magnitude lower than exposure from other pathways, and the pathway is not expected to contribute significantly to overall risk to the receptor. These potentially complete, but not assessed, pathways are unlikely to have any bearing on mathematical estimations of total risk to receptors and therefore do not warrant quantitative evaluation in the HHRA.

Figure 3-1 shows the CSM of potential human exposure pathways for OU 4. The CSM is a schematic representation of the chemical sources, chemical release mechanisms, environmental transport media, human intake routes, and human receptors for OU 4. The CSM is used to identify the complete

exposure pathways for quantitative risk assessment and to identify pathways that are incomplete or do not warrant quantitative assessment because they would not contribute measurably to the estimate of overall risk. A summary of potentially complete exposure pathways evaluated in the risk assessment is provided in Table 3-1.

### **OU-Wide Exposure Pathways Not Assessed**

Pathways that are incomplete or would not contribute measurably to the estimate of overall risk were not quantitatively addressed in this risk assessment and are not included in the CSM. The following exposure pathways are either incomplete or potentially complete but not assessed for all receptors.

- Ingestion of fish in RFETS surface waters is an incomplete exposure pathway for all OU 4 receptors because sport fishing is unlikely (due to intermittent flow in the creeks), and because fishing will not occur under open-space or occupational use. OU 4 does not contain any surface water.
- Ingestion of livestock is an incomplete pathway for all OU 4 receptors, because beef ingestion will not occur under occupational and open-space uses.
- Groundwater direct exposure pathways are incomplete for all receptors because drinking water is currently provided by a municipal supply that does not tap aquifers at RFETS. This supply, which has provided all of the drinking and industrial supply for thousands of onsite workers, is expected to be maintained in the future. Open-space recreational users are expected to bring their own water during outdoor activities.
- Inhalation of VOCs released to both indoor and outdoor air through volatilization from soil or groundwater is an incomplete pathway for all receptors; no VOCs were included as COCs in either of the OU 4 AOCs.
- Although included in the CSM, dermal uptake from all media is considered a potentially complete pathway, but was not assessed for all receptors or media. Because the permeability constants for metals and radionuclides are so low (EPA, 1989a), dermal exposure to these constituents was not included in this risk assessment. The only analyte for which dermal exposure was estimated was Aroclor-1254, which was determined to be a COC in AOC No. 1 surface soil only.
- Ingestion of homegrown produce is an incomplete pathway for all receptors because gardening will not occur under occupational or open-space use.
- Ingestion of and dermal contact with surface water and sediments are considered complete buffer zone pathways for open-space recreational users, but were not evaluated for the OU 4 HHRA. Evaluation of these pathways has been completed in the OU 6 HHRA.

### **3.2 EXPOSURE POINT CONCENTRATIONS**

Exposure point concentrations of COCs were calculated for each exposure area and exposure medium (surface soil, subsurface soil, and pond liner material). The exposure point concentration of a

chemical in a sampled medium is usually the 95 percent upper confidence limit (95% UCL) on the arithmetic mean, based on a normal or lognormal distribution. The 95% UCL on the mean is a conservative estimate of the average concentration to which people would be exposed over time in the exposure area. If the calculated 95% UCL concentration exceeded the maximum detected concentration, the maximum was used as the exposure concentration (EPA, 1989a). This can occur with small data sets or in data sets with a high frequency of nondetects. For convenience in this report, the 95% UCL or maximum concentration is referred to as the reasonable maximum exposure (RME) concentration. RME concentrations were used in estimating risk for both the central tendency (CT) and RME exposure conditions. Table 3-2 summarizes the exposure concentrations of COCs in surface soil, subsurface soil, and pond liner materials for each AOC evaluated in the HHRA. The RME concentrations are shown in bold print in Table 3-2. Appendix B, *Estimating the Intake Factor*, discusses the statistical procedures used to determine exposure point concentrations.

### 3.2.1 Surface Soil

Table 3-2 summarizes the RME concentrations of COCs in surface soil in each exposure area. COCs are Aroclor-1254, beryllium, cadmium, americium-241, plutonium-239/240, and uranium-238. Exposure point concentrations were calculated for AOC No. 1 and AOC No. 2. The exposure concentrations in surface soil were used to estimate health risks associated with soil ingestion, inhalation of particulates, external irradiation, and dermal contact by current onsite workers, future office workers, and open-space recreational users. Aroclor-1254 was not detected in AOC No. 2, therefore it is not a COC for that area.

### 3.2.2 Subsurface Soil

Exposure concentrations of COCs in subsurface soil are also summarized in Table 3-2. COCs are cadmium, americium-241, plutonium-239/240, radium-226, and uranium-238. The subsurface soil concentrations were used to estimate health risks associated with construction worker exposure. Exposure concentrations were calculated for AOC No. 1, where construction activities are assumed to potentially occur.

### 3.2.3 Pond Liner Materials

Exposure concentrations on COCs in pond liner materials are shown in Table 3-2. The COCs for this medium includes cadmium, americium-241, plutonium-239/240, uranium 233/234, and uranium-238. The pond liner materials concentrations were used to estimate health risks associated with the future construction worker and current security worker exposures. Exposure concentrations were calculated for AOC No. 1, where potential construction activities in the ponds would occur.

### 3.2.4 Onsite Air Concentrations of Particulates from Wind Erosion

Table 3-2 lists the air concentrations that were derived for COCs in OU 4. These concentrations were derived from multiplying either the surface soil or subsurface soil concentrations by the inverse of the particulate emission factor (PEF), or  $1/4.63E+9$  m<sup>3</sup>/kg. For the sake of expediency, this conservative, default method for estimating particulate air emissions from soil (EPA, 1991a) was selected rather than using site-specific air modeling. The PEF relates the contaminant concentration in soil with the concentration of respirable particulates (PM<sub>10</sub>) in the air that result from fugitive dust emissions from surface contamination sites (wind erosion).

Air concentrations for surface soil COCs were calculated for AOC No. 1 and AOC No. 2. Aroclor-1254 was not detected in soil in AOC No. 2, therefore it is not a COC in that area. Air concentrations of COCs were used to estimate health risks associated with dust inhalation by current onsite workers, future office workers, and future open-space recreational users.

Air concentrations for subsurface soil COCs were calculated for AOC No. 1, where construction activities are assumed to potentially occur. Air concentrations, which are based only on wind erosion of subsurface soil, were used to estimate health risks associated with construction worker exposure. It was agreed among the agencies that inhalation of particulates from pond liner materials would be an insignificant pathway and would not need to be assessed; therefore, no air concentrations were derived for that medium.

### 3.3 ESTIMATING CHEMICAL INTAKES

Intake is a measure of exposure expressed as the mass of a substance in contact with the exchange boundary per unit body weight per unit time (EPA, 1989a). Chemical intake is expressed in terms of milligram (mg) chemical ingested, inhaled, or dermally absorbed per kilogram of body weight per day (mg/kg-day). Intake of radionuclides is expressed simply in terms of pCi total intake (body weight per unit time are not included). Intakes are estimated following guidance in *Risk Assessment Guidance for Superfund* (EPA, 1989a) and are based on reasonable estimates of body weight, inhalation volume, ingestion rates, soil matrix effects, frequency and duration of exposure, and chemical concentration. These estimates, also called exposure factors, are presented in Appendix B. These exposure factors were mutually agreed upon by all agencies concerned with the remediation of Rocky Flats.

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

RME for each of the receptors and exposure pathways are presented in the exposure factors tables in Appendix B.

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

$$\text{Intake} = \frac{\text{chemical concentration} \times \text{contact rate} \times \text{exposure frequency} \times \text{exposure duration}}{\text{bodyweight} \times \text{averaging time}} \quad (3-1)$$

with corresponding units of

$$\text{mg/kg-day} = \frac{\text{mg/volume or mass} \times \text{volume or mass/day} \times \text{day/year} \times \text{year}}{\text{kg} \times \text{day}} \quad (3-2)$$

Intake of radionuclides was calculated using equations similar to those for calculating intake of chemicals. Intake of radionuclides by either ingestion or inhalation is a function of radionuclide activity concentration, intake rate (or the amount of potentially contaminated medium contacted per unit time or event), and exposure frequency and duration. The only difference between calculating intake for radionuclides and nonradioactive substances is that averaging time and body weight are excluded from the intake equations for radionuclides.

Appendix B presents the intake equations for each pathway evaluated in the risk assessment. This appendix also includes discussions on age-adjusted ingestion rates, chemical-specific matrix effects and absorption factors, and special features of estimating intake of radionuclides.

Omitting chemical concentration from the intake equation yields an *intake factor* for each exposure pathway/receptor combination. The intake factor can then be multiplied by the concentration of each chemical to obtain the pathway/receptor-specific intake of that chemical. Intake factors were calculated for each potentially exposed receptor and exposure pathway, and are shown on the risk calculation tables presented in Appendix C, *Risk Characterization Calculations*.

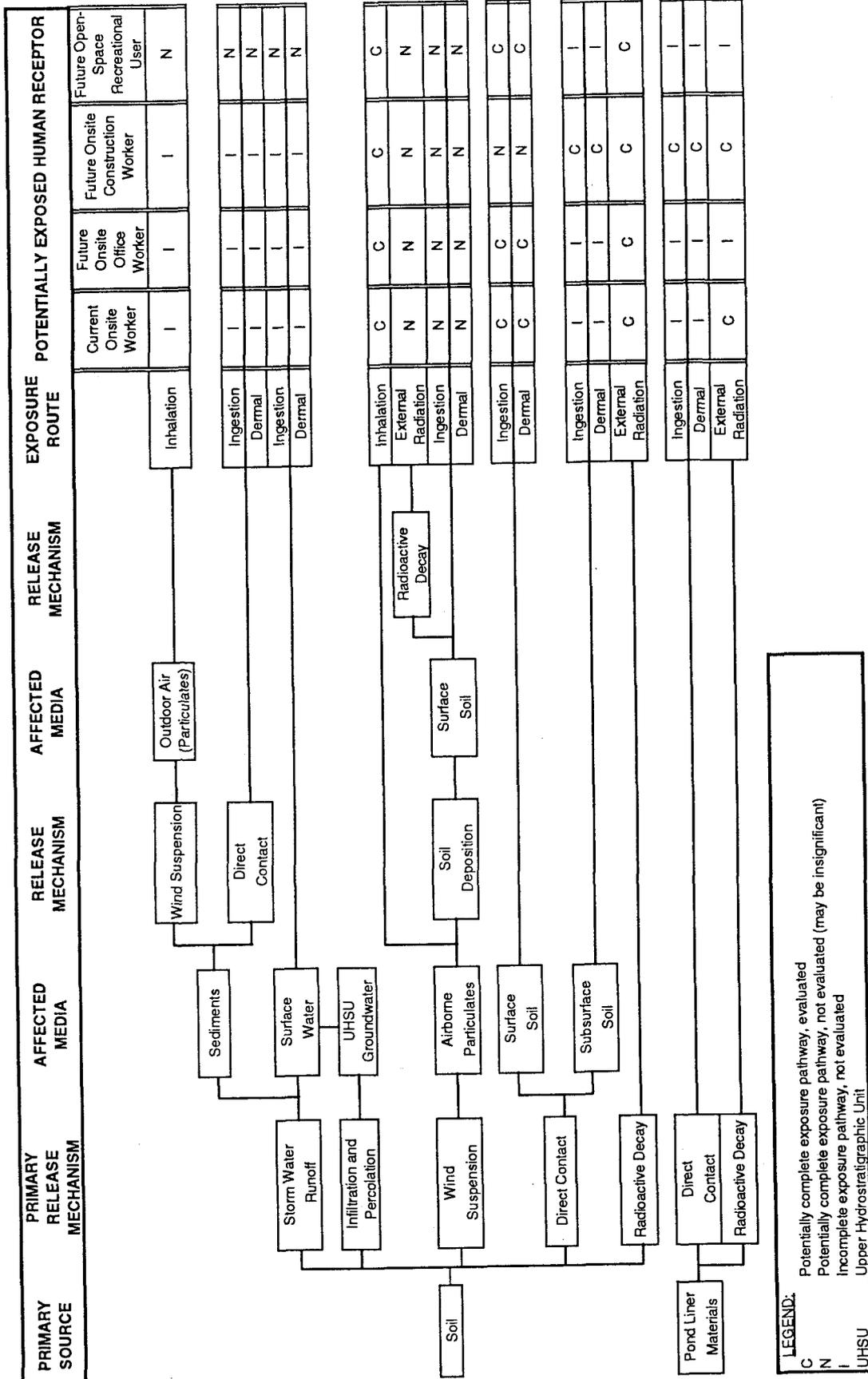


Figure 3-1 Conceptual Site Model for OU 4

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Table 3-1 Potentially Complete Exposure Pathways to be Quantitatively Evaluated

Potentially Exposed Receptor	Scenario	Areas of Concern	Potentially Complete Exposure Pathways
Onsite security worker	Current	1 and 2	Ingestion of surface soil
			Inhalation of airborne particulates from OU 4 surface soil
			Dermal contact with surface soil
			External irradiation from surface soil
Onsite office worker	Future	1	External irradiation from pond liner materials
			Ingestion of surface soil
			Inhalation of airborne particulates from OU 4 surface soil <sup>a</sup>
			Dermal contact with surface soil
Onsite construction worker	Future	1	External irradiation from surface soil
			Ingestion of subsurface soil
			Inhalation of airborne particulates from subsurface soil
			External irradiation from subsurface soil
Onsite open-space recreational user	Future	2	External irradiation from pond liner materials
			Ingestion of pond liner materials
			Ingestion of surface soil
			Inhalation of airborne particulates from OU4 surface soil
			External irradiation from surface soil

a. For the purpose of this risk assessment, the future onsite office worker is conservatively assumed to be exposed to outdoor air particulate matter and surface soil for the entire time at work.

Table 3-2 Exposure Point Concentrations for OU 4 Human Health Risk Assessment

Analyte	No. of Samples	Percent Detection (%)	Distribution Used	Minimum Detect (mg/kg or pCi/g)	Maximum Detect (mg/kg or pCi/g)	Mean (mg/kg or pCi/g)	Standard Deviation	95% UCL (mg/kg or pCi/g) <sup>a</sup>	Concentration in Air (mg/m <sup>3</sup> or pCi/m <sup>3</sup> ) <sup>b</sup>
<b>AOC No.1 -- Pond Liner Material COCs:</b>									
Americum-241	12	50	Normal	0.45	4.03	0.95	1.51	<b>1.73</b>	c
Cadmium	12	100	Lognormal	0.80	<b>69.7</b>	1.53	1.46	71.4	c
Plutonium-239/240	12	83	Lognormal	0.053	<b>3.13</b>	-1.853	2.11	40.58	c
Uranium-233/234	12	100	Lognormal	0.68	4.66	0.42	0.5	<b>2.38</b>	c
Uranium-238	12	100	Lognormal	0.52	2.68	0.11	0.48	<b>1.71</b>	c
<b>AOC No.1 – Surface Soil COCs:</b>									
Americum-241	22	100	Lognormal	0.044	<b>130</b>	0.91	2.39	518.3	2.81E-08
Aroclor-1254	28	7.14	Normal	0.6	2.96	0.27	0.57	<b>0.45</b>	9.72E-11
Beryllium	25	40	Lognormal	1.5	9.6	0.07	0.86	<b>2.34</b>	5.05E-10
Cadmium	25	72	Lognormal	1.7	356	1.72	2.03	<b>231.6</b>	5.00E-08
Plutonium-239/240	16	100	Lognormal	0.032	<b>56</b>	0.75	1.92	115.2	1.21E-08
Uranium-238	25	100	Lognormal	0.66	8.4	0.48	0.77	<b>3.09</b>	6.67E-10
<b>AOC No.1 – Subsurface Soil COCs:</b>									
Americum-241	92	100	Normal	-0.003	2.7	0.2	0.53	<b>0.3</b>	6.48E-11
Cadmium	95	27.4	Normal	1.3	547	18.69	76.17	<b>31.7</b>	6.85E-09
Plutonium-239/240	91	100	Normal	-0.004	3	0.2	0.52	<b>0.29</b>	6.26E-11
Radium-226	78	100	Lognormal	0.37	6.84	0.06	0.67	<b>1.55</b>	3.35E-10
Uranium-238	95	100	Normal	0.49	11.48	2.17	2.36	<b>2.57</b>	5.55E-10
<b>AOC No.2 – Surface Soil COCs:</b>									
Americum-241	29	100	Lognormal	0.03	7.5	-1.25	1.68	<b>3.44</b>	7.43E-10
Beryllium	29	3.45	Normal	2.5	2.5	0.76	0.35	<b>0.87</b>	1.88E-10
Cadmium	29	44.83	Normal	1.3	382	15.18	70.6	<b>37.5</b>	8.10E-09
Plutonium-239/240	28	100	Lognormal	0.013	19	-1.01	1.93	<b>9.42</b>	2.03E-09
Uranium-238	29	100	Normal	0.7	27	2.41	4.81	<b>3.93</b>	8.49E-10
<b>AOC No.2 – Subsurface Soil COCs:</b>									
Americum-241	3	100	Normal	0.005	<b>0.35</b>	0.21	0.18	0.51	7.56E-11
Cadmium	25	12	Normal	1.4	15.5	1.26	2.98	<b>2.28</b>	4.92E-10
Plutonium-239/240	3	100	Normal	0.28	<b>0.83</b>	0.5	0.29	0.99	1.79E-10
Radium-226	3	100	Normal	0.52	<b>0.84</b>	0.69	0.16	0.96	1.81E-10
Uranium-238	23	100	Normal	0.42	1.9	1.15	0.33	<b>1.27</b>	2.74E-10

- a. The 95% UCL was used as the exposure point concentration unless this value was greater than the maximum detected value, in which case, the maximum concentration was used. The value used is bolded in the table.
- b. The concentration in air is calculated by multiplying the soil concentration by 1/4,630,000,000; 4.63E+9 m<sup>3</sup>/kg is the particulate emission factor.
- c. The inhalation pathway was not assessed for exposure to pond liner materials.

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## 4.0 TOXICITY ASSESSMENT

This section describes the toxicity factors that are combined with estimated intakes of COCs to estimate potential risk associated with exposure. The toxicity factors used in the HHRA are EPA-verified or provisional carcinogenic slope factors (SFs), and noncarcinogenic reference doses (RfDs) or reference air concentrations (RfCs) for the COCs in OU 4. The toxicity factors presented in Table 4-1 are the most current factors available at this writing.

The principal indices of toxicity for chemicals with noncarcinogenic effects are the oral RfD and inhalation RfC. RfDs and RfCs can be considered threshold doses or exposure levels. At chemical doses or exposures below threshold values, adverse effects are not expected to occur. RfDs and RfCs incorporate a number of safety factors to ensure that they are protective of the health of all human populations, including sensitive subgroups (e.g., children and the elderly).

Oral and inhalation SFs are used to characterize the potency of carcinogens. A SF is a dose-response factor used to relate carcinogenic response to chemical dose. SFs are used to estimate the upperbound probability of an individual developing cancer as a result of exposure to a potential carcinogen. EPA policy assumes that carcinogenic responses have no threshold, and that exposure to a carcinogen may result in some finite cancer risk at any dose, no matter how small (EPA, 1989a).

SFs for radionuclides are derived considering the energy level of the radionuclide and residence time of the radionuclide in various body tissues. Duration of exposure is determined by the residence time of the radionuclide. SFs for external exposure to radionuclides are determined by the energy level of the radionuclide and duration of the exposure (i.e., time spent at the exposure point).

EPA assumes that any dose of a radionuclide has the potential to produce carcinogenic effects (no threshold). However, EPA does not recommend the evaluation of noncarcinogenic effects of radionuclides because the impacts have been shown to be insignificant compared to carcinogenic effects at most Superfund sites with potential radionuclide contamination (EPA, 1989a). EPA has developed both internal (i.e., inhalation and ingestion) and external SFs for the carcinogenic response to radionuclide exposure (EPA, 1994b).

The RfDs, RfCs, and SFs that were used in the OU 4 risk assessment were obtained from the following sources:

- EPA's Integrated Risk Information System on-line database (EPA, 1995b)
- EPA's Health Effects Assessment Summary Tables and Supplements (EPA, 1994b)

- EPA's Environmental Criteria and Assessment Office (ECAO) for interim and provisional values

#### **4.1 DERMAL EXPOSURE TO CHEMICALS**

EPA recommends using oral toxicity factors, adjusted (if possible) by a gastrointestinal absorption fraction, to evaluate toxic effects from dermal contact with potentially contaminated media (EPA, 1989a; 1992b). The oral toxicity factor relates the toxic response to an administered dose (intake) of chemical, which may be only partially absorbed by the body. Chemical intake from dermal contact is estimated as an absorbed dose. Therefore, EPA (1989a) suggests adjusting the oral toxicity factors by chemical-specific gastrointestinal absorption rates, if available, to yield toxicity factors for dermally absorbed chemicals. When chemical-specific gastrointestinal absorption rates are not available, gastrointestinal absorption is assumed to be 100% and the unadjusted oral toxicity factor is used to assess response to dermal absorption.

EPA (1992b) provides the following guidance on using oral toxicity factors to evaluate response to dermal exposure:

Until more appropriate dose-response factors are available, it is recommended that assessors use the oral factors. . . . Alternatively, if estimates of the gastrointestinal absorption fraction are available for the compound of interest in the appropriate vehicle, then the oral dose-response factor, unadjusted for absorption, can be converted to an absorbed dose basis. . . . Lacking this information, the oral factor should be used as is accompanied by a strong statement of the uncertainty involved.

Because chemical-specific gastrointestinal absorption rates are not available for most chemicals, unadjusted oral toxicity factors were used to assess effects of dermal absorption. If dermal absorption of particular chemicals is demonstrated to be a potential significant contributor to overall risk in the risk assessment, a more detailed analysis of the toxicity by dermal absorption may be warranted.

Table 4-1 Toxicity Factors <sup>a</sup> for OU 4 Chemicals of Concern

Analyte	Slope Factors			EPA Cancer Weight-of-Evidence	Reference Doses	
	Oral	Inhalation	External		Oral	Inhalation
<b>Organic Compounds:</b>						
Aroclor-1254	7.70E+00	-	-	B2	2.00E-05 <sup>b</sup>	-
<b>Metals:</b>						
Beryllium	4.30E+00	8.40E+00	-	B2	5.00E-03	-
Cadmium	-	6.30E+00	-	B1	5.00E-04	-
<b>Radionuclides:</b>						
Americium-241 <sup>c</sup>	3.28E-10	3.85E-08	4.59E-09	A	-	-
Plutonium-239/240 <sup>c,d</sup>	3.16E-10	2.78E-08	1.87E-11	A	-	-
Radium-226+D <sup>c</sup>	2.96E-10	2.75E-09	6.74E-06	A	-	-
Uranium-233/234 <sup>c,e</sup>	4.44E-11	1.40E-08	2.14E-11	A	-	-
Uranium-238+D <sup>c</sup>	6.20E-11	1.24E-08	5.25E-08	A	-	-

Sources:

- a. All toxicity values are from IRIS (EPA, 1995) unless otherwise noted.
- b. HEAST Supplement Number 1, July 1994 (EPA, 1994)
- c. HEAST Supplement Number 2, November 1994 (EPA, 1994)
- d. The slope factor used was the more conservative of plutonium-239 or -240.
- e. Slope factors shown are for uranium-234.

EPA Cancer Weight-of-Evidence :

- A = Human carcinogen
- B1 = Probable human carcinogen (limited human data)
- B2 = Probable human carcinogen (animal data only)
- C = Possible human carcinogen
- D = Noncarcinogenic (inadequate evidence)
- = Not classifiable or not carcinogenic

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## 5.0 RISK CHARACTERIZATION AND UNCERTAINTY

### 5.1 RISK CHARACTERIZATION

Risk characterization is the final step of the risk assessment process. In this step, the toxicity factors, noncarcinogenic reference doses (RfDs), and carcinogenic slope factors (SFs) for the COCs are applied in conjunction with estimated chemical intakes, to predict potential noncarcinogenic and carcinogenic health hazards and risks to exposed individuals. Spreadsheets with risk calculations are presented in Appendix C.

#### 5.1.1 Estimating the Hazard Index for Noncarcinogenic Effects

The potential for noncarcinogenic effects is characterized by comparing estimated chemical intakes (see Section 3.3) with chemical-specific RfDs (see Table 4-2). The resulting ratio is called a hazard quotient (HQ). It is derived in the following manner

$$\text{Noncancer Hazard Quotient} = \frac{\text{Chemical Intake (mg/kg-day)}}{\text{RfD (mg/kg-day)}} \quad (5-1)$$

The RfD concept assumes that there is a level of intake (the RfD) below which it is unlikely that even sensitive individuals will experience adverse health effects over a lifetime of exposure. If the average daily intake exceeds the RfD (if the HQ exceeds 1), concern for potential noncancer effects may increase (EPA, 1989a). It should be noted, however, that the level of concern does not increase linearly as the RfD is approached or exceeded. This is because all RfDs are not assessed equally and are not based on the same severity of toxic effects. Because the HQ does not define a dose-response relationship, the numerical value is not a direct estimate of risk (EPA, 1986), but rather an indicator that adverse health effects are more likely to occur as the HQ increases.

To assess exposure to multiple chemicals, the HQs for each chemical are summed to yield a hazard index (HI) for each receptor pathway. The assumption of additive effects reflected in the HI is most properly applied to substances that induce the same effect by the same mechanism (EPA 1986). Consequently, summing HQs for substances that are not expected to induce the same type of effect is likely to overestimate the potential for adverse effects. The HI provides a conservative measure of the potential for adverse effects and is dependent on the quality of experimentally derived evidence.

Where an individual may be exposed by multiple pathways, the HIs from all relevant pathways are summed to obtain the total HI for that receptor. If the total HI is less than or equal to 1, multiple-pathway exposures to COCs at the site are judged unlikely to result in an adverse health effect. If the

sum is greater than 1, further evaluation of exposure assumptions and toxicity, including consideration of specific target organs affected and mechanisms of toxic actions of COCs, is warranted to ascertain if the cumulative exposure would be likely to harm exposed individuals.

### 5.1.2 Estimating Carcinogenic Risk

Potential carcinogenic effects are characterized in terms of the incremental probability of an individual developing cancer over a lifetime (70 years) as a result of exposure to a potential carcinogen. Known as the excess lifetime cancer risk, it is an estimate of the increased risk of developing cancer above the background rate, which is estimated at about 3E-01 (30%). Excess lifetime cancer risk is estimated from the projected lifetime average daily intake and the cancer SF, which represents an upperbound estimate of the dose-response relationship. Excess lifetime cancer risk is calculated by multiplying the average daily chemical intake by the cancer SF

$$\text{Cancer Risk} = \text{Average Daily Intake (mg/kg-day)} \times \text{SF (mg/kg-day)}^{-1} \quad (5-2)$$

Carcinogenic risks estimated using SFs are upperbound estimates. This means that the actual risk is likely to be less than the estimated risk (EPA, 1989a). RME cancer risks may be significantly overestimated because they are calculated by multiplying together 95th percentile estimates of cancer potency, 95% UCLs of concentrations, and high-end estimates of several exposure parameters.

The risks resulting from exposure to multiple carcinogens are assumed to be additive (EPA, 1986). The total cancer risk is estimated by summing the risks estimated for each COC and for each pathway. This is a highly conservative approach that results in an artificially elevated estimate of cancer risk, especially if several carcinogens are present, because 95th percentile estimates are not strictly additive (EPA, 1989a).

In accordance with EPA guidance (EPA, 1989a), radionuclide risks were calculated separately for each exposure pathway in each AOC. The carcinogenic risks for each pathway (as a result of radionuclide presence) are presented in Appendix C. The radiological and chemical risks were summed for the summary tables (Tables 5-1 and 5-2) in order to determine the overall potential human health hazard at the site. EPA (1989a) provides the following guidance:

Estimates of lifetime risk of cancer to exposed individuals resulting from radiological and chemical risk assessments may be summed in order to determine the overall potential human health hazard associated with the site.

EPA policy must be considered in order to interpret the significance of the cancer risk estimates. The National Oil and Hazardous Substances Pollution Contingency Plan (EPA, 1990) states that "For known or suspected carcinogens, acceptable exposure levels are generally concentration levels that represent an excess upperbound lifetime cancer risk of between  $10^{-4}$  and  $10^{-6}$ ." When cumulative carcinogenic risk to an individual (based on RME exposure) does not exceed  $10^{-4}$  and the total HI does not exceed 1, action is generally not warranted for protection of public health (EPA, 1991).

### 5.1.3 AOC No. 1

As discussed in Section 2.3, health hazards/risks for onsite receptors were evaluated in two AOCS identified in the OU 4. Onsite receptors evaluated in AOC No. 1 include current security workers, future office workers, and future construction workers.

AOC No. 1 is the Solar Pond Area (IHSS 101), which comprises about 11 acres. Hazard/risk results for current and future receptors evaluated in AOC No. 1 are summarized in Table 5-1 and detailed in Appendix C, Tables C-1 to C-16.

### Noncarcinogenic Hazard Index

The cumulative HIs for noncarcinogenic health effects for current and future onsite receptors in AOC No. 1 are 0.1 or less for the CT and RME conditions (Table 5-1). Because the HIs are less than 1, no adverse noncancer health effects are expected under RME conditions, even for sensitive individuals. Results for each receptor are discussed below:

Current Security Worker—Exposure pathways evaluated for noncarcinogenic effects for the current security worker were:

- Inhalation of airborne particulates from surface soil
- Surface soil ingestion
- Dermal contact with surface soil

The cumulative HIs for noncarcinogenic health effects for current security workers are 0.001 and 0.01 for the CT and RME conditions, respectively (see Table 5-1), indicating that no adverse noncancer health effects are expected for the current security worker from AOC No. 1.

Future Office Worker—Exposure pathways evaluated noncarcinogenic health effects for the future office worker were the same as for the current security worker.

The cumulative HIs for noncarcinogenic health effects for the future office worker are 0.01 and 0.1 for the CT and RME conditions, respectively (see Table 5-1). These values are below 1, indicating that no adverse noncancer health effects are expected for future office workers in AOC No. 1.

Future Construction Worker—The future construction worker was evaluated for the following exposure pathways:

- Inhalation of airborne particulates from subsurface
- Ingestion of subsurface soil
- Ingestion of pond liner materials
- Dermal contact with subsurface soil

The cumulative HIs for noncarcinogenic health effects for the future construction worker are 0.01 and 0.1 for the CT and RME conditions, respectively (Table 5-1), indicating that no adverse noncancer health effects are expected for this receptor in AOC No. 1.

### **Carcinogenic Risk**

Excess lifetime cancer risk estimates for onsite receptors in AOC No. 1 are summarized in Table 5-1 and detailed in Appendix C. The highest cancer risk estimate for all receptors is  $2E-05$  (2 in 100,000), which is within EPA's target risk range of  $1E-06$  to  $1E-04$  for evaluating risk associated with exposure to chemicals released from hazardous waste sites, and indicates that no action may be warranted (EPA, 1989a). Results for each receptor are discussed below.

Current Security Worker—The same exposure pathways were evaluated as for calculation of the HI, with the addition of:

- External irradiation from decay of radionuclides in surface soil
- External irradiation from decay of radionuclides in pond liner materials

The estimated excess lifetime cancer risk for the current security worker in AOC No. 1 is  $3E-08$  under the CT exposure condition and  $8E-07$  under the RME condition (Table 5-1).

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Future Office Worker—The estimated excess lifetime cancer risk for the future office worker in AOC No. 1 is  $6E-07$  under the CT exposure condition and  $2E-05$  under the RME condition (Table 5-1). This scenario falls within the EPA's target risk range of  $1E-06$  to  $1E-04$ .

Future Construction Worker—The same exposure pathways were evaluated as for calculation of the HI, with the addition of:

- External irradiation from decay of radionuclides in surface soil
- External irradiation from decay of radionuclides in pond liner materials

The estimated excess lifetime cancer risk for the future construction worker is  $4E-07$  under the CT exposure condition and  $1E-06$  under the RME condition (Table 5-1). This scenario is at the bottom end of the EPA's target risk range of  $1E-06$  to  $1E-04$ .

#### 5.1.4 AOC No. 2

AOC No. 2 includes the down slope area, to the north of the solar ponds, and is approximately 28 acres in size. Onsite receptors evaluated in this AOC were the current security worker and future open space recreational users. Exposure pathways evaluated for the current security worker were the same as for AOC No. 1, with the exception of exposures to the pond liner materials. Exposure pathways evaluated for the future open-space recreational user are listed below.

- Inhalation of airborne particulates from surface soil
- Surface soil ingestion - adults (noncarcinogens)
- Surface soil ingestion - children (noncarcinogens)
- Surface soil ingestion (carcinogens)
- Dermal contact with surface soil
- External irradiation from decay of radionuclides in surface soil

Exposure pathways evaluated and hazard/risk results for all receptors in AOC No. 2 are summarized in Table 5-2 and detailed in Appendix C, Tables C-17 to C-24.

## Noncarcinogenic Hazard Index

For all current and future onsite receptors, the cumulative HIs for noncarcinogenic effects in AOC No. 2 are 0.01 or less for the CT and RME conditions (Table 5-2). Therefore, no adverse health effects are expected, even for sensitive individuals, under RME conditions. Results for each receptor are listed below.

Current Security Worker—The cumulative HIs for noncarcinogenic health effects are 0.0003 and for the CT and 0.002 RME conditions.

Future Open-Space Recreational User—The cumulative HIs for noncarcinogenic health effects for a future open-space recreational user are 0.004 and for the CT and 0.02 RME conditions.

## Carcinogenic Risk

For current and potential, future onsite receptors, the estimated excess lifetime cancer risks in AOC No. 2 are less than  $1\text{E}-06$  (1 in 1 million) for both CT and RME conditions (Table 5-2). The estimates signify that cancer risks are negligible for AOC No. 2 receptors. They are below EPA's target risk range of  $1\text{E}-06$  to  $1\text{E}-04$  from exposure to chemicals released from hazardous waste sites (EPA, 1989a). This indicates that no action is needed to reduce health risks and hazards from AOC No. 2 surface soil. Cancer risk estimates for each receptor are listed below.

Current Security Worker—The estimated excess lifetime cancer risk is  $7\text{E}-09$  for the CT exposure condition and  $2\text{E}-07$  under the RME condition.

Future Open-Space Recreational User—The estimated excess lifetime cancer risk is  $3\text{E}-08$  for the CT exposure condition and  $5\text{E}-07$  under the RME condition.

### 5.1.5 Summary of Cumulative Hazard/Risk Results

Noncarcinogenic HIs and cancer risks were estimated for five onsite receptors in two AOCS in OU 4. Results are summarized in Tables 5-1 and 5-2 and detailed in Appendix C.

The exposure pathways evaluated for all receptors included soil ingestion and dermal contact, inhalation of particulates from soil, and external irradiation from soil. Additional pathways evaluated for the future construction worker included ingestion of pond liner materials and external irradiation from pond liner materials (see Section 3.1). Exposure of current and future onsite receptors to OU 4 groundwater was not evaluated in this risk assessment by agreement between DOE, EPA, and CDPHE (Kaiser-Hill, 1995).

Cumulative HIs were less than 1 and cancer risk estimates were  $2E-05$  or lower for all receptors in both AOCs. When cumulative carcinogenic risk to an individual (based on RME exposure), does not exceed  $10^{-4}$  and the total HI does not exceed 1, action is generally not warranted for protection of public health (EPA, 1991b).

## 5.2 RADIATION DOSE CALCULATIONS

Total radiation doses for one year of exposure (expressed as total Effective Dose Equivalent [EDE], in mrem/year) were estimated for receptors exposed to radionuclides in soil, air, and other media by ingestion, inhalation, and external irradiation pathways. The estimated doses are compared to DOE radiation standards for protection of public health, also expressed in mrem/yr.

### 5.2.1 Methodology

This section defines the terms used in estimating annual radiation doses, explains how the doses are calculated, and describes the national annual radiation protection standards that are used for comparison to the calculated doses. Definitions of frequently used terms are given below for convenience of the reader.

- *Absorbed Dose* - is the energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest in that material. The absorbed dose is expressed in units of rad (or gray). (1 rad = 0.01 gray.)
- *Committed Dose Equivalent* - is the predicted total dose equivalent to a tissue or organ over a 50-year period after a known intake of a radionuclide into the body. It does not include contributions from external dose. Committed dose equivalent is expressed in units of rem (or sievert).
- *Committed Effective Dose Equivalent (CEDE)* - is the sum of the committed dose equivalents to various tissues in the body, each multiplied by the appropriate weighting factor. Committed effective dose equivalent is expressed in units of rem (or sievert).
- *Dose Equivalent* - is the product of absorbed dose in rad (or gray) in tissue and a quality factor. Dose equivalent is expressed in units of rem (or sievert).
- *Effective Dose Equivalent (EDE)* - is the summation of the products of the dose equivalent received by specified tissues of the body and a tissue-specific weighting factor. This sum is a risk-equivalent value and can be used to estimate the health-effects risk of the exposed individual. The tissue-specific weighting factor represents the fraction of the total health risk resulting from uniform whole-body irradiation that would be contributed by the particular tissue. The EDE

includes the CEDE from internal deposition of radionuclides and the EDE due to penetrating radiation from sources external to the body. Effective dose equivalent is expressed in units of rem (or sievert).

- *Weighting Factor* - is tissue-specific and represents the fraction of the total health risk resulting from uniform, whole-body irradiation that could be contributed to that particular tissue. The weighting factors recommended by the ICRP (ICRP, 1977) are as follows:

<u>Organ or Tissue</u>	<u>Weighting Factor</u>
Gonads	0.25
Breasts	0.15
Red Bone Marrow	0.12
Lungs	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder <sup>a</sup>	0.30

<sup>a</sup>Remainder means the other organs with the highest dose (e.g., liver, kidney, spleen, thymus, adrenal, pancreas, stomach, small intestine, or upper and lower large intestine, but excluding skin, lens of the eye, and extremities). The weighting factor for each of these organs is 0.06.

*Quality Factor* - is the principal modifying factor used to calculate the dose equivalent from the absorbed dose. For the purposes of the Order, the following quality factors, which are taken from DOE 5480.11, are to be used.

<u>Radiation Type</u>	<u>Quality Factor</u>
X-rays, gamma rays, positrons, and electrons (including tritium)	1
Neutrons, <10 keV	3
Neutrons, >10 keV Protons and single charged particles of unknown energy with rest mass > one atomic mass unit	10
Alpha Particles Multiple charges particles (and particles of unknown energy)	20

Note: \* For neutrons of known energies, the more detailed quality factors given in DOE Order 5480.11 may be used.

- *Radioactivity* - means the property or characteristic of radioactive material to spontaneously "disintegrate" with the emission of energy in the form of radiation. The unit of radioactivity is the curie (or becquerel).

## 5.2.2 Calculating Annual Radiation Doses

Annual radiation doses were determined by selecting dose conversion factors and calculating the radionuclide intake for each receptor and pathway. The annual EDE was then calculated.

### Selection of Dose Conversion Factors

Radionuclide-specific dose conversion factors for the CEDE were used in the calculation of EDEs for the ingestion and inhalation routes of exposure. Radionuclide-specific dose conversion factors for the EDEs were used for the external irradiation route of exposure. These values were obtained from EPA's *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, (EPA, 1988) for the inhalation and ingestion route of exposure, and from the *External Exposure to Radionuclides in Air, Water, and Soil* (EPA, 1993a).

For some radionuclides, dose conversion factors (DCF) vary based on the chemical species (e.g., oxidation state or mineralized form) of the radionuclide. Differences in DCFs for the ingestion route of exposure reflect differences in fractional uptake ( $f_1$ ) of radionuclide species from the small intestine to blood. Less soluble radionuclide forms have smaller DCFs than more soluble forms because the less soluble forms are absorbed to a lesser degree from the gastrointestinal tract into the bloodstream (EPA, 1988d). Because the form of radionuclide is not known, the most conservative (or greatest  $f_1$ ) was used for the most conservative estimate of radionuclide intake via ingestion. Table 5-3 lists the fractional uptakes and ingestion DCFs (in Sv/Bq) for each radionuclide of concern.

DCFs for the inhalation route of exposure also vary based on the chemical species of the radionuclide. The different DCFs reflect the difference in the rates that radionuclide species are cleared from the lungs. Lung clearance rates are classified as days (D), weeks (W), or years (Y). In general, less soluble forms of the radionuclide are cleared from the lungs more slowly than more soluble forms. Once again, the species of each radionuclide of concern is not known, so the most conservative lung clearance class was used in order to determine radionuclide intake via inhalation. Table 5-3 lists the most conservative lung clearance class and corresponding inhalation DCF (in Sv/Bq) for each radionuclide of concern. A check was performed to ensure that the  $f$  value and the lung clearance class were compatible and that the combination gave the highest combined ingestion and inhalation CEDE.

For the external irradiation route of exposure, the DCF is the annual EDE received (mrem/yr) from exposure to radiation from each radionuclide present external to the body. The radiation field is assumed to be equal to the radiation level at a distance of 1 meter (m) above the ground surface. The

DCFs for external radiation exposure from surface soil were taken from an EPA report (EPA, 1993) and are listed in terms of mrem/year per pCi/gram in Table 5-3.

### Ingestion and Inhalation Routes of Exposure

For the inhalation and ingestion routes of exposure, annual intake of radionuclides, expressed in pCi/yr, is first calculated using

$$\text{Intake (pCi/year)} = C \times IR \times EF \quad (5-3)$$

where

C = activity concentration at the exposure point (pCi/g, pCi/L, or pCi/m<sup>3</sup>)

IR = intake rate (mg/day, L/day, m<sup>3</sup>/day)

EF = exposure frequency (days/year).

Exposure factors used in calculating annual radionuclide intake for specific receptors and pathways are identical to the exposure factors used in the intake equations in Sections 3.1 through 3.3. The annual intake of each radionuclide in pCi/year is multiplied by the CEDE DCF (mrem/pCi or Sv/Bq) from Table 5-3 to estimate the CEDE for one year (mrem/year).

### External Irradiation

For the external irradiation route of exposure, a concentration in soil (AC in pCi-yr/gram) is calculated using

$$AC \left( \frac{\text{pCi-yr}}{\text{gram}} \right) = C \times ED \times EF_r \times (1 - Se) \times Te \quad (5-4)$$

where

C = mass activity concentration at the exposure point (pCi/g-soil)

ED = exposure duration (1 year)

EF<sub>r</sub> = exposure frequency ratio (unitless)

Se = gamma shielding factor (unitless)

Te = gamma exposure factor (unitless).

The concentration of each radionuclide in soil, AC (in pCi-year/gram), is multiplied by the dose conversion factor for external radiation (mrem/year per pCi/gram) (Table 5-3) to estimate the annual EDE (mrem) for each radionuclide.

## Estimating Annual Radiation Dose

The sum of the CEDEs from all radionuclides taken into the body in a year, and the EDEs for all radionuclides external to the body, is compared to radiation protection standards.

Annual radiation doses were estimated for all receptors and exposure areas. The results are summarized (Tables 5-4 and 5-5) and compared to radiation protection standards in the following sections.

### 5.2.3 Radiation Protection Standards

DOE Order 5480.11, *Radiation Protection for Occupational Workers*, limits radiation exposure of radiological workers to 50 mSv/year (5,000 mrem/yr). DOE Order 5400.5, *Radiation Protection of the Public and the Environment*, limits the annual radiation dose for members of the public to 1 mSv/year (100 mrem/year) for all combined routes of exposure. The occupational limit for general employees (i.e., those not considered to be radiological workers) may be 100 mrem/year to 5,000 mrem/year, depending on employment circumstances. However, general employees who have not completed Radiological Worker I or II Training are not permitted unescorted access to any area in which they are expected to receive doses in excess of 100 mrem in one year. General employees who have not received Radiological Worker I or II Training are not normally expected to exceed 100 mrem in a year. These values are for radiation doses received in addition to that from natural background radiation (U.S. average background radiation is approximately 300 mrem/year [NCRP, 1987]) and that received from routine medical treatments (U.S. average is approximately 50 mrem/year [NCRP, 1987]). Background levels in the Denver area are estimated to range from 350 to 700 mrem/year; these levels are higher than the national average because of naturally occurring high levels of radium, thorium, and radon in native rock and soils, and because cosmic radiation exposure increases at higher elevations (NCRP, 1987).

### 5.2.4 Point Estimates of Annual Radiation Dose

Annual radiation doses in terms of mrem/year were calculated for onsite receptors in AOC No. 1, and AOC No. 2. Results are summarized in Tables 5-4 and 5-5. Detailed spreadsheets are presented in Appendix C, Tables C-25 through C-24.

### Future Construction Worker

Radionuclide exposure pathways evaluated for the future construction worker as follows:

- Ingestion of subsurface soil

- Ingestion of pond liner materials
- Inhalation of airborne particulates from subsurface soils
- External irradiation from subsurface soil
- External irradiation from pond liner materials

The future construction worker is a potential receptor in AOC No. 1. The estimated total annual radiation dose from subsurface soil for the future construction worker in AOC No. 1 is  $9.5E-03$  mrem/year for the CT exposure and  $4.7E-02$  mrem/year for the RME. The total annual radiation dose for the construction worker from exposure to pond liner materials in AOC No. 1 is  $8.3E-02$  mrem/year for the CT exposure and  $3.0E-01$  mrem/year for the RME (Table 5-4). These values are below the DOE limits for radiological workers (5,000 mrem/year) and members of the public (100 rem/year).

#### **Current Security Worker**

Radionuclide exposure pathways evaluated for the current security worker were as follows:

- Ingestion of surface soil
- Inhalation of airborne particles from surface soil
- External irradiation from surface soil
- External irradiation from pond liner materials

The current security worker is a potential receptor in AOC No. 1 and AOC No. 2. The estimated total annual dose for the current security worker in AOC No. 1 is  $1.5E+00$  mrem/year for the CT exposure conditions and  $8.5E+00$  mrem/year for the RME conditions (Table 5-4). The total annual radiation dose for the current security worker in AOC No. 2 is  $1.1E-01$  mrem/year for the average (CT) exposure condition and  $5.9E-01$  mrem/year for the RME condition (Table 5-5). These values are below the DOE limits for radiological workers (5,000 mrem/year) and members of the public (100 rem/year).

#### **Future Office Worker**

The future office worker is a potential receptor in AOC No. 1. The office worker is not a potential receptor in AOC No. 2. Radionuclide exposure pathways evaluated for the office worker were as follows:

- Ingestion of surface soil
- Inhalation of airborne particulates from surface soil
- External irradiation from surface soil

The estimated total annual dose for the future office worker in AOC No. 1 is 1.2E+00 mrem/year for the CT exposure conditions and 9.3E+00 mrem/year for the RME conditions (Table 5-4). These values are below the DOE limits for radiological workers (5,000 mrem/year) and members of the public (100 rem/year).

#### **Future Open-Space User**

The future open-space user is a potential receptor in AOC No. 2, but not in AOC No. 1. Radionuclide exposure pathways for the adult recreational user were as follows:

- Ingestion of surface soil
- Inhalation of airborne particles from surface soil
- External irradiation from surface soil

The estimated total annual dose for the adult recreational receptor in AOC No. 2 is 1.2E-02 mrem/year for the CT exposure conditions and 6.1E-02 mrem/year for the RME conditions (Table 5-5). These values are below the DOE limits for radiological workers (5,000 mrem/year) and members of the public (100 rem/year).

The radionuclide exposure pathway for the child open-space user in AOC No. 2 was ingestion of surface soil. The estimated total annual dose for the child receptor in AOC No. 2 is 2.3E-02 mrem/yr for CT conditions, and 1.2E-01 mrem/year for RME exposure conditions (Table 5-5).

#### **5.2.5 Summary of Results**

Estimated total annual radiation doses for all receptors in all AOCs were less than 10 mrem/yr, which falls well below the DOE limit of 100 mrem/yr for members of the public and indicates that estimated exposure to radionuclides in OU 4 are not high enough to be of concern.

### **5.3 SUMMARY OF ECOLOGICAL RISK ASSESSMENT AT RFETS**

Initially, ecological risk assessments (ERAs) were planned for each OU as part of the OU-specific RFI/RI. However, EPA, CDPHE, and DOE agreed that it is ecologically more appropriate to conduct the ERAs for each watershed. This scale is more relevant to ecological receptors, because they are not constrained by the administrative boundaries associated with the OUs. ERAs are now required for four areas: (1) the industrial area/protected area, (2) the Walnut Creek watershed, (3) the Woman Creek watershed, and (4) offsite areas.

The ERA results for the downgradient portion of OU 4 (AOC No. 2) are included in the ERA conducted for the Walnut Creek watershed. The complete Walnut Creek ERA, which is partially summarized in this section, is presented in total as Appendix F to the RFI/RI report for OU 6 (DOE, 1995a). The only appropriate receptors for the OU 4 AOC No. 2 ERA are small mammals, terrestrial-feeding raptors, and vegetation communities. An ERA for the industrial area, of which OU 4 AOC No. 1 is a part, has not yet been conducted.

Preliminary risk estimates indicated little risk to small mammals from ingestion of contaminants in RFETS source areas. Preble's meadow jumping mouse (PMJM) was chosen to represent small mammals in the exposure pathway model because of its small home range, its omnivorous diet, and its status as a federal Category 2 species. Exposure risk to PMJM was evaluated by estimating contaminant uptake through ingestion of contaminated vegetation and terrestrial arthropods, as well as incidental ingestion of soil and dry sediment. The potential risk to PMJM at RFETS is fairly consistent across source areas. Although the PMJM hazard index (sum of hazard quotients [HQs] in an area) for OU 4 AOC No. 2 is 8.1, there is no ecological chemical of concern (ECOC) with an HQ greater than 1. Three metals have HQs greater than 1, but they are not PCOCs; they are considered background. Therefore, risk to small mammals from chemicals detected in OU 4 AOC No. 2 is considered minimal.

The American kestrel was selected as the limiting raptorial receptor in the Walnut Creek ERA due to its small home range compared to other local raptor species, and it is known to breed within the boundaries of RFETS. Exposure risk to American kestrels was evaluated by estimating contaminant uptake through ingestion of contaminated arthropods and small mammals, as well as incidental ingestion of soil while feeding on these prey. Mercury, chromium, lead, and vanadium were selected as the ECOCs for this receptor at RFETS. However, the results of the preliminary exposure screen for the American kestrel indicated that mercury was the only ECOC found at OU 4 AOC No. 2. At AOC No. 2, mercury was found to contribute 32.26 percent of the total risk, with a resulting HQ of 1.36; indicating potentially significant risk from exposure to mercury. The primary exposure pathway was ingestion of small mammals. Further refinement of the exposure estimates, accomplished by reviewing information on contaminant distribution and making probabilistic exposure estimates, has

lead the RFETS ecological risk assessors to conclude that risks to American kestrel from eating small mammals in AOC No. 2 would be minimal.

Results of the Tier 3 ERA screen for risks to vegetation communities indicated several PCOCs, mostly metals, exceed subsurface soil toxicity reference values (TRVs) in several areas. For OU 4 AOC No. 2, the vegetation ECOCs in subsurface soil are nitrate/nitrite (HQ = 4.8), zinc (HQ = 1.4), and lead (HQ = 1.3). Nitrate concentrations in this area are probably associated with a plume of contaminated groundwater originating in the Solar Ponds area. The HQs for the metal ECOCs in subsurface soil were both below 2. Although HQs greater than 1 may indicate concentrations that exceed background, there is too much uncertainty surrounding the use of TRVs and background comparisons to state conclusively that these metals are creating risk to the vegetation communities. Areas of obvious vegetation stress were not observed during preliminary field surveys. Thus, the importance of these risk estimates is not clear.

Transuranic radionuclides were identified as PCOCs for most OUs. The ECOC screen indicated relatively few areas at RFETS with radionuclide concentrations (activities) in soils that exceeded TRVs. Because no radionuclide activities in OU 4 AOC No. 2 soils exceeded TRVs, risks of adverse effects to the ecological communities in this area appear to be negligible.

The conclusions of the Walnut Creek ERA, with regard to OU 4, indicate that ecological risks due to contaminants present in AOC No. 2 are minimal.

#### **5.4 UNCERTAINTIES AND LIMITATIONS**

This section discusses the major uncertainties and limitations of the OU 4 HHRA and how the results and conclusions may be affected.

Uncertainties and limitations are inherent in the risk assessment process. The level of certainty associated with the conclusions of the risk assessment are conditional upon the quality of data, methods used to identify COCs, estimates of chemical concentrations, assumptions made in estimating exposure conditions, the conservatism of the methods used to develop toxicity values, and the conservatism of methods used to characterize risk.

At all stages of this risk assessment, conservative assumptions were made to avoid underestimating potential health risk or hazard. Carcinogenic risks estimated using SFs are upperbound estimates. RME cancer risks may be overestimated because they are calculated by multiplying together 95th percentile estimates of cancer potency, 95% UCLs of concentrations, and high-end estimates of several exposure parameters. Estimates of noncarcinogenic toxicity values (RfDs) are also very

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conservative and may result in an overestimate of noncarcinogenic health hazards. This means that the actual risk is likely to be less than the estimated risk (EPA, 1989a).

RME estimates of potential health risks associated with current and potential future exposures in OU 4 should be considered upper bounds. It is unlikely that true risk is greater than the estimated risk. Although point estimates of risk are made, it should be recognized that each one represents a range of possible risk and is only an indicator.

CT estimates of potential health risks combine average or median values for all exposure factors. CT risk estimates are meant to better define the likely range of potential risks and address the uncertainty associated with the RME estimates (EPA, 1993b). Both CT and RME estimates should be examined carefully in order to come to an understanding of the risk range or distribution, and the uncertainty associated with the point estimates.

Uncertainties in the human health risk assessment for OU 4 at RFETS lie chiefly in the identification of COCs, the estimation of exposure point concentrations, sampling limitations, media not evaluated, the assumptions regarding human exposure scenarios at RFETS, and in the assessment of chemical toxicity. Each of these is discussed in the following sections.

#### 5.4.1 Identification of COCs

Samples of surface soil, subsurface soil, and pond liner materials were collected in OU 4 according to approved work plans, and most of the chemical analytical results were validated by a validation subcontractor in accordance with EPA and RFETS data validation guidelines. Work plans are presented in the *Final Phase I RFI/RI Work Plan* for OU No. 4 (DOE, 1992), and the chemical analytical database and data review are described in Appendix A. All analytical results were screened to identify a subset of chemicals to evaluate in the risk assessment. The screening process is intended to identify all analytes whose concentrations are high enough that there may be concern for potential health hazards. A background comparison for inorganic analytes, a frequency of detection test, an essential nutrient screen, and concentration/toxicity screens that estimate the relative contribution to overall risk based on maximum detected concentrations are the basic components of the screen (see Sections 2.0 through 2.3 and Appendix A).

Concentration/toxicity screens have the potential for eliminating chemicals that could contribute significantly to overall risk if the relative magnitude of maximum concentrations differs from the relative magnitude of exposure concentrations (95% UCLs of the mean). However, the results of the risk assessment demonstrate that the selection process was sufficiently conservative to ensure that potentially significant sources of health risk were not overlooked.

Chemicals of concern in surface soil, subsurface soil, and pond liner material were PCOCs identified in the concentration/toxicity screens as contributors of at least 1 percent of an overall "risk factor," based on maximum detected concentrations. Of the chemicals retained as COCs on the basis of the screen, only two or three COCs were found to contribute the majority of total estimated risk, and other COCs evaluated in the quantitative risk assessment contributed negligible total risk.

Three COCs were identified in surface soil on the basis of the carcinogenic concentration/toxicity screen. Seven polycyclic aromatic hydrocarbons (PAHs) were not included as COCs (see Appendix C, Table C-14). The two PAHs contributing the greatest amount to the total risk factor were benzo(a)pyrene and dibenz(a,h)-anthracene. These compounds also have the highest oral SFs of the compounds that contributed less than 1 percent of the total risk factor. Even at maximum concentrations, risks from oral ingestion to future office workers are an order of magnitude or more lower than the total estimated risk. Ingestion risk for the future office worker from benzo(a)pyrene is  $3E-06$  and from dibenz(a,h)-anthracene is  $7E-07$ . These risk values would have no effect on the total risk estimate (see discussion in Section 5.4.5).

In subsurface soil, cadmium was the only analyte identified as a noncarcinogenic COC, based on the concentration/toxicity screen, because the oral RfD for cadmium is 100 times lower than the RfDs for other PCOCs in subsurface soil. Consequently, cadmium contributed 100 percent of the RME HI of 0.1 for the office worker scenario. Analytes excluded by the concentration/toxicity screen for noncarcinogens were lithium, nitrate, strontium, zinc, bis(2-ethylhexyl)phthalate, toluene, 2-butanone, acetone, di-n-butylphthalate, and methylene chloride. Of these, lithium and nitrate contributed the most to the total risk factor. However, even at the maximum concentrations, RME HIs for these compounds are two orders of magnitude lower than the HQ reported for the construction worker.

These examples show that compounds excluded by the concentration/toxicity screen would have contributed insignificantly to estimated total noncarcinogenic hazard or carcinogenic risk from exposure to surface and subsurface soils.

#### **5.4.2 Exposure Point Concentrations**

The major uncertainties in estimating exposure point concentrations of COCs lie in the numerical estimate of an average exposure concentration and in the default PEF used to estimate concentrations in air. The uncertainties can result in either an underestimate or overestimate of the average exposure concentration; however, conservative approaches were taken so as not to underestimate average exposure concentrations for the exposure scenarios and areas being evaluated in the risk assessment.

## Estimating the Concentration Term

Concentration terms were either the 95% UCLs of the mean (normal or lognormal distribution), or the maximum detected concentrations. The 95% UCL is used rather than the arithmetic mean concentration to provide an additional level of conservatism in accounting for the uncertainties involved in estimating the true mean from a relatively small data set. Although small sample size, variability in sample results, extreme values, and accounting for negative or zero values add to the uncertainty in estimating the mean, these uncertainties usually result in a high, rather than a low, bias to the estimate. Therefore, the uncertainties in the statistical evaluation of the data are not expected to result in an underestimation of exposure or risk.

## Air Exposure Concentrations

The EPA default PEF was used to estimate potential exposure of receptors in OU 4 to chemicals through inhalation of particulates (EPA, 1991a). This was done to facilitate a rapid evaluation of risk due to fugitive dust emissions. The PEF relates the concentration of contaminants in soil to the concentration of respirable particles (PM<sub>10</sub>) in air. This relationship was derived by the EPA for evaluation of dust emissions over an extended period of time from a surface with unlimited erosion potential. The model was selected as the default by EPA because it represents a conservative estimate for intake of particulates. It is unlikely that the default underestimates true fugitive dust emissions. The site-specific exposure factor for the PM<sub>10</sub> fraction was not used in the calculations for OU 4, because the PEF is an estimate of the PM<sub>10</sub> fraction present in the receptors' breathable airspace. The use of the PEF produces a conservative estimate of inhalation risks.

### 5.4.3 Media Not Evaluated

The C-pond in AOC No. 1 was not included in the original sampling. When data for OU 4 were evaluated for this HHRA, no C-pond data were available. A limited amount of data have since become available. Three borings of asphalt and subgrade materials were taken in September 1995. Asphalt samples were analyzed for metals and radionuclides. Subgrade samples were composited in 2-foot intervals to a depth of 6 feet.

Results for inorganics and radionuclides are summarized in Table 5-6. Background values for the mean and UTLs for the upper hydrostratigraphic unit (UHSU) are also shown for comparison. In the C-pond liner materials, activities of americium-241, plutonium-239/240, and uranium-238 are greater than the background UHSU UTLs. Radium-228 activity was above the UTL at one location. In the subgrade materials, concentrations of nitrate and activities for americium-241 and plutonium-239/240 are consistently above the UTLs at all depths. Uranium-233/234, -235, and -238 have scattered

detections above the UTLs. There is one B-qualified arsenic result above the UTL. The COC list would not change based on these results.

A comparison of the C-pond data in Table 5-6 to data presented in Appendix A for the other ponds demonstrates that the differences between the C-pond data for inorganics and radionuclides and the data from sampling points in the other ponds are not significant. This conclusion is also supported by a comparison of UCLs for AOC No. 1, calculated both with and without the C-pond data.

Table 5-7 shows a comparison of the exposure concentrations for inorganic and radionuclide COCs used in the risk assessment and what they would be if the C-pond data were included. The values for the maximum detect and the UCL are in bold if greater than the value used in the HHRA. Some values are slightly higher, some are lower. Overall, the changes would have no significant effect on the total risk calculations or on risk management decisions drawn from them.

Results for organic analyses of the subgrade materials indicate no significant levels of organic contamination. There were scattered J-qualified results, indicating very low concentrations of PAHs (all below 100  $\mu\text{g}/\text{kg}$ ). These very low concentrations, if confirmed, would have no significant affect on the risk calculations.

The C-pond materials do not appear to differ significantly from materials beneath the other ponds. The data do not indicate the need to recalculate risk levels with the C-pond materials included.

#### 5.4.4 Exposure Scenarios and Pathways

The major uncertainty in the exposure assessment is future land use at RFETS. Because of the uncertainty in future land use, several possible scenarios were developed, ranging from commercial through open-space recreational exposures to surface soil and construction worker exposure to subsurface soil. In addition, CT and RME exposure factors were developed for each scenario using EPA values and best estimates based on site-specific or local information. Therefore, the uncertainty in future land use and exposure conditions at RFETS is addressed by the range of scenarios evaluated. Residential land use was not considered an option, as discussed in correspondence from EPA and CDPHE to DOE (EPA, 1995a; CDPHE, 1995; DOE, 1995b).

Among the exposure scenarios that were considered possible at RFETS, the future office worker is the maximum exposed individual at AOC No. 1 and provides the reasonable maximum estimated risk associated with exposure to the surface soil. This receptor was evaluated for the following exposure pathways from surface soil: ingestion, inhalation, dermal contact pathways, and external irradiation from radionuclides. In AOC No. 2, the future onsite open-space recreational user was chosen to define the reasonable maximum estimated risk associated with exposure to the surface soil. This receptor

was evaluated for exposure to surface soil ingestion by both adults and children, dermal contact, inhalation of particulates, and external radiation pathways.

The construction worker exposure scenario defines the risks for subsurface soil under anticipated land uses. Estimated risks for this receptor were evaluated for AOC No. 1. This scenario was not evaluated for AOC No. 2 due to steep slopes and anticipated open-space use.

All four receptors evaluated in the risk assessment are assumed to be exposed to a 30- or 50-acre area, corresponding to an industrial park or open space. However, AOC No. 1 and AOC No. 2 contain approximately 11 and 28 acres, respectively. The assumption that a current security worker, future office worker, open-space recreational user, or construction worker is exposed only to the smaller area, results in an overestimation of potential risk to those receptors.

#### **5.4.5 Toxicity Assessment**

Toxicity values (RfDs and cancer SFs) derived by EPA are conservative upperbound estimates of potential toxicity or carcinogenicity of chemicals, and their use in risk assessment tends to result in an overestimate of potential risk. Four PCOCs, all organics, do not have EPA-established toxicity factors (see Table 2-13). Therefore, they could not be evaluated in a quantitative risk assessment. All of the compounds were either detected at low frequency (<5 percent) or low concentrations, or both. The exclusion of infrequently detected compounds (both 2-hexanone and phenanthrene were detected at well below 5 percent frequency) from the risk assessment is not expected to contribute to an underestimation of potential risk because their concentrations and frequency of occurrence are trivial compared to those of OU-wide COCs.

Phenanthrene and benzo(g,h,i)perylene were detected at frequencies above 5 percent in surface soil. The maximum concentrations of phenanthrene and benzo(g,h,i)perylene (3.7 mg/kg and 1.3 mg/kg in surface soil, respectively) were similar to other PAHs detected. Inadequate data are available to assess toxicity of these compounds (EPA, 1994b), and they are likely to have lower toxicity than benzo(a)pyrene (which is among the most carcinogenic of the organic COCs in these media). Because benzo(a)pyrene did not cause unacceptable risk to any receptors in these media, the exclusion of phenanthrene and benzo(ghi)perylene from quantitative risk assessment would have no effect on the estimate of total site risk (see Section 5.4.1).

**Table 5-1 Summary of Estimated Risk for Solar Ponds AOC No.1**

Pathway	<u>Central Tendency</u>		<u>Reasonable Maximum</u>	
	Hazard Index	Cancer Risk	Hazard Index	Cancer Risk
<b>Current Onsite Security Worker</b>				
Ingestion of surface soil	0.001	1.16E-08	0.01	4.59E-07
Inhalation of particulates from surface soil	a	1.64E-10	a	1.30E-09
Dermal contact with surface soil	b	3.74E-09	b	1.48E-07
External irradiation from surface soil	a	1.64E-08	a	1.92E-07
External irradiation from pond liner materials	a	2.11E-09	a	2.47E-08
<b>Total</b>	<b>0.001</b>	<b>3E-08</b>	<b>0.01</b>	<b>8E-07</b>
<b>Future Onsite Office Worker</b>				
Ingestion of surface soil	0.01	2.65E-07	0.1	1.57E-05
Inhalation of particulates from surface soil	a	2.08E-09	a	2.17E-08
Dermal contact with surface soil	b	3.85E-08	b	3.85E-08
External irradiation	a	2.74E-07	a	3.19E-06
<b>Total</b>	<b>0.01</b>	<b>6E-07</b>	<b>0.1</b>	<b>2E-05</b>
<b>Future Onsite Construction Worker</b>				
Ingestion of subsurface soil	0.003	2.07E-09	0.02	1.16E-08
Ingestion of pond liner materials	0.01	1.74E-07	0.04	9.76E-07
Inhalation of particulates from subsurface soil	a	9.76E-12	a	6.51E-12
Dermal contact with subsurface soils	b	b	b	b
External irradiation from sursurface soil	a	2.54E-07	a	3.17E-07
External irradiation from pond liner materials	a	2.35E-09	a	2.93E-09
<b>Total</b>	<b>0.01</b>	<b>4E-07</b>	<b>0.1</b>	<b>1E-06</b>

a. Exposure pathway cannot be quantified for COCs (e.g., COCs have either slope factors or RfDs, but not both)

b. Dermal absorption of metals and radionuclides is considered insignificant. Risk for this pathway estimated for Aroclor-1254 only.

**Table 5-2 Summary of Estimated Risk for Solar Ponds AOC No.2**

Pathway	Central Tendency		Reasonable Maximum	
	Hazard Index	Cancer Risk	Hazard Index	Cancer Risk
<b>Current Onsite Security Worker</b>				
Ingestion of surface soil	0.0003	2.51E-09	0.002	9.96E-08
Inhalation of particulates from surface soil	a	6.49E-13	a	9.29E-12
Dermal contact with surface soil	b	b	b	b
External irradiation	a	4.80E-09	a	5.60E-08
Total	0.0003	7E-09	0.002	2E-07
<b>Future Onsite Open-Space User</b>				
Ingestion of surface soil by child	0.003	a	0.02	a
Ingestion of surface soil by adult	0.0004	a	0.002	a
Carcinogenic risks of surface soil ingestion	a	2.54E-08	a	4.05E-07
Inhalation of particulates from surface soil	a	1.08E-11	a	5.07E-10
Dermal contact with surface soil	b	b	b	b
External irradiation	a	4.80E-09	a	9.34E-08
Total	0.004	3E-08	0.02	5E-07

- a. Exposure pathway cannot be quantified for COCs (e.g., COCs have either slope factors or RfDs, but not both).
- b. Dermal absorption of metals and radionuclides is considered insignificant; no organic compounds were assessed for this pathway.

**Table 5-3 Effective Dose Conversion Factors for Radionuclides**

Radionuclide	f <sub>1</sub> <sup>a</sup>	Ingestion		Lung Clearance Class <sup>c</sup>	Inhalation DCF (Sv/Bq) <sup>b</sup>	External DCF (mrem/yr per pCi/gram)
		DCF (Sv/Bq) <sup>b</sup>	DCF (Sv/Bq) <sup>b</sup>			
Americium - 241	1.00E-03	9.84E-07	1.20E-04	W	1.20E-04	4.1E-02
Plutonium - 239 <sup>d</sup>	1.00E-03	9.56E-07	1.16E-04	W	1.16E-04	2.1E-04
Uranium - 234 <sup>e</sup>	5.00E-02	7.66E-08	2.13E-06	W	2.13E-06	3.4E-04
Uranium - 235	5.00E-02	7.19E-08	1.97E-06	W	1.97E-06	5.0E-01
Uranium - 238	5.00E-02	6.88E-08	1.90E-06	W	1.90E-06	1.0E-04

- a. Fractional uptake from the small intestine to the blood.
- b. To convert to conventional units of mrem/pCi, multiply the table entry by 3.7E+03.
- c. Lung clearance class: W = weeks.
- d. Used to evaluate Pu-239/240.
- e. Used to evaluate U-233/234.

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**Table 5-4 Radiation Dose for AOC No. 1**

Pathway	Annual Radiation Dose	
	Central Tendency (mrem/yr)	Reasonable Maximum (mrem/yr)
<b>Construction Worker</b>		
Ingestion of subsurface soil	9.2E-03	4.6E-02
Inhalation of airborne particulates	1.9E-05	2.1E-05
External irradiation from subsurface soil	3.1E-04	3.9E-04
Total	9.5E-03	4.7E-02
<b>Construction Worker</b>		
Ingestion of pond liner	5.3E-02	2.7E-01
External irradiation from pond liner	3.0E-02	3.7E-02
Total	8.3E-02	3.0E-01
<b>Current Security Worker</b>		
Ingestion of surface soil	1.5E+00	8.4E+00
Inhalation of airborne particulates	2.6E-02	2.9E-02
External irradiation from pond liner	6.7E-03	1.4E-02
External irradiation from surface soil	2.9E-02	5.9E-02
Total	1.5E+00	8.5E+00
<b>Office Worker</b>		
Ingestion of surface soil	7.4E-01	8.4E+00
Inhalation of airborne particulates	1.9E-02	2.9E-02
External irradiation from surface soil	4.8E-01	8.9E-01
Total	1.2E+00	9.3E+00

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**Table 5-5 Summary of Annual Radiation Dose for AOC No. 2**

Pathway	Annual Radiation Dose	
	Central Tendency (mrem/yr)	Reasonable Maximum (mrem/yr)
<b>Current Security Worker</b>		
Ingestion of surface soil	1.0E-01	5.9E-01
Inhalation of airborne particulates	1.8E-03	2.0E-03
External irradiation from surface soil	7.7E-04	1.6E-03
Total	1.1E-01	5.9E-01
<b>Open Space Recreational User (adult)</b>		
Ingestion of surface soil	1.2E-02	5.9E-02
Inhalation of airborne particulates	8.0E-05	3.4E-04
External irradiation from surface soil	3.4E-04	2.0E-03
Total	1.2E-02	6.1E-02
<b>Open Space Recreational User (child)</b>		
Ingestion of surface soil	2.3E-02	1.2E-01
Total	2.3E-02	1.2E-01

**Table 5-6 OU 4 Data for C-Pond Asphalt and Subsurface Soil (Units = mg/kg or pCi/g)**

	Depth (ft)	Cyanide	Nitrate	Aluminum	Antimony	Arsenic	Barium	Beryllium	Cadmium	Calcium
LOCATION 48195										
AS00001PE	Asphalt	0.19		6100	3.1	21.6	50.4	0.33	0.81	2640
BH00101PE	0-2		1599	13300	2.6	11.6	71.1	0.63	0.41	2700
BH00102PE	2-4	0.25	923	15400	2.6	11.1	49.3	0.86	0.42	1690
BH00103PE	4-6	0.17	206	9960	2.6	11.1	29.3	0.5	0.41	2160
BGCR MEAN a	UHSU b		16.7	12710	47	3.7	96.3	4.66	2.3	7050
BGCR SD	UHSU		14	11330		4.4	96.5	4.77		16180
BGCR UTL c	UHSU		57	45110		16.2	372	18.3		53250
LOCATION 48295										
AS00002PE	Asphalt	0.17		4210	5	21.3	41.6	0.27	0.8	2150
BH00104PE	0-2		1062	14500	2.9	12.1	72.9	0.59	0.45	1760
BH00105PE	2-4	0.17	619	11200	2.6	10.9	33	0.54	0.41	1120
BH00106PE	4-6	0.17	316	7900	2.6	11.2	25.9	0.37	0.42	1090
BGCR MEAN	UHSU		16.7	12710	47	3.7	96.3	4.66	2.3	7050
BGCR SD	UHSU		14	11330		4.4	96.5	4.77		16180
BGCR UTL	UHSU		57	45110		16.2	372	18.3		53250
LOCATION 48395										
AS00003PE	Asphalt	0.17		6970	5.9	24.7	56.4	0.31	0.93	2200
BH00107PE	0-2		ND	9670	3.9	12.1	69.6	0.38	0.45	3390
BH00108PE	2-4	0.17	920	43000	3.3	13.8	175	1.9	0.51	4320
BH00109PE	4-6	0.17	430	15100	2.7	27.2	139	0.78	0.42	2360
BGCR MEAN	UHSU		16.7	12710	47	3.7	96.3	4.66	2.3	7050
BGCR SD	UHSU		14	11330		4.4	96.5	4.77		16180
BGCR UTL	UHSU		57	45110		16.2	372	18.3		53250

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Table 5-6 (continued)

	Depth (ft)	Chromium	Cobalt	Copper	Iron	Lead	Lithium	Magnesium	Manganese	Molybdenum
LOCATION 48195										
AS00001PE	Asphalt	15.7	4.3	9.6	11100	9.5	12.1	2410	149	2.4
BH00101PE	0-2	56.9	5.9	14.6	17900	11.3	21.1	2530	192	3.1
BH00102PE	2-4	50.8	7.1	12.2	14500	5.5	9.7	1360	167	4
BH00103PE	4-6	28.4	5.6	12.8	14000	5.4	9.2	3000	157	4.4
BGCR MEAN a	UHSU b	18.8	7.4	12.6	14530	10.8	10.2	2875	218	15.4
BGCR SD	UHSU	24.7	6.6	12.8	13260	7.1	8.4	3232	342	9
BGCR UTL c	UHSU	89.2	26.4	49	52390	31	34.2	12100	1194	41.1
LOCATION 48295										
AS00002PE	Asphalt	13	4	9.7	8710	9.3	8.5	2180	127	2.4
BH00104PE	0-2	25.9	5.1	11	14400	7.1	21.4	2550	149	1.8
BH00105PE	2-4	19.6	3.2	8.6	7570	4	6	1240	90.1	1.2
BH00106PE	4-6	15.5	2.6	7.8	7370	4.9	5.7	1460	75.5	1.9
BGCR MEAN	UHSU	18.8	7.4	12.6	14530	10.8	10.2	2875	218	15.4
BGCR SD	UHSU	24.7	6.6	12.8	13260	7.1	8.4	3232	342	9
BGCR UTL	UHSU	89.2	26.4	49	52390	31	34.2	12100	1194	41.1
LOCATION 48395										
AS00003PE	Asphalt	20.6	4.1	11.7	12200	10.8	13.1	2750	162	2.8
BH00107PE	0-2	26.7	6.1	11	10600	5.3	18.5	2540	142	1.4
BH00108PE	2-4	33.8	11	20.1	31100	7.7	21.9	5700	792	1.5
BH00109PE	4-6	16.8	8.8	13.6	16000	7.9	11.3	2510	772	2.3
BGCR MEAN	UHSU	18.8	7.4	12.6	14530	10.8	10.2	2875	218	15.4
BGCR SD	UHSU	24.7	6.6	12.8	13260	7.1	8.4	3232	342	9
BGCR UTL	UHSU	89.2	26.4	49	52390	31	34.2	12100	1194	41.1

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Table 5-6 (continued)

	Depth (ft)	Nickel	Potassium	Selenium	Silver	Sodium	Strontium	Thallium	Tin	Vanadium
LOCATION 48195										
AS00001PE	Asphalt	10.4	2800	10.3	0.81	1540	17.6	17.8	4.3	36.8
BH00101PE	0-2	29.5	5050	5.2	0.44	3880	21.6	9	3.3	41.1
BH00102PE	2-4	25	2020	5.3	0.47	1920	17.8	9.2	3.9	31
BH00103PE	4-6	12.6	715	5.3	0.41	731	14.7	9.1	2.3	21.7
BGCR MEAN a	UHSU b	19.8	1614	13.7	5.7	3680	55.2	4.1	67.1	31.5
BGCR SD	UHSU	20.6	1981		9.4		45.6		110	28.5
BGCR UTL c	UHSU	78.7	7276		33.1		186		384	113
LOCATION 48295										
AS00002PE	Asphalt	8.6	2300	10.1	0.8	1240	15.4	17.5	4.3	34.2
BH00104PE	0-2	20.5	5060	5.7	0.45	3550	18.2	10	3.5	33.3
BH00105PE	2-4	8.1	1350	5.2	0.41	1320	14.4	9	2.2	14.4
BH00106PE	4-6	8.2	966	5.3	0.42	675	9.2	9.2	2.4	13
BGCR MEAN	UHSU	19.8	1614	13.7	5.7	3680	55.2	4.1	67.1	31.5
BGCR SD	UHSU	20.6	1981		9.4		45.6		110	28.5
BGCR UTL	UHSU	78.7	7276		33.1		186		384	113
LOCATION 48395										
AS00003PE	Asphalt	7.8	3110	11.8	0.93	1230	17.3	20.4	4.9	35.5
BH00107PE	0-2	6.5	3960	5.7	0.5	2380	22.6	10	2.6	23.2
BH00108PE	2-4	39.6	4890	6.5	0.67	4430	28.5	11.3	2.7	66.4
BH00109PE	4-6	20.7	2170	5.4	0.42	1770	26.2	9.3	2.3	39
BGCR MEAN	UHSU	19.8	1614	13.7	5.7	3680	55.2	4.1	67.1	31.5
BGCR SD	UHSU	20.6	1981		9.4		45.6		110	28.5
BGCR UTL	UHSU	78.7	7276		33.1		186		384	113

Table 5-6 (continued)

	Depth (ft)	Zinc	Gross alpha	Gross beta	Am-241	Cs-134	Cs-137	ERR
LOCATION 48195								
AS00001PE	Asphalt	28	26	30.5	8.188	-0.0485	-0.0021	0.023
BH00101PE	0-2	32	25	32	0.852	0.0101	0.0158	0.026
BH00102PE	2-4	22	10.5	25.5	0.308	-0.0246	0.0415	0.023
BH00103PE	4-6	27	9	23	0.557	-0.0396	-0.0019	0.028
BGCR MEAN a	UHSU b	36	24.9	24.7	-0.002		0.012	
BGCR SD	UHSU	51	9.3	6.1	0.007		0.041	
BGCR UTL c	UHSU	183	51.4	42	0.022		0.129	
LOCATION 48295								
AS00002PE	Asphalt	24	9.5	20	3.063	-0.0124	0.0237	0.02
BH00104PE	0-2	30	24	34	0.646	-0.00332	-0.0052	0.028
BH00105PE	2-4	17	14.5	32	0.561	0.00854	-0.0022	0.024
BH00106PE	4-6	15	10.5	23.5	0.598	0.00299	0.0158	0.021
BGCR MEAN	UHSU	36	24.9	24.7	-0.002		0.012	
BGCR SD	UHSU	51	9.3	6.1	0.007		0.041	
BGCR UTL	UHSU	183	51.4	42	0.022		0.129	
LOCATION 48395								
AS00003PE	Asphalt	33	23.5	42	2.951	-0.00069	0.00768	0.02
BH00107PE	0-2	30	20.5	38	0.238	-0.00048	0.00496	0.027
BH00108PE	2-4	53	19	35	0.775	-0.00367	-0.0037	0.021
BH00109PE	4-6	25	20	34	0.753		0.012	
BGCR MEAN	UHSU	36	24.9	24.7	-0.002		0.041	
BGCR SD	UHSU	51	9.3	6.1	0.007		0.041	
BGCR UTL	UHSU	183	51.4	42	0.022		0.129	

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Table 5-6 (continued)

LOCATION	Depth (ft)	Pu-239/240	Ra-226	Ra-228	Sr-89/90	U-233/234	U-235	U-238	ERR
LOCATION 48195									
AS00001PE	Asphalt	3.361	1.59	2.73	-0.00041	2.107	0.106	2.04	0.1
BH00101PE	0-2	1.578	9.28	1.73	0.044	10.363	0.387	4.59	0.19
BH00102PE	2-4	0.332	2.37	0.987	0.0253	3.938	0.157	1.111	0.05
BH00103PE	4-6	0.613	1.85	1.21	0.0955	1.755	0.056	1.103	0.06
BGCR MEAN a	UHSU b	0.004	0.746	1.4	0.031	0.779	0.022	0.733	
BGCR SD	UHSU	0	0.231	0.318	0.358	0.932	0.046	0.376	
BGCR UTL c	UHSU	0.025	1.42	2.33	1.05	3.44	0.153	1.81	
LOCATION 48295									
AS00002PE	Asphalt	1.532	2.31	2	0.0422	2.011	0.065	2.047	0.09
BH00104PE	0-2	1.192	3.83	1.86	0.0158	3.015	0.114	1.217	0.08
BH00105PE	2-4	0.363	2.21	1.7	0.0838	3.111	0.1	1.592	0.1
BH00106PE	4-6	0.414	1.51	1.35	0.202	6.098	0.195	3.971	0.17
BGCR MEAN	UHSU	0.004	0.746	1.4	0.031	0.779	0.022	0.733	
BGCR SD	UHSU	0	0.231	0.318	0.358	0.932	0.046	0.376	
BGCR UTL	UHSU	0.025	1.42	2.33	1.05	3.44	0.153	1.81	
LOCATION 48395									
AS00003PE	Asphalt	1.31	1.32	2.08	0.272	1.463	0.049	1.411	0.07
BH00107PE	0-2	1.747	8.66	1.65	0.0859	14.371	0.461	5.624	0.23
BH00108PE	2-4	0.328	1.64	1.54	0.152	1.915	0.072	1.764	0.09
BH00109PE	4-6	0.494	0.746	1.4	0.031	2.232	0.083	1.983	0.09
BGCR MEAN	UHSU	0.004	0.231	0.318	0.358	0.779	0.022	0.733	
BGCR SD	UHSU	0	0.231	0.318	0.358	0.932	0.046	0.376	
BGCR UTL	UHSU	0.025	1.42	2.33	1.05	3.44	0.153	1.81	

a. BGCR = Data from the Background Geochemical Characterization Report for Rocky Flats Plant (DOE, 1993).  
 b. UHSU = Upper Hydrostratigraphic Unit. SD = Standard deviation of the mean. ERR term is 95% UCL and is provided for radionuclide data in RFEDS.

c. UTL = Upper tolerance limit, calculated using data from the BGCR. The 99/99 UTL values are presented here.

d. MX = Background data set contained more than 80-percent nondetects, so maximum background value is shown.

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Table 5-7 Exposure Point Concentrations for AOC No.1 as used in the Risk Calculations and including Data from C-Pond

Analyte	Exposure Concentration without C-pond					Exposure Concentration with C-pond				
	No. of Samples	Percent Detection (%)	Maximum Detect (mg/kg or pCi/g)	Mean (mg/kg or pCi/g)	95% UCL (mg/kg or pCi/g)	No. of Samples	Percent Detection (%)	Maximum Detect (mg/kg or pCi/g)	Mean (mg/kg or pCi/g)	95% UCL (mg/kg or pCi/g)
<b>AOC No.1 -- Pond Liner Material COCs:</b>										
Americium-241	12	50	4.03	0.95	1.73	15	60	8.18	1.7	2.77
Cadmium	12	100	69.7	1.53	71.4	15	80	69.7	1.05	57.85
Plutonium-239/240	12	83	3.13	-1.853	40.58	15	86.7	3.36	-1.35	41.99
Uranium-233/234	12	100	4.66	0.42	2.38	15	100	4.66	0.46	2.24
Uranium-238	12	100	2.68	0.11	1.71	15	100	2.68	0.21	1.79
<b>AOC No.1 -- Subsurface Soil COCs:</b>										
Americium-241	92	100	2.7	0.2	0.3	101	100	2.7	0.24	0.32
Cadmium	95	27.4	547	18.69	31.7	104	25	547	17.09	28.96
Plutonium-239/240	91	100	3	0.2	0.29	100	100	3	0.25	0.34
Radium-226	78	100	6.84	0.06	1.55	86	100	9.28	0.15	1.79
Uranium-238	95	100	11.48	2.17	2.57	104	100	11.48	2.2	2.58

## 6.0 SUMMARY AND CONCLUSIONS

This section briefly summarizes the results of the HHRA for OU 4 and suggests conclusions that may be drawn from the assessment.

### 6.1 SUMMARY

The HHRA for RFETS OU 4 estimated health risks and annual radiation doses for current and future onsite receptors who could be exposed directly or indirectly to COCs at or released from sources in OU 4. COCs were identified as the chemicals, metals, or radionuclides in soil, groundwater, sediment, or surface water that were likely to contribute at least 1 percent of the estimated risk. The major COCs were americium-241, plutonium-239/240, and uranium-238 in all media; uranium-233/234 in the pond liner materials; Aroclor-1254, cadmium, and beryllium in surface soils; and radium-226 and cadmium in subsurface soils.

Exposure scenarios evaluated were a current security worker, a future office worker, a future construction worker, and a future open-space recreational user. Exposure media evaluated were surface soil, subsurface soil (construction worker only), and indoor and outdoor air.

Human health risks and hazards were estimated for two AOCs in OU 4. AOC No. 1 is the solar ponds area (IHSS 101). AOC No. 2 includes the portion of OU 4 that is north of the solar ponds and down slope. Annual radiation doses in units of mrem/year were also estimated for comparison to national radiation standards.

The risk characterization process combines average and reasonable maximum estimates of exposure with upperbound estimates of toxicity to yield conservative (protective) estimates of human health risk. Estimates of health risk for CT and RME conditions are provided so that risk management decisions can be based on a range of estimated potential risk for different exposure scenarios.

Hazard/risk estimates are summarized in Tables 5-1 and 5-2. Results of the risk assessment are as follows:

- *AOC No. 1:* Cumulative HIs were below 1 and RME cancer risk estimates were below or within the EPA's target acceptable risk range and 1E-06 to 1E-04 for all receptors. The highest cancer risk was for the future office worker with an RME risk of 2E-05; however, the average or CT risk was below 1E-06. The cancer risks for the future construction worker were 1E-06 and were driven by potential exposures to pond liner materials. These results indicate that no adverse noncarcinogenic health hazards and acceptable cancer risks are expected for all receptors evaluated in AOC No. 1.

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- *AOC No. 2:* Cumulative HIs were well below 1 and RME cancer risk estimates were below the EPA's target acceptable risk range and 1E-06 to 1E-04 for both receptors. These results indicate that no adverse noncarcinogenic health hazards and negligible cancer risks are expected for all receptors evaluated in AOC No. 2.
- Estimated annual radiation doses for onsite receptors were 10 mrem/year or less, well below the DOE standard of 100 mrem/year for protection of the public.
- Results of the ERA for AOC No. 2 indicate that risks to ecological receptors from the PCOCs detected in the surface and subsurface soils in this area would be minimal.

## **6.2 CONCLUSIONS**

Under expected future land use scenarios at RFETS, none of the receptors for OU 4 evaluated in AOC No. 1 and AOC No. 2 are exposed to unacceptable levels of chemical constituents in surface soil, subsurface soil, or indoor and outdoor air.

In general, cancer risk levels that do not exceed 1E-04, combined with HIs that do not exceed 1, may be used to support a decision that remediation is not warranted for the protection of public health (EPA 1991b). These results suggest that remediation of exposure media evaluated in the OU 4 HHRA (surface soil and subsurface soil) may not be necessary for protection of public health.

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## **Appendix A**

### **Selection of PCOCs for OU 4 Surface and Subsurface (Borehole) Soils**

## A.1 INTRODUCTION

The constituents in Operable Unit 4 (OU 4) soils are the result of natural processes, precipitation of particulates and aerosols from the Solar Ponds, evaporative spraying programs, worldwide anthropogenic background (including radioactive fallout from atmospheric testing of nuclear weapons), leakage of fluids from the Solar Ponds, and routine or accidental releases of site-specific chemicals from the former Rocky Flats Plant (RFP). To distinguish site-related contributions from those of natural origin or anthropogenic background, statistical tests were performed using OU 4 and RFP background data for inorganic constituents. The background data for surficial soils were taken from the final report for the *Background Soils Characterization Program* (BSCP) (DOE, 1995). Background data for subsurface soils of the upper hydrostratigraphic unit (UHSU) were taken from the *Background Geochemical Characterization Report* (BGCR) (DOE, 1993).

## **A.2 DATA PREPARATION**

Data for OU 4 surface soils and subsurface (borehole) soils were extracted from the Rocky Flats Environmental Database System (RFEDS) and compiled as SAS® data sets for each analytical suite in each medium. The SAS data sets for metals, radionuclides, water-quality parameters, and organics were then screened to exclude rejected data and quality control (QC) data from the working data sets. Records for tentatively identified compounds (TICs) in the data sets for organics were compiled and reviewed separately. Records with null result fields or with a combination of null detection limit and null qualifier fields were excluded from the final working data set. To conserve time, duplicate/real pairs (DUP/REAL pairs) were treated as described below. In all cases, the more conservative choices were made.

For surface soils, data for duplicate records (DUP) were compared with the results of the corresponding real records (REAL) and resolved according to the following five criteria:

1. Validated record (whether REAL or DUP) selected over the nonvalidated record
2. Detect record selected over nondetect record
3. Higher-value detects selected over lower-value detects (checking first to ensure that results were of comparable numeric value)
4. Lower-value nondetects selected over higher-value nondetects
5. All other factors being equal, choose the record for which there is a corresponding QC sample (QC PARTNER)

Reviewing DUP/REAL pairs for the subsurface-soil data was complicated by the collection of multiple samples—representing different depth increments—at each sampling location. Because of this complication, both DUPs and REALs were used in the statistical comparisons and in the statistical summaries for subsurface soils. This simplification should not affect the outcome of the statistical tests other than to increase the power of the tests (i.e., increase the ability of the test to detect smaller differences, which is a conservative error). In general, the borehole materials were collected from the interval above the water table. This was verified by comparing the water levels in nearby groundwater monitoring wells with the sampling depths for the boreholes.

## **A.3 STATISTICAL COMPARISONS OF OU 4 AND BACKGROUND DATA**

### **A.3.1 COMPARISON OF OU 4 ASPHALT-LINER DATA AND BACKGROUND SURFACE-SOIL DATA**

Because the liner data are not in RFEDS, formal statistical tests were not conducted for the liner data. Instead, summary statistics for the entire population of liner samples (N = 12) were calculated and visually compared with the summary statistics for background surface soils (Tables A-1 and A-2). Metal constituents with mean values greater than those of corresponding background include cadmium, chromium, copper, magnesium, nickel, and sodium. Radionuclides with higher means for the liner data include americium-241, plutonium-239/240, strontium-89/90, uranium-233/234, uranium-235, and uranium-238. For all other metals and radionuclides, background means are greater than OU 4 means.

A comparison of the maximum values for OU 4 and background data shows that the OU 4 maximum values exceed the background maximum values for cadmium (69.7 vs. 2.3 mg/kg), chromium (37.5 vs. 16.9 mg/kg), copper (22.1 vs. 15.9 mg/kg), lead (107 vs. 53.3 mg/kg), lithium (13.2 vs. 11.6 mg/kg), nickel (16.2 vs. 14 mg/kg), sodium (1050 vs. 105 mg/kg), americium-240 (4.032 vs. 0.025 pCi/g), plutonium-239/240 (3.126 vs. 0.072 pCi/g), uranium-233/234 (4.66 vs. 3.1 pCi/g), and uranium-238 (2.68 vs. 2.60 pCi/g). Data for cadmium, chromium, lead, sodium, americium-241, plutonium-239/240, uranium-233/234, uranium-235, and uranium-238 show exceedances of the 99/99 UTLs for background surface soil.

Taking into account the UTL exceedances, relative means, standard deviations, and range of values, the data for cadmium, chromium, americium-241, plutonium-239/240, uranium-233/234, uranium-235, and uranium-238 appear to be significantly different from those of background surface soils. The asphalt liners were not analyzed for radium isotopes.

### **A.3.2 APPLICATION OF GILBERT METHODOLOGY FOR SURFACE-SOIL AND SUBSURFACE-SOIL DATA**

Data for inorganic constituents in OU 4 soils were compared with corresponding background data using the statistical methodology described by Gilbert (Gilbert, 1993) and jointly accepted by DOE, EPA, and CDPHE. This methodology includes comparison of site and background data using ". . . a set of statistical tools that, when used with professional judgment and a knowledge of RFP operations, provide an acceptably high probability of correctly identifying a PCOC. . ." (Gilbert, 1993). Four formal statistical tests (Gehan, slippage, quantile, and t-test) with specified error rates of 0.05 (i.e., 5 percent) are used for the comparisons. In addition, site data are screened against normal upper tolerance limits (UTLs) for metals, radionuclides, and water-quality parameters. Records for

detected organic constituents in OU 4 media are retained for evaluation and assessment via the concentration/toxicity screen.

The UTL functions as a hot-spot test to ensure that isolated areas of high concentration/activity are not overlooked. The normal 99/99 UTL is computed such that there is 99-percent confidence that the value of the UTL is equal to or greater than the true 99th percentile of the background population, if that population is normally distributed. In many cases, the distribution of the data is lognormal or some other distribution, rather than normal. Because distributional or other assumptions may not actually be met, professional judgment is necessary for evaluating the meaning of UTL exceedances. For the OU 4 area, UTL exceedances were plotted on maps to give a broader picture of the spatial distribution of higher values detected for metals and radionuclides in and around OU 4.

The **slippage test** is a nonparametric test that simply counts the number of site measurements that exceed the maximum background value. If this number exceeds a critical value (based on sample size and error rate; values in published tables), then the data sets show a statistical difference at the 5-percent level of significance (i.e., p-values are  $< 0.05$ ). The slippage test is not applicable if the maximum background value is a nondetect.

The **quantile test** is a nonparametric test that is similar to the slippage test. According to Gilbert (1993): "the quantile test has more power than the Wilcoxon Rank Sum test to detect when analyte concentrations in a small portion of the site are highly contaminated." However, the quantile test can only be used when (1) the data sets contain no nondetects, or (2) low-value nondetects are present at values less than a specified number (obtained from tables) of data points in the combined data set.

The **Gehan test** is a nonparametric test used for data sets with multiple detection limits. This test is a generalization of the Wilcoxon Rank Sum test, which ranks the data in the site and background data sets. The Gehan test is used to determine when analyte concentrations throughout the OU are generally higher than those in background.

As noted by Gilbert (1993): "The **t-test** is one of the most widely known statistical tests for testing that the means of two populations are different. When the background and OU data are normally and independently distributed, each distribution has the same variance, and neither data set contains any nondetects, the t-test is the preferred test." For Rocky Flats data, the t-test is not applied if either the site or background data sets contain more than 20-percent nondetects.

In addition to the statistical comparisons of OU 4 and background data, summary statistics (number of records, percent detection, minimum value, maximum value, mean, and standard deviation) were

calculated for each inorganic analyte in the OU 4 data sets (Tables A-3 and A-4). A value of one-half the detection limit was used as a replacement value for nondetect records, in order to generate the summary statistics. Results of statistical tests are not reliable for those analytes having a nondetect rate greater than 80 percent because estimates of central tendency are strongly biased by the replacement values used in data sets with high rates of nondetects. Additionally, the results of tests applied to data sets with 50- to 80-percent nondetects should be evaluated with caution. The results of statistical tests applied to largely nondetect data generally have large uncertainties, are not very meaningful, and should not be used to make management decisions (see Helsel, 1990; Sanford et al., 1993; Gilbert, 1987).

Output from the statistical comparisons was reviewed using statistical and geochemical professional judgment. This judgment includes: (1) the applicability of the statistical test to the population, based on population characteristics, (2) temporal and spatial distributions of each analyte, and (3) pattern of geochemical behavior (pattern-recognition concepts). The results and conclusions of these evaluations are discussed in the following sections. Tables showing the results of the statistical tests and the summary statistics are referenced in the following sections and attached at the end of the appendix.

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## A.4 PCOC SELECTION: RESULTS OF STATISTICAL TESTS AND APPLICATION OF PROFESSIONAL JUDGMENT

### A.4.1 METALS IN OU 4 SURFACE SOILS

After reviewing the results of the statistical tests, the population characteristics, and the spatial distribution of UTL exceedances for metals in OU 4 surface soils, ten metals were selected as PCOCs. The results of statistical tests are provided for each of these PCOCs (see Table A-5), and are described in more detail in the section discussing metal PCOCs in OU 4 surface soils. Unless otherwise specified, the background data for surficial soils are those from the BSCP.

Antimony, cesium, molybdenum, silver, thallium, and tin were detected in less than 20 percent of the samples (see Table A-3), so inferential statistical tests could not be applied with any validity. Of these six metals, only silver and thallium are reported on the hazardous-substance list for Rocky Flats (DOE, 1992). Antimony has virtually the same detection rate in background and OU 4 data sets (4.0 and 5.1 percent, respectively). Cesium was not detected in background surface soils, but was detected in 4.8 percent of the OU 4 samples. Molybdenum samples from background surface soils show a 9-percent detection rate, compared with 3.6 percent for OU 4 samples. Silver was not detected in background surface soils, but was detected in 13.3 percent of OU 4 surface-soil samples. Thallium, like silver, was not found in samples of background surface soil analyzed for the BSCP study, but shows a 35-percent detection rate in the Rock Creek background data. Thallium was detected in 6.3 percent of the OU 4 samples. Tin was detected in only 9 percent of background samples, but 25.3 percent of OU 4 samples.

Silver is retained as a PCOC because it has a 0-percent detection rate in both the background data sets for surficial soils (BSCP and Rock Creek studies), but shows a 13.3-percent detection rate in the OU 4 samples. Silver is also listed as a process chemical used at the Rocky Flats Plant. Tin also shows a higher detection rate for OU 4 samples (25.3 percent) than for BSCP samples (9.5 percent). However, data for background samples from Rock Creek show a 61-percent detection rate, with a mean of 32.5 mg/kg and a UTL of 84 mg/kg. Tin is not listed in the Historical Release Report (HRR) (DOE, 1992) or the ChemRisk (1994) study, but is included as a PCOC at CDPHE's request.

Although elevated above background concentrations (see Table A-4), calcium, magnesium, and sodium are essential nutrients that should not be considered as PCOCs. Silicon is not a PCOC because it forms the primary mineral in Rocky Flats soils (i.e., quartz = SiO<sub>2</sub>), and because it is the second-most abundant element in the Earth's crust. The OU 4 data for antimony, cesium, molybdenum, and thallium show detection rates fairly comparable to those of background. Of these four metals, only thallium is listed on the RFP hazardous-substance list. One of the background data sets for surface soils (Rock Creek, 35-percent detection rate) has mean and maximum values of 0.23

mg/kg and 0.41 mg/kg, respectively, for thallium. The OU 4 data set for thallium has a lower detection rate (6.3 percent), but shows slightly higher mean and maximum values (0.44 mg/kg and 0.99 mg/kg, respectively). Based on the similarity of the mean and maximum values, as well as the higher detection rate in one of the background data sets, thallium is not included as a PCOC in OU 4 surficial soils.

Other metals that show no significant differences according to the statistical tests, yet that have a few UTL exceedances include **aluminum** (3 exceedances), **arsenic** (2 exceedances), **cobalt** (1 exceedance), **iron** (1 exceedance), **lead** (4 exceedances), **manganese** (3 exceedances), and **vanadium** (2 exceedances). Of these metals, only aluminum and lead are listed as site-specific chemicals (DOE, 1992). However, for all seven of these metals showing exceedances, all but one (manganese = 7,650 mg/kg) of the exceedances are of low magnitude — 1 to 2.5 times the values of the BSCP UTL. The isolated, extreme outlier for manganese may represent a hot spot, although manganese has not been noted as a site-specific chemical. Additionally, all OU 4 exceedances for aluminum and lead lie within the baseline range of concentration established for surface soils of the Colorado Front Range (Severson and Tourtelot, 1994). Results of this Front Range study gave a baseline range of 32,280 to 98,440 mg/kg for aluminum and 9.7 to 130 mg/kg for lead. Therefore, based on available background data and the spotty or isolated occurrence of these exceedances, none of these seven metals is considered to be a PCOC.

Nine metals with UTL exceedances and significant differences ( $p < 0.05$ ) for at least one statistical test are found in close spatial association with the Solar Ponds. These metals include barium, cadmium, chromium, copper, lithium, mercury, nickel, strontium, and zinc. Most are found in samples collected for OU 4, but six samples with UTL exceedances were collected within IHSS 176 for OU 10. In addition, beryllium data show 12 exceedances of the UTL value, and this metal is included in the following discussions of the chemistry and spatial distribution of each of these metals (Table A-5). Additional information on metals in background surface soils is contained within the final report for the *Background Soils Characterization Program* (DOE, 1995).

#### A.4.1.1 Metal PCOCs in OU 4 Surface Soils

**Beryllium** is the lightest of the alkaline-earth metals, but bears little resemblance in geochemical behavior to the rest of the group. Beryllium ions are small enough to replace silicon in igneous-rock minerals, and the pegmatitic mineral, beryl, is the primary natural residence for beryllium. In OU 4, the UTL exceedances for beryllium in surface-soil samples are located within or near the Solar Ponds; all are inside the fenced perimeter of the Protected Area (PA). Because of the spatial distribution of these exceedances and the known history of beryllium use at Rocky Flats, beryllium is retained as a PCOC for OU 4 surface soils.

**Barium** — along with beryllium, strontium, calcium, and magnesium — is an alkaline-earth metal. Barite ( $\text{BaSO}_4$ ) is a common barium mineral; barium carbonate (witherite) and substitution of barium ions into calcium-carbonate minerals are less common. Barium may also be sorbed to metal oxides or hydroxides. In groundwater at Rocky Flats, barite appears to control the solubility of barium (EG&G, 1995a). For surface soils in OU 4, the exceedances of the UTL for barium are scattered and generally associated with exceedances for strontium, a metal with a geochemical behavior similar to that of barium. The association of barium with OU 4 surface soils may be more indicative of the evaporative concentration of pond water rather than with barium as an introduced contaminant. However, barium is listed in the Historical Release Report (DOE, 1992) on the hazardous-substance list. Because of this listed usage, in addition to the spatial distribution of UTL exceedances and the significant results for two statistical tests (slippage and quantile tests), barium is retained as a PCOC for OU 4 surface soils.

**Cadmium** exhibits chemical similarities to zinc, although it is much less abundant. Cadmium volatilizes at high temperatures and is liberated to the environment by combustion of fossil fuels and metallurgy. Cadmium substitutes for calcium (both in carbonate minerals and human bone), and may also be adsorbed on mineral surfaces or coprecipitated with manganese oxides. At Rocky Flats, cadmium has been used in plating operations, as neutron absorbers, and as shielding (ChemRisk, 1992). In OU 4, the highest concentrations of cadmium in surface soils are restricted to the area within the fenced perimeter of the PA. There are no exceedances of the UTL for soil samples collected outside this perimeter. The spatial distribution of these exceedances, along with the significant results for three statistical tests ( $p < 0.05$  for Gehan, slippage, and quantile tests), indicates an association with the Solar Ponds; hence, cadmium is retained as a PCOC in OU 4 surface soils.

**Chromium** in rock minerals exists primarily in the +3 oxidation state, but in alkaline oxidizing solutions the chromate anion (+6 oxidation state) may be stable (Hem, 1992). At Rocky Flats, chromium has been used for plating operations and to chemically mill beryllium (ChemRisk, 1992). Chromium in the surface soils of OU 4 shows a clustering of the highest concentrations in and around the Solar Ponds. Chromium exceedances tend to be spatially associated with UTL exceedances for cadmium. There are no exceedances of the chromium UTL for samples collected beyond the fenced perimeter of the PA. Because of the historical usage at Rocky Flats, the spatial distribution of UTL exceedances, and the significant results for all statistical tests ( $p < 0.05$  for the Gehan, slippage, quantile, and t-test), chromium is retained as a PCOC for OU 4 surface soils.

All UTL exceedances for **copper** in OU 4 surface soils are for samples collected within the fenced perimeter. Some of these exceedances are for samples collected west of the Solar Ponds, adjacent to the 700-series buildings. Copper exceedances are most closely associated with exceedances for cadmium, beryllium, mercury, lithium, and zinc. These associations, along with the spatial distribution of exceedances and the significant results for two statistical tests ( $p < 0.05$  for slippage and t-test), suggest that copper is a PCOC in OU 4 surface soils.

**Lithium** is an alkali metal that forms no weathering products of low solubility. The primary lithium minerals include spodumene and lepidolite (lithium mica), which both occur in pegmatites. Pegmatitic granites in the Front Range west of Rocky Flats are probably the primary source of naturally occurring lithium in the area. However, in OU 4 surface soils, all UTL exceedances for lithium are for samples collected inside the fenced perimeter of the PA; this suggests a close association with wastes treated at the ponds. Because of this association, and in addition to the significant results for three statistical tests ( $p < 0.05$  for the Gehan, slippage, and t-test), lithium is retained as a PCOC in OU 4 surface soils.

At normal earth-surface temperatures, elemental **mercury** is a liquid volatile metal. This volatility may have contributed to the distribution of mercury outside of the perimeter fence. The data for mercury show significance for two statistical tests ( $p < 0.05$  for Gehan and slippage tests), in addition to 14 exceedances of the UTL. Three of these exceedances are northeast of the PA perimeter fence. Because of these characteristics, mercury is retained as a PCOC for OU 4 surface soils.

**Nickel** is a trace metal in the Earth's crust, but has been widely redistributed through industrial use. Soils along the Front Range of Colorado contain an average of 75 mg/kg nickel (Severson and Tourtelot, 1994), although background soils at Rocky Flats contain only about 12 mg/kg (DOE, 1995). At Rocky Flats, nickel plating of weapons components, including nickel-carbonyl plating, was conducted until shutdown of the plating laboratory in 1990 (ChemRisk, 1992). For nickel in OU 4, three statistical tests are significant ( $p < 0.05$  for Gehan, slippage, and t-test) and there are three UTL exceedances, only one of which (176 mg/kg) is significantly greater than the value of the UTL (19.7 mg/kg). However, these three exceedances are clustered around the northern end of the 207B ponds. Because of this spatial clustering and the significant statistical differences, nickel is retained as a PCOC in OU 4 surface soils.

**Silver** is a precious trace metal that averages only 0.07 mg/kg in crustal rocks; shales show a slight enrichment, with 0.1 mg/kg silver (Krauskopf, 1979). However, widespread industrial use of silver has led to a higher anthropogenic background. There are eleven detected concentrations of silver in OU 4 surface soils (13.3-percent detection rate), ranging from 1.1 to 3.6 mg/kg. Silver was not detected in either the Rock Creek or BSCP studies, and was detected in only 3 percent of samples from the Front Range study (Severson and Tourtelot, 1994). Because of the higher rate of detection of silver in surface-soil samples collected in OU 4, and because of the inclusion of silver on the RFP hazardous-substance list, silver is retained as a PCOC in OU 4 surface soils. It should be noted, however, that the *mean* concentration of silver in background subsurface soils of the UHSU is 5.7 mg/kg, and the background subsurface concentrations of silver range from 0.27 to 40.9 mg/kg.

**Strontium** is an alkaline-earth metal with a geochemical behavior similar to that of calcium; it readily substitutes for calcium in carbonate minerals. Both the carbonate (strontianite) and sulfate (celestite)

of strontium are common in sediments. In OU 4, the highest concentrations of strontium in surface soils are found with relatively high concentrations of calcium, barium, cadmium, and beryllium. All statistical tests ( $p < 0.05$  for Gehan, slippage, quantile, and t-test) show significant differences between the background and OU 4 data sets for surface soil. Spatially, the 16 exceedances of the UTL are restricted to areas within and adjacent to the Solar Ponds and north of the ponds; there are no exceedances for samples collected outside the PA. Moreover, strontium is included on the hazardous-substance list for the Rocky Flats Plant (DOE, 1992). Because of the listed usage of strontium, the significant difference from background indicated by all four statistical tests, and the 16 UTL exceedances, strontium is retained as a PCOC for OU 4 surface soils.

Tin averages 2.5 mg/kg in crustal rocks, but is relatively enriched in shales (6.0 mg/kg) (Krauskopf, 1979). In surface soils of the Colorado Front Range, tin averages 1.3 mg/kg and ranges from 0.1 to 34 mg/kg. There is a higher detection rate for OU 4 samples (25.3 percent) than for BSCP samples (9.5 percent). However, data for background samples from Rock Creek show a 61-percent detection rate, with a mean of 32.5 mg/kg and a UTL of 84 mg/kg. Although the mean concentration in OU 4 is not excessively high (11.5 mg/kg), there is a maximum value of 61.5 mg/kg. Tin is not listed in the HRR or the ChemRisk study, but is included as a PCOC at CDPHE's request.

Zinc is likely to be related to other metal oxides or mineral surfaces through adsorption or coprecipitation. Zinc is widely used in industrial processes and products, resulting in significant remobilization and redistribution in the environment. At Rocky Flats, zinc is included on the hazardous-substance list. For OU 4 data, all four statistical tests ( $p < 0.05$  for Gehan, slippage, quantile, and t-test) show significant differences from background data for surface soil. In addition, there are 14 exceedances of the UTL (95.9 mg/kg). The sampling locations associated with these exceedances are distributed across the Solar Ponds area, except for one exceedance associated with a location outside of the fenced perimeter. Because of historical usage at Rocky Flats, the significance of statistical test results, and the 14 UTL exceedances, zinc is retained as a PCOC in OU 4 surface soils.

#### **A.4.2 RADIONUCLIDES IN OU 4 SURFACE SOILS**

Summary statistics were calculated for radionuclide data for surface-soil samples (Table A-6), and statistical tests were used to compare OU 4 data with those of background (Table A-7). After reviewing the results of the statistical tests, the records of historical chemical usage at Rocky Flats, the population characteristics of radionuclide data, and the spatial distribution of UTL exceedances in OU 4 surface soils, seven radionuclides were selected as PCOCs. The results of statistical tests are provided for each of these PCOCs (Table A-8), and are discussed in more detail in the section on radionuclides for OU 4 surface soils. Those radionuclides with recorded historical usage at Rocky

Flats include plutonium-239/240, americium-241, tritium, uranium-233/234, uranium-235, and uranium-238 (DOE, 1992).

**Radium-228** is not listed for historical usage at Rocky Flats and, based on the results of the formal statistical tests, radium-228 in OU 4 surface soils has activities indistinguishable from those of background surface soils. However, radium-228 data did show one UTL exceedance; consequently, radium-228 is evaluated in the following paragraph, prior to the discussion of PCOCs.

Unlike radium-226, which is a product of the uranium-238 decay chain, radium-228 is a disintegration product (alpha decay) of thorium-232 (half-life  $1.39 \times 10^{10}$  years), for which there are no analytical data. Although radium-228 data for samples of OU 4 surface soils show no significant differences from those of background, according to results of the statistical tests, there is one UTL exceedance of 16.0 pCi/g, which is five times the value of the UTL. Although thorium-232 was used for several applications at Rocky Flats (ChemRisk, 1992), the 10-billion-year half-life makes it unlikely that much radium-228 would have accumulated by radiogenic decay of pure thorium-232. Therefore, because there is no mention of radium-228 usage at Rocky Flats, the isolated occurrence of one UTL exceedance is not compelling evidence that radium-228 should be retained as a PCOC for OU 4 surface soils.

#### **A.4.2.1 Radionuclide PCOCs for OU 4 Surface Soils**

**Americium-241**, a transuranic element (atomic number 95), is the product of nuclear fission and has a half-life of about 500 years. Under an oxidizing neutral to alkaline environment, americium is strongly bound to soil particles and unlikely to be remobilized by infiltrating precipitation. Thus releases of americium to the environment will tend to remain in the upper portion of the soil profile. A study of americium and plutonium in surface soils at Rocky Flats found that more than 90 percent of the actinide activity was contained in the upper 12 cm of the soil (Litaor et al., 1994). Operable Unit 4 data for americium-241 show significant results for all tests ( $p < 0.05$  for Gehan, slippage, quantile, and t-test) in the statistical comparison with background data. Additionally, all but one of the 69 detections are greater than the UTL value. The spatial distribution of these exceedances blankets OU 4, both inside and outside of the fenced perimeter. Because of the results of the statistical tests and the known usage and release to the environment at Rocky Flats, americium-241 is included as a PCOC in OU 4 surface soils.

**Plutonium** (atomic number 94) is also a product of fission reactions; however, it has a much longer half-life than americium. The half-life for plutonium-239 is approximately 24,000 years. Like americium, plutonium sorbs strongly to the solid phase and is unlikely to migrate — under oxidizing, neutral to alkaline conditions — downward toward the water table at Rocky Flats. Data for plutonium-239/240 in OU 4 soils show significant differences for all statistical tests ( $p < 0.05$ ), and show 45

exceedances of the UTL. The activities of plutonium in OU 4 surface soils indicate a significant increase over those of background. Because of the results of the statistical tests and the known usage and release to the environment at Rocky Flats, plutonium-239/240 is retained as a PCOC for OU 4 surface soils.

**Radium-226** is a naturally occurring disintegration product of the uranium-238 decay chain, and has a half-life of 1,620 years. Radium is an alkaline-earth metal with a geochemical behavior somewhat similar to that of barium. Unlike the two transuranic elements discussed above, radium is less strongly bound to the solid phase, and may be remobilized by infiltrating solutions. Radium-226 is not on the inventory of chemicals used at RFP (DOE, 1992; ChemRisk, 1992), but all four statistical tests show significant differences ( $p < 0.05$ ) between radium-226 activities in OU 4 soils and those of background. This indicates that, although radium-226 is not on the hazardous-substance list for Rocky Flats, the activities in OU 4 and background surface soils are significantly different. Consequently, radium-226 is retained as a PCOC for OU 4 surface soils.

**Strontium-89/90** is a product of fission reactions. Strontium has a geochemical behavior similar to that of calcium, another alkaline-earth metal. Radiogenic strontium is not included on the hazardous-substance list for Rocky Flats (DOE, 1992); however, statistical tests show that activities of strontium-89/90 in OU 4 surface-soil samples are significantly greater than those for background surface soils. All four statistical tests have p-values less than 0.05 and there are eight exceedances of the UTL. Although there is no historical record for use of strontium-89/90 material at Rocky Flats, the results of statistical tests suggest that strontium-89/90 be retained for further evaluation as a PCOC.

There are no background data for **tritium** in surface soils, although background data for subsurface soils indicate a range of -150 to 440 pCi/g (DOE, 1993). The surface-soil samples collected from OU 4 contain tritium in the range of -87 to 227,000 pCi/g. In addition, tritium was statistically indicated as a PCOC in OU 4 subsurface soils, and there is a known history of usage and release of tritium at Rocky Flats. Because of these factors, tritium is retained as a PCOC for the surface soils of OU 4.

Both enriched and depleted uranium have been used at RFP since the 1950s. Naturally occurring uranium consists of mainly the uranium-238 isotope (about 99 percent by weight); whereas, enriched uranium contains more uranium-235 (about 93 percent at Rocky Flats, according to ChemRisk, 1992). Activities for all uranium isotopes analyzed (**uranium-233/234, uranium-235, and uranium-238**) in samples of OU 4 surface soil are significantly different statistically than those of background surface soils. All four inferential statistical tests (Gehan, slippage, quantile, and t-test) produce p-values less than 0.05 for these uranium isotopes. In addition, approximately one-quarter to one-third of the OU 4 samples contain activities of uranium isotopes that exceed the corresponding UTLs. Although all these isotopes are naturally occurring, the results of statistical tests and the historic usage of uranium

isotopes at Rocky Flats offer compelling evidence to retain uranium-233/234, uranium-235, and uranium-238 as PCOCs for OU 4 surface soils.

#### A.4.2.2 "Water-Quality" Parameters in OU 4 Surface Soils

Only two "water-quality" parameters were available for comparison with background (see Table A-7): nitrate/nitrite (reported together in RFEDS data) and total organic carbon (TOC). The latter analyte is basically a measure of the amount of organic matter in soil, and is not considered to be a contaminant.

#### A.4.2.3 "Water-Quality" PCOCs in OU 4 Surface Soils

Nitric acid was used in large quantities at the RFP for the dissolution of plutonium and other metals, and for cleaning and radioactive decontamination (ChemRisk, 1992). Data for nitrate in OU 4 surface soils yield significant differences for three of the four statistical tests when compared with data for background surface soils and show 20 UTL exceedances. In addition, nitrate in groundwater has been associated with the Solar Ponds (EG&G, 1994). Consequently, nitrate is included as a PCOC for surface soils (see Table A-8). Although reported together as nitrate/nitrite, nitrite is unstable in the presence of oxygen, and will quickly oxidize to nitrate (Drever, 1988). Measurable or significant quantities of nitrite are not expected.

### A.4.3 METALS IN OU 4 SUBSURFACE (BOREHOLE) SOILS

Summary statistics were calculated for metals data for subsurface-soil samples (Table A-9), and statistical tests were used to compare OU 4 data with those of background (Table A-10). After reviewing the results of the statistical tests, the records of historical chemical usage at Rocky Flats, the population characteristics, and the spatial distribution of UTL exceedances for metals in OU 4 subsurface soils, four metals were selected as PCOCs. The results of statistical tests are provided for each of these PCOCs (Table A-11), and are described in more detail in the discussion on metal PCOCs in OU 4 subsurface (borehole) soils.

**Antimony, beryllium, cesium, molybdenum, selenium, silver, and thallium** were detected in less than 20 percent of the OU 4 samples, so inferential statistical tests could not provide reliable results. However, in most cases, the detection rates for these seven metals are higher in the background data set than in the OU 4 data set (see Table A-10). For **antimony**, the background detection rate (6.2 percent) is higher than that for OU 4 (0.7 percent). Additionally, the maximum background value is greater than the maximum OU 4 value for antimony. **Beryllium** shows the same relationship; that is, the detection rate for background is greater than that for OU 4, and the background maximum is greater than the OU 4 maximum. **Cesium** was not detected in OU 4 subsurface soils. **Molybdenum** was detected in half of the background samples, but only 1.3 percent of the OU 4 samples. The

detection rate for **selenium** is comparable for background (2.5 percent) and OU 4 (4.3 percent) samples, but the value of the background maximum (13.7 mg/kg) far exceeds that of the OU 4 maximum (1.0 mg/kg). **Silver** was detected at a greater frequency in background (39.8 percent) than in OU 4 (1.2 percent) samples. The maximum value for silver in background samples (40.9 mg/kg) exceeds that of OU 4 samples (5.0 mg/kg). The detection rate for **thallium** is comparable for background (4.0 percent) and OU 4 (5.0 percent) samples, but the value of the background maximum (4.1 mg/kg) is greater than that of the OU 4 maximum (1.2 mg/kg).

Although elevated above background concentrations, **calcium**, **potassium**, and **sodium** are not considered as PCOCs because they are essential nutrients.

For **arsenic** data, one statistical test is considered significant (Gehan,  $p = 0.0430$ ) and there is only one exceedance of the UTL. The value of the exceedance (18.7 mg/kg) is only slightly greater than the value of the UTL (16.2 mg/kg), and the OU 4 mean (3.96 mg/kg) is only slightly greater than the background mean (3.68 mg/kg). In addition, the 18.7 mg/kg result is for a sample collected on August 29, 1989, from location P213089, which lies west of the ponds and next to building 774. The next highest result for arsenic is 13.3 mg/kg from location 46693. The lack of other UTL exceedances for samples collected more recently within the rest of OU 4, as well as the very slight difference in the mean concentrations of arsenic in OU 4 and background, suggest that arsenic should not be included as a PCOC for subsurface soils in OU 4.

The data for copper show significance for one test ( $p = 0.0360$  for quantile test), although the background mean is slightly higher (12.9 mg/kg) than the OU 4 mean (12.3 mg/kg). Because the quantile test looks at maximum values, the same data point responsible for the one UTL exceedance (UTL = 49.0 mg/kg, exceedance datum = 50.2 mg/kg) also resulted in a  $p$ -value  $< 0.05$  for the quantile test. However, because copper is not on the list of chemicals used at Rocky Flats (DOE, 1992; ChemRisk, 1994) and because the mean concentrations of copper in shales and crustal rocks is 50 mg/kg (Krauskopf, 1979), copper is not retained as a PCOC in OU 4 subsurface soils.

Other metals that show no significant differences according to the statistical tests, yet that have a few UTL exceedances include **barium** (2 exceedances), **cobalt** (1 exceedance), **lead** (2 exceedances), **manganese** (2 exceedances), **mercury** (1 exceedance), and **nickel** (1 exceedance). None of these seven metals is considered to be a PCOC; most exceedance values are only slightly above the corresponding UTL values. Only one exceedance (barium = 4,150 mg/kg) is significantly greater than the value of the corresponding UTL (372 mg/kg). This exceedance for barium is associated with several exceedances for calcium, an element with geochemical behavior similar to that of barium, and known to occur as caliche horizons in subsurface soils.

#### A.4.3.1 Metal PCOCs in OU 4 Subsurface (Borehole) Soils

**Cadmium** was only detected in 7.4 percent and 21.1 percent of background and OU 4 samples, respectively. Thus, the results of the statistical tests for cadmium are of dubious validity; however, the highest values detected for cadmium are clustered around and within the Solar Ponds. In addition, for OU 4, there are 23 detected concentrations above the maximum background value of 2.3 mg/kg. Therefore, because of the spatial distribution of cadmium in OU 4, the number of detections greater than the maximum background value, and the higher detection rate for OU 4 samples, cadmium is retained as a PCOC for subsurface soils in OU 4.

**Lithium** is included on the hazardous-substance list for Rocky Flats (DOE, 1992). In OU 4 subsurface soils, all six UTL exceedances for lithium are for samples collected inside the fenced perimeter of the PA; this suggests a close association with wastes treated at the ponds. Because of this association, in addition to the significant result of the Gehan test ( $p < 0.05$ ) and the historical usage, lithium is retained as a PCOC for OU 4 subsurface soils.

**Strontium** is also included on the list of hazardous substances used at Rocky Flats (DOE, 1992). In OU 4, the highest concentrations of strontium in subsurface soils are found with relatively high concentrations of calcium. This is not unexpected, considering the geochemical similarities of calcium and strontium. Strontium is indicated as a PCOC only by the Gehan test ( $p < 0.05$ ); however, the eight exceedances of the UTL are restricted to areas within and adjacent to the Solar Ponds. There are no strontium exceedances for samples collected outside the PA. Because of the spatial distribution and Gehan test results, as well as historical usage, strontium is retained as a PCOC for further evaluation.

**Zinc** is another metal listed for historical use at Rocky Flats (DOE, 1992). When the data for background and OU 4 subsurface soils are compared, zinc concentrations are indicated as significantly different by two statistical tests (Gehan and quantile tests). In addition, there is one exceedance of the UTL. Although the p-values for the statistical tests are not extremely small (Gehan  $p = 0.0150$ , quantile  $p = 0.0496$ ), the results of these two tests, in addition to the UTL exceedance and the historical usage of zinc, suggest that zinc be retained as a PCOC for OU 4 subsurface soils.

#### A.4.4 RADIONUCLIDES IN OU 4 SUBSURFACE (BOREHOLE) SOILS

Summary statistics were calculated for radionuclide data for subsurface-soil samples (Table A-12), and statistical tests were used to compare OU 4 data with those of background (Table A-13). After reviewing the results of the statistical tests, the records of historical chemical usage at Rocky Flats, the population characteristics of radionuclide data, and the spatial distribution of UTL exceedances in OU 4 subsurface soils, eight radionuclides were selected as PCOCs. The results of statistical tests are

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provided for each of these PCOCs (Table A-14), and are discussed in more detail in Section A.4.4.1. Those radionuclides with recorded historical usage at Rocky Flats include plutonium-239/240, americium-241, tritium, uranium-233/234, uranium-235, and uranium-238 (DOE, 1992).

**Gross alpha** and **gross beta** are indicator parameters rather than chemicals; these parameters provide a measure of the total alpha and total beta activities, respectively, of a sample. Uranium and radium isotopes and plutonium-239/240 are alpha emitters that contribute to the gross alpha measured in a sample. In OU 4 subsurface soils, the comparison of gross alpha data with those of background yields only one significant statistical test. The slippage test, with a p-value of 0.0338, indicates the presence of at least one high-value result. According to the Gehan test and the t-test, the background mean and the OU 4 mean are not significantly different. There are four locations of UTL exceedances for gross alpha in OU 4 subsurface soils; one is just north of building 780A (borehole 43593), one is inside Pond 207B North, and two lie between Ponds 207A and 207B North and Central. These exceedances are associated with exceedances for americium, plutonium, tritium, and in some cases, radium and uranium isotopes.

Radium-228 and lead-212 are some of the beta emitters in the thorium-232 decay chain; whereas, thorium-234, palladium-234, and lead-214 are some of the beta emitters in the uranium-238 decay chain (Friedlander et al., 1964). In comparison with background data, OU 4 subsurface-soil data show significant differences for gross beta, according to two of the four statistical tests; the slippage and quantile tests have p-values <0.05. There are also 11 exceedances of the UTL value for gross beta. The locations of these exceedances lie within and without the Solar Ponds.

Strontium-89 and strontium-90 are not separable by the analytical method used for RFETS samples; data for these isotopes are reported as combined **strontium-89/90**. Both these isotopes are fission products whose presence in soils is a result of world-wide fallout from atmospheric testing of nuclear weapons. There are no historical records indicating a radiogenic strontium source from Rocky Flats (DOE, 1992); however, strontium-89/90 activities in OU 4 subsurface soils are indicated as significantly different from those in background by both the Gehan test and the t-test. There are no exceedances of the UTL and the maximum background activity (1.20 pCi/g) exceeds that of OU 4 (0.84 pCi/g). Based on the lack of documented usage and the higher maximum activity for background subsurface soils, strontium-89/90 is not retained as a PCOC for OU 4 subsurface soils.

**Cesium-137** is an anthropogenic radioactive (gamma-emitting) isotope of the alkali metal, cesium, of which cesium-133 is the stable isotope. Cesium-137 is produced by fission reactions and has been distributed as world-wide fallout from the atmospheric testing of nuclear weapons. Cesium is strongly sorbed to the solid phase. Because of this strong binding to soils, in addition to the ease of detecting cesium-137 with field instruments, cesium-137 has been used as an indicator of surface-soil disturbance. The data for cesium-137 show significant differences for two statistical tests (Gehan,

quantile) and show seven exceedances of the UTL. However, the maximum activity of cesium-137 in OU 4 subsurface soils is 0.42 pCi/g; this is in contrast to the mean activity of 1.41 pCi/g in background surface soils (DOE, 1995). Thus cross-contamination with surface soils containing background levels of cesium-137 could easily produce the activities measured in OU 4 subsurface soils. In addition, cesium-137 has not been associated with industrial activities at Rocky Flats. Therefore, cesium-137 is not included as a PCOC for OU 4 subsurface soils.

#### A.4.4.1 Radionuclide PCOCs in OU 4 Subsurface (Borehole) Soils

All tests in the statistical comparison with background show significant differences between the OU 4 and background data sets for **americium-241** in subsurface soils ( $p < 0.05$  for Gehan, slippage, quantile, and t-tests). Additionally, there are 45 results greater than the UTL value. The spatial distribution of these exceedances blankets OU 4, both inside and outside of the fenced perimeter. Because of the results of the statistical tests and the known usage and release to the environment at Rocky Flats, americium-241 is included as a PCOC for OU 4 subsurface soils.

Additionally, for OU 4 americium data, the more shallow subsurface samples show higher activities of americium than deeper samples collected from the same borehole. These findings were true in nearly every case, and are consistent with the findings of Litaor et al. (1994), in which more than 90 percent of the actinide activity was confined in the upper 12 cm of the soil profile. By using the depth data and the analytical data, the levels of americium at various depths could be contoured in the OU 4 area. This contouring would be critical for any remediation solution involving excavation or in situ treatment.

The data for **plutonium-239/240** show significant results for all four statistical tests and 44 exceedances of the UTL. The spatial distribution of these exceedances blankets OU 4, both inside and outside of the fenced perimeter of the PA. Because of the results of the statistical tests and the known usage and release to the environment at Rocky Flats, plutonium-239/240 is included as a PCOC for OU 4 subsurface soils. As with americium-241, however, almost without exception, the shallower subsurface samples show higher activities of plutonium than do deeper samples collected from the same borehole. By using the depth data and the analytical data, the levels of plutonium at various depths could be contoured in the OU 4 area. This contouring would be critical for any remediation solution involving excavation or in situ treatment.

All four statistical tests comparing OU 4 and background data indicate significant differences for **radium-226**. In addition, there are 25 exceedances of the UTL. All exceedances are for samples collected from within the fenced perimeter, and most lie within the boundary of OU 4. Based on the spatial distribution of the UTL exceedances and the results of the statistical tests, radium-226 is

retained as a PCOC for OU 4 subsurface soils, despite the lack of documented historic usage at Rocky Flats.

The four statistical tests also show that activities of **radium-228** in OU 4 subsurface soils significantly exceed those of background subsurface soils. In addition, radium-228 data show ten exceedances of the UTL value. Like those for radium-226, all these exceedances are for samples collected within the PA, and most lie within the boundary of OU 4. Both the statistical comparisons and the UTL exceedances indicate that radium-228 should be retained as a PCOC for OU 4 subsurface soils.

The issue of radium-226 and radium-228 in soils at RFETS has been reviewed in an internal memorandum (Siders, 1995). The correlation of radium 226 (daughter) with uranium 238 and uranium 234 (parents) was evaluated for both background and OU 4 data sets. In general, if the radium 226 activities correlate with those for these uranium isotopes, and if the correlations are comparable for both the background and OU 4 data sets, then a natural origin is suggested for the radium 226. Results showed similar correlation coefficients ( $r$ ) for the background (0.70) and OU 4 (0.77) data. The results indicate radium in Rocky Flats soils may have a natural origin; however, they are not conclusive.

**Tritium** emits low-energy beta particles and has a half-life of approximately 12.3 years. Prior to atmospheric testing of nuclear weapons, tritium comprised an extremely small percentage of hydrogen isotopes; about one tritium atom per  $10^{17}$  normal hydrogen atoms (Hem, 1992). In OU 4, statistical comparisons with background data yield small p-values ( $p < 0.0001$ ) for all four tests. In addition, tritium data for OU 4 subsurface soils show 96 exceedances of the UTL, and tritium has a documented history of use at RFETS. Clearly, the tritium activities measured in OU 4 subsurface soils are a result of RFETS-introduced contamination; the background mean is 142 pCi/L; whereas, the OU 4 mean is 7,820 pCi/L. Tritium is therefore listed as a PCOC for OU 4 subsurface soils.

**Uranium-233/234** activities in OU 4 subsurface soils are significantly different from those of background according to results of the Gehan, slippage, quantile, and t-tests. The OU 4 data also show 20 exceedances of the UTL. Samples collected from within the fenced perimeter are responsible for all of these exceedances. The values of the exceedances range from 1.1 to 6.1 times the UTL of 3.44 pCi/g. Results of the statistical tests and the number of UTL exceedances dictate the retention of uranium-233/234 as a PCOC in OU 4 subsurface soils.

P-values for the Gehan, slippage, and t-tests indicate that activities of **uranium-235** in OU 4 subsurface soils are significantly different from those of background. The OU 4 data also exceed the value of the background UTL 18 times. As with uranium-233/234, all exceedances are for samples collected within the fenced perimeter; most are within or adjacent to the Solar Ponds. Values of these exceedances range from 1.1 to 5.7 times the value of the UTL (0.153 pCi/g). Due to the 18

exceedances of the UTL and the significance of three statistical tests, uranium-235 is retained as a PCOC in OU 4 subsurface soils.

The OU 4 data for **uranium-238** are significantly different from background data, according to all four statistical tests. The OU 4 data also show 29 exceedances of the UTL value. All but one of the samples showing these exceedances were collected from within the fenced perimeter. These samples show activities of uranium-238 that range from 1.1 to 6.4 times the value of the UTL. Results of the statistical tests and the number of UTL exceedances indicate that uranium-238 should be retained as a PCOC in OU 4 subsurface soils.

#### **A.4.5 "WATER-QUALITY" PARAMETERS IN OU 4 SUBSURFACE (BOREHOLE) SOILS**

Data for three "water-quality" parameters were available for comparison with background data: nitrate/nitrite, pH, and sulfide. The data for all three of these parameters show significant differences from background (see Table A-10). Because pH is an indicator parameter, not a chemical, it cannot be retained as a PCOC. However, despite the indication of a significant difference ( $p = 0.0413$  for Gehan test), the values for pH in OU 4 subsurface soils (range from 7.6 to 9.1) lie well within the range of pH expected for alkaline soils.

Sulfide was detected more frequently in background samples (16.9 percent) than in OU 4 samples (10.2 percent). The concentrations in OU 4 samples range from 1.0 to 21.2 mg/kg; concentrations in background samples range from 2.0 to 21.0 mg/kg. The Gehan test ( $p = 0.0413$ ) indicates that the OU 4 mean is significantly greater than the background mean; however, the high percentage of nondetects (approximately 90 percent for OU 4 samples) makes the outcome of any statistical test questionable. With such high nondetect rates, the estimation of population means is greatly influenced by the method of replacement for nondetects. Even a ranking test, such as the Gehan test, cannot reliably predict population differences for sample populations consisting almost wholly of nondetect data. This lack of reliability, combined with the known occurrence of sulfide minerals in UHSU materials (EG&G, 1995b) and the similarity in the range of reported values for the background and OU 4 samples, suggests that sulfide not be included as a PCOC for OU 4 subsurface soils.

##### **A.4.5.1 "Water-Quality" PCOCs in OU 4 Subsurface (Borehole) Soils**

Of the three parameters tested, only nitrate/nitrite shows both UTL exceedances (48) and significance in three of the four statistical tests. The p-values for the Gehan, slippage, and quantile tests are  $<0.0001$ , indicating a very low probability that the difference is due to chance alone.

## A.5 SUMMARY AND CONCLUSIONS

The PCOCs for OU 4 surface and subsurface soils (see Tables A-2, A-5, A-8, A-11, and A-14) were selected on the basis of statistical tests and professional judgment. Because of evaporative concentration of the solutions retained in the ponds, even those solutions that contained background levels of constituents may be expected to contain levels above background after evaporation had concentrated the original solutes. Due to solubility constraints, the excess solutes may have precipitated out of solution and been deposited in the asphalt liner or surrounding and underlying soils.

Of the 12 nonradioactive metals selected as PCOCs for OU 4 surface soils (barium, beryllium, cadmium, chromium, copper, lithium, mercury, nickel, silver, strontium, tin, and zinc), only copper and tin are not on the RFP hazardous-substance list (DOE, 1992). Of the eight radionuclides selected as PCOCs for OU 4 surface soils (americium-241, plutonium-239/240, radium-226, strontium-89/90, tritium, uranium-233/234, uranium-235, and uranium-238), only radium-226 and strontium-89/90 are not on the RFP hazardous-substance list (DOE, 1992). Additionally, nitrate was selected as a PCOC in OU 4 surface soils; nitric acid is on the list of hazardous substances used at RFP (DOE, 1992).

All four nonradioactive metals selected as PCOCs for OU 4 subsurface soils (cadmium, lithium, strontium, and zinc) are on the RFP hazardous-substance list (DOE, 1992). Of the eight radionuclides selected as PCOCs in OU 4 subsurface soils (americium-241, plutonium-239/240, radium-226, radium-228, tritium, uranium-233/234, uranium-235, and uranium-238), only radium-226, and radium-228 are not on the RFP hazardous-substance list (DOE, 1992).

Based on 1990 data, the chemistry of pond waters was fundamentally a sodium-chloride composition, with high concentrations of nitrate and detectable concentrations of cyanide (38 to 324 µg/L). Aside from trace amounts of acetone and methylene chloride (both common lab contaminants), no VOCs were reported in pond waters; this concurs with more recent (1990-present) data that show no VOC contamination in subsurface soils beneath the ponds.

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Table A-1 Data Comparisons for Metals: OU 4 Asphalt Liner vs. Background Surface Soil

Analyte	Background Data (DOE, 1995)										OU4 Liner Data									
	N	% Detect	Mean	Std Dev	Min	Max	99/99-U TL	N	% Detect	Mean	Std Dev	Min	Max	UNITS						
Aluminum	20	100	10244	3330	4050	17100	23000	12	100	3793	723	3680	4890	mg/kg						
Antimony	20	4	N/A	N/A	.19U	0.47	N/A	12	0	N/A	N/A	11.2U	11.2U	mg/kg						
Arsenic	20	100	6.1	2	2.3	9.6	13.75	12	92	1.14	0.4	0.6U	1.7	mg/kg						
Barium	20	100	102	19.4	45.7	134	176	12	100	44.4	9.4	26.9	57.5	mg/kg						
Beryllium	20	100	0.66	0.15	0.24	0.9	1.25	12	42	0.23	0.2	0.20U	0.7	mg/kg						
Cadmium	20	61	0.71	0.45	.295U	2.3	2.34	12	100	12.6	20.8	0.8	69.7	mg/kg						
Calcium	20	100	2970	750	1450	4550	5840	12	100	1710	566	832	2660	mg/kg						
Cesium	20	0	N/A	N/A	6.0U	7U	N/A	12	100	0.82	0.24	0.43	1.3	mg/kg						
Chromium	20	100	11.3	2.8	5.5	16.9	22.2	12	100	15.2	9.9	5.7	37.5	mg/kg						
Cobalt	20	100	7.3	1.8	3.4	11.2	14.2	12	100	3.35	0.95	1.4	4.7	mg/kg						
Copper	20	100	12.9	2.6	5.2	15.9	22.8	12	100	13.8	6.5	4.4	22.1	mg/kg						
Cyanide	0	N/A	N/A	N/A	N/A	N/A	N/A	6	17	0.085	0.055	0.10U	0.17	mg/kg						
Iron	20	100	12550	2740	7390	18100	23060	12	100	7410	1280	5350	9400	mg/kg						
Lead	20	100	33.6	10.5	8.6	53.3	73.9	12	100	28.6	36.6	3.8	107	mg/kg						
Lithium	20	100	7.7	1.9	4.8	11.6	15.1	12	100	7.4	2.8	3.8	13.2	mg/kg						
Magnesium	20	100	1910	470	1310	2800	3710	12	100	2000	310	1320	2400	mg/kg						
Manganese	20	100	237	64	129	357	482	12	100	117	17	91.9	140	mg/kg						
Mercury	20	35	0.07	0.03	.04U	0.12	0.19	12	0	N/A	N/A	N/A	N/A	mg/kg						
Molybdenum	20	9	N/A	N/A	.29U	0.9U	N/A	12	0	N/A	N/A	5.8U	6.2U	mg/kg						
Nickel	20	100	9.6	2.6	3.8	14	19.7	12	100	12.3	2.9	8.7	16.2	mg/kg						
Potassium	20	100	2060	450	1110	2830	3800	12	100	1660	466	1010	2370	mg/kg						
Selenium	20	61	0.63	0.3	.29U	1.4	1.76	12	0	N/A	N/A	0.40U	0.60U	mg/kg						
Silver	20	0	N/A	N/A	.19U	0.22U	N/A	12	0	N/A	N/A	0.60U	1.4U	mg/kg						
Sodium	20	100	62.2	14.8	44	105	119	12	100	508	304	135	1050	mg/kg						
Strontium	20	100	28.4	10.2	9.6	45.2	67.9	12	100	10.1	3.5	5.4	14.8	mg/kg						
Thallium	14	0	N/A	N/A	.39U	.45U	N/A	12	8	N/A	N/A	0.80U	0.96	mg/kg						
Tin	20	9	N/A	N/A	1.35U	2.9	N/A	12	100	0.49	0.11	0.31	0.66	mg/kg						
Vanadium	20	100	27.8	8.9	10.8	45.8	61.8	12	100	27.9	7.7	16.3	39	mg/kg						
Zinc	20	100	49.6	12.1	21.1	75.9	95.9	12	100	29.4	15.1	19.9	74	mg/kg						

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Table A-2 Data Comparisons for Radionuclides: OU 4 Asphalt Liner vs. Background Surface Soil

Analyte	Background Data (DOE, 1995)							OU4 Liner Data						
	N	% Detect	Mean	Std Dev	Min	Max	99/99-UTL	N	% Detect	Mean	Std Dev	Min	Max	UNITS
Americium-241	50	100	0.0107	0.006	0.001	0.025	0.037	12	100	0.948	1.51	0.003	4.032	pCi/g
Cesium-134	50	100	0.2	0.056	0.05	0.3	0.369	12	100	0.19	0.064	0.04	0.25	pCi/g
Cesium-137	50	100	0.941	0.372	0.3	1.7	2.25	12	100	0.116	0.037	0.07	0.17	pCi/g
Plutonium-239/240	50	100	0.038	0.014	0.017	0.072	0.084	12	100	0.427	0.878	0.007	3.126	pCi/g
Strontium-89,90	50	100	0.254	0.128	0.065	0.64	0.708	12	100	0.276	0.229	-0.1	0.5	pCi/g
Uranium-233,234	20	100	1.097	0.578	0.6	3.1	3.31	12	100	1.723	1.031	0.68	4.66	pCi/g
Uranium-235	20	100	0.0539	0.02	0.11	0.34	0.13	12	100	0.138	0.088	0.018	0.11	pCi/g
Uranium-238	20	100	1.09	0.455	0.74	2.6	2.83	12	100	1.72	1.03	0.52	2.68	pCi/g

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Table A-3 OU 4 Surface Soils: Summary Statistics for Metals

Analyte	N	%Detect	Mean	Std Dev	Min	Max	Units	Bkgd Max	USGS Range
Aluminum	83	100	10520	5290	2500	32500	mg/kg	17100	32,280-98,440
Antimony	79	5.1	11.3	4.1	2.4	24.8	mg/kg	0.47	N/A
Arsenic	83	100	4.4	4.8	0.44	34.4	mg/kg	9.6	0.6-22
Barium	83	100	114	57.3	38.9	393	mg/kg	134	450-1,800
Beryllium	83	24.1	1.44	1.1	0.32	9.6	mg/kg	0.9	0.5-2.8
Cadmium	83	56.6	17.5	61.6	0.36	382	mg/kg	2.3	N/D
Calcium	83	100	19750	31470	1290	248000	mg/kg	4550	1,500-45,810
Cesium	83	4.8	111	45	4	247	mg/kg	7U	N/A
Chromium	83	100	16.4	8.6	4.2	48.4	mg/kg	16.9	7.2-130
Cobalt	83	96.4	6.3	3.4	2.1	31	mg/kg	11.2	0.3-47
Copper	83	97.6	17	11.4	5.9	77.5	mg/kg	15.8	2.3-74
Iron	83	100	12720	3990	4010	27900	mg/kg	18100	6,710-69,240
Lead	83	100	21	19	2.8	121	mg/kg	53.3	9.7-130
Lithium	83	98.8	9.6	4.8	2.1	34.9	mg/kg	11.6	7.7-52
Magnesium	83	100	2526	920	690	6500	mg/kg	2800	905-18,640
Manganese	83	100	298	821	58	7650	mg/kg	357	90-850
Mercury	76	32.9	0.18	0.28	0.048	1.8	mg/kg	0.12	0.06-0.099
Molybdenum	83	3.6	4.8	1.1	2.2	9.9	mg/kg	.9U	N/A
Nickel	83	91.6	13.8	18.5	4.1	176	mg/kg	14	0.36-130
Potassium	83	100	2230	1030	574	6620	mg/kg	2830	11,620-55,620
Selenium	83	1.2	0.52	0.1	0.41	0.99	mg/kg	1.4	N/A
Silicon	72	100	3160	2490	463	11300	mg/kg	1650	248,000-402,000
Silver	83	13.3	2.25	0.64	0.57	3.7	mg/kg	.22U	N/A
Sodium	83	24.1	344	379	44.8	2440	mg/kg	105	3,190-23,660
Strontium	83	100	53.1	61.4	8.8	510	mg/kg	45.2	85-860
Thallium	80	6.3	0.44	0.22	0.21	0.99	mg/kg	.45U	N/D
Tin	83	25.3	24.4	11.5	1.6	61.5	mg/kg	2.9	N/A
Vanadium	83	100	28.9	11.5	10.2	67.6	mg/kg	45.8	18-260
Zinc	83	100	76.4	69.5	15.2	460	mg/kg	75.9	21-190

Note: Summary statistics were calculated using one-half times the detection limit as a replacement value for nondetects. However, statistics calculated for analytes having less than a 20-percent detection rate are of dubious value. Background maximum values are from Background Geochemical Characterization Report (DOE, 1993). USGS refers to the study by Severson and Tourtelot, 1994. N/A = not applicable; N/D = no data collected.

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Table A-4 OU 4 Surface Soils: Results of Statistical Tests and UTL Comparisons for Metals

Analyte	Site		Bkgrnd		Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	Bkgrnd 99/99 UTL	Units	No. of Exceed.
	N	% Det	N	% Det								
Aluminum	83	100.0	21	100.0	0.6749	0.1531	0.5767	0.4760	N	23565	mg/kg	3
Antimony	79	5.1	21	4.8	0.1490	0.6224	N/A	N/A	N	N/A	mg/kg	N/A
Arsenic	83	100.0	21	100.0	>.9999	0.5046	0.9931	0.9927	N	13.5	mg/kg	2
Barium	83	100.0	21	100.0	0.4613	0.0011	0.0048	0.0662	Y	174.2	mg/kg	8
Beryllium	83	24.1	21	100.0	0.0677	0.0560	N/A	N/A	N	1.26	mg/kg	12
Cadmium	83	56.6	21	66.7	<0.0001	0.0003	0.0048	N/A	Y	2.24	mg/kg	31
Calcium	83	100.0	21	100.0	<0.0001	<.0001	0.0048	<.0001	Y	5727	mg/kg	56
Cesium	83	4.8	21	0.0	0.5000	1.0000	N/A	N/A	N	N/A	mg/kg	N/A
Chromium	83	100.0	21	100.0	0.0022	0.0008	0.0036	<.0001	Y	22.8	mg/kg	13
Cobalt	83	96.4	21	100.0	0.9935	0.7981	N/A	0.9647	N	14.5	mg/kg	1
Copper	83	97.6	21	100.0	0.0908	0.0001	N/A	0.0029	Y	22.6	mg/kg	11
Iron	83	100.0	21	100.0	0.6362	0.7981	0.5767	0.5962	N	24800	mg/kg	1
Lead	83	100.0	21	100.0	>.9999	0.3996	0.9987	0.9999	N	72.2	mg/kg	4
Lithium	83	98.8	21	100.0	0.0482	0.0064	N/A	0.0083	Y	15.3	mg/kg	7
Magnesium	83	100.0	21	100.0	0.0008	0.0011	0.0048	0.0001	Y	3720	mg/kg	8
Manganese	83	100.0	21	100.0	0.9859	0.5046	0.9987	0.2624	N	480	mg/kg	3
Mercury	76	32.9	21	38.1	0.0270	0.0029	N/A	N/A	Y	0.18	mg/kg	14
Molybdenum	83	3.6	21	9.5	0.0093	1.0000	N/A	N/A	Y	N/A	mg/kg	N/A
Nickel	83	91.6	21	100.0	0.0101	0.0011	N/A	0.0187	Y	20.2	mg/kg	3
Potassium	83	100.0	21	100.0	0.4261	0.0432	0.1194	0.1689	Y	3814	mg/kg	5
Selenium	83	1.2	21	61.9	0.9788	1.0000	N/A	N/A	N	1.53	mg/kg	0
Silicon	72	100.0	21	100.0	<0.0001	<.0001	0.0041	<.0001	Y	2070	mg/kg	40
Silver	83	13.3	21	0.0	0.0196	0.3157	N/A	N/A	Y	N/A	mg/kg	N/A
Sodium	83	24.1	21	100.0	0.0001	0.4320	N/A	N/A	Y	117	mg/kg	12
Strontium	83	100.0	21	100.0	0.0077	<.0001	0.0048	0.0004	Y	67	mg/kg	16
Thallium	80	6.3	21	0.0	0.5000	1.0000	N/A	N/A	N	N/A	mg/kg	N/A
Tin	83	25.3	21	9.5	0.0078	0.2487	N/A	N/A	Y	N/A	mg/kg	N/A
Vanadium	83	100.0	21	100.0	0.6720	0.2487	0.3380	0.4301	N	60	mg/kg	2
Zinc	83	100.0	21	100.0	0.0202	0.0064	0.0384	0.0007	Y	95	mg/kg	14

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data are from the Background Soils Characterization Report (DOE, 1995). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate.

N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

Table A-5 PCOCs in OU4 Surface Soils: Results of Statistical Tests and UTL Comparisons for Metals

Analyte	Site		Bkgrnd		Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	Bkgrnd 99/99 UTL	Units	No. of Exceed.
	% Det	N	% Det	N								
Barium	83	100.0	21	100.0	0.4613	0.0011	0.0048	0.0662	Y	174.2	mg/kg	8
Beryllium	83	24.1	21	100.0	0.0677	0.0560	N/A	N/A	N	1.26	mg/kg	12
Cadmium	83	56.6	21	66.7	<0.0001	0.0003	0.0048	N/A	Y	2.24	mg/kg	31
Chromium	83	100.0	21	100.0	0.0022	0.0008	0.0036	<.0001	Y	22.8	mg/kg	13
Copper	83	97.6	21	100.0	0.0908	0.0001	N/A	0.0029	Y	22.6	mg/kg	11
Lithium	83	98.8	21	100.0	0.0482	0.0064	N/A	0.0083	Y	15.3	mg/kg	7
Mercury	76	32.9	21	38.1	0.0270	0.0029	N/A	N/A	Y	0.18	mg/kg	14
Nickel	83	91.6	21	100.0	0.0101	0.0011	N/A	0.0187	Y	20.2	mg/kg	3
Silver	83	13.3	21	0.0	0.0196	0.3157	N/A	N/A	Y	N/A	mg/kg	N/A
Strontium	83	100.0	21	100.0	0.0077	<.0001	0.0048	0.0004	Y	67	mg/kg	16
Tin	83	25.3	21	9.5	0.0078	0.2487	N/A	N/A	Y	N/A	mg/kg	N/A
Zinc	83	100.0	21	100.0	0.0202	0.0064	0.0384	0.0007	Y	95	mg/kg	14

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data are from the Background Soils Characterization Report (DOE, 1995). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate.

N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

Table A-6 OU 4 Surface Soils: Summary Statistics for Radionuclides and Nitrate

Analyte	N	% Detect	Mean	Std Dev	Min	Max	Units	Bkgd Max
Americium-241	69	100	6.98	21.06	0.028	130	pCi/g	0.025
Cesium-134	57	100	0.023	0.061	-0.239	0.15	pCi/g	0.3
Cesium-137	71	100	0.17	0.19	-0.007	0.79	pCi/g	1.7
Gross alpha	65	100	41.8	79	8.56	490	pCi/g	N/A
Gross beta	72	100	32.5	13.1	18	110	pCi/g	N/A
Plutonium-239/240	60	100	3.47	8.03	0.01	56	pCi/g	0.072
Radium-226	48	100	0.79	0.37	0.32	2.9	pCi/g	0.805
Radium-228	60	100	1.74	1.92	0.49	16	pCi/g	2.3
Strontium-89/90	65	100	0.35	0.32	-0.16	1.50	pCi/g	0.64
Tritium	68	100	5855	30850	-87	227000	PCi/l	N/A
Uranium-233/234	71	100	2.60	5.08	0.457	41	pCi/g	3.1
Uranium-235	71	100	0.138	0.287	0.016	2.3	pCi/g	0.34
Uranium-238	71	100	2.01	3.33	0.515	27	pCi/g	2.6
Nitrate/Nitrite	72	100	44	127	0.66	765	mg/kg	7

Note: Summary statistics were calculated using one-half times the detection limit as a replacement value for nondetects for nitrate/nitrite. However, statistics calculated for analytes with less than a 20-percent detection rate are of dubious value. Radionuclide data treated as 100-percent detected, per DOE Order 5400.1. Background maximum values are from the Background Soils Characterization Report (DOE, 1995).  
N/A = not applicable; N/D = no data collected.

**Table A-7 OU 4 Surface Soils: Results of Statistical Tests and UTL Comparisons for Radionuclides and Nitrate/Nitrite**

Analyte	Site		Bkgrnd N % Det	Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	Bkgrnd 99/99 UTL	Units	No. of Exceed.
	N % Det	N % Det									
Americium-241	69	100	83	<.0001	<.0001	<0.0001	0.0038	Y	0.03	pCi/g	68
Cesium-134	57	100	74	>0.9999	1.0000	>0.9999	>0.9999	N	0.32	pCi/g	0
Cesium-137	71	100	74	>0.9999	1.0000	>0.9999	>0.9999	N	2.1	pCi/g	0
Gross alpha	65	100	0	N/A	N/A	N/A	N/A	N/A	N/A	pCi/g	N/A
Gross beta	72	100	0	N/A	N/A	N/A	N/A	N/A	N/A	pCi/g	N/A
Plutonium-239/240	60	100	53	<0.0001	<0.0001	<0.0001	0.0008	Y	0.18	pCi/g	45
Radium-226	48	100	21	0.0025	0.0050	0.0132	0.0042	Y	1.2	pCi/g	2
Radium-228	60	100	21	0.0583	0.2931	0.4708	0.0688	N	3.13	pCi/g	1
Strontium-89/90	65	100	53	0.0347	0.0069	0.0230	0.0143	Y	0.68	pCi/g	8
Tritium	68	100	0	N/A	N/A	N/A	N/A	N/A	N/A	pCi/g	N/A
Uranium-233/234	71	100	20	0.0004	0.0034	0.0048	0.0049	Y	2.27	pCi/g	22
Uranium-235	71	100	20	0.0083	0.0018	0.0048	0.0061	Y	0.11	pCi/g	21
Uranium-238	71	100	20	0.0082	0.0167	0.0390	0.0071	Y	2.1	pCi/g	15
Nitrate/Nitrite	72	100	21	0.3066	0.001	0.0041	0.0048	Y	10.9	mg/kg	20

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data from the Background Soils Characterization Report (DOE, 1995). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate. N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

**Table A-8 PCOCs in OU 4 Surface Soils: Results of Statistical Tests and UTL Comparisons for Radionuclides and Nitrate/Nitrite**

Analyte	Site		Bkgrnd		Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	BKGRND 99/99 UTL	Units	No. of Exceed.
	N	% Det	N	% Det								
Americium-241	69	100	83	100	<.0001	<.0001	<0.0001	0.0038	Y	0.03	pCi/g	68
Plutonium-239/240	60	100	53	100	<0.0001	<0.0001	<0.0001	0.0008	Y	0.18	pCi/g	45
Radium-226	48	100	21	100	0.0025	0.0050	0.0132	0.0042	Y	1.2	pCi/g	2
Strontium-89/90	65	100	53	100	0.0347	0.0069	0.0230	0.0143	Y	0.68	pCi/g	8
Tritium	68	100	0	100	N/A	N/A	N/A	N/A	N/A	N/A	pCi/g	N/A
Uranium-233/234	71	100	20	100	0.0004	0.0034	0.0048	0.0049	Y	2.27	pCi/g	22
Uranium-235	71	100	20	100	0.0083	0.0018	0.0048	0.0061	Y	0.11	pCi/g	21
Uranium-238	71	100	20	100	0.0082	0.0167	0.0390	0.0071	Y	2.1	pCi/g	15
Nitrate/Nitrite	72	100	21	100	0.3066	0.001	0.0041	0.0048	Y	10.9	mg/kg	20

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data are from the Background Soils Characterization Report (DOE, 1995). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate. N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

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Table A-9 OU 4 Subsurface (Borehole) Soils: Summary Statistics for Metals

Analyte	N	%Detect	Mean	Std Dev	Min	Max	Units	Bkgd Max
Aluminum	162	100	10750	6740	1400	42400	mg/kg	102000
Antimony	148	0.7	13.6	9.1	5.9	25	mg/kg	47
Arsenic	162	95.7	3.96	2.7	0.48	18.7	mg/kg	41.8
Barium	162	98.8	119	325	9.7	4150	mg/kg	777
Beryllium	162	15.4	1.37	0.95	0.39	2.5	mg/kg	23.5
Cadmium	161	21.1	12.3	59	0.5	547	mg/kg	2.3
Calcium	162	100	32370	56350	706	328000	mg/kg	157000
Cesium	161	0	N/A	N/A	N/A	N/A	mg/kg	2830
Chromium	162	96.9	12.3	7.5	1	47.2	mg/kg	176
Cobalt	162	80.3	6.9	4.7	1.2	36.2	mg/kg	93.9
Copper	162	99.4	12.3	8	2.2	50.2	mg/kg	123
Iron	162	100	12110	6230	1060	50800	mg/kg	132000
Lead	161	100	10.8	7.1	2.4	47.5	mg/kg	39.8
Lithium	162	87.7	11.1	10.1	2.6	79.9	mg/kg	83.2
Magnesium	162	100	2410	1060	296	5860	mg/kg	32500
Manganese	162	100	202	290	27.4	3140	mg/kg	3330
Mercury	160	21.9	0.11	0.11	0.02	1.2	mg/kg	5.9
Molybdenum	160	1.3	16.4	5.9	1.4	25	mg/kg	67.6
Nickel	162	89.5	15.2	11.4	2.6	82.1	mg/kg	193
Potassium	162	96.3	2180	2340	180	21100	mg/kg	18700
Selenium	161	4.3	0.7	0.24	0.49	1	mg/kg	13.7
Silicon	108	100	2200	2360	360	14000	mg/kg	N/A
Silver	162	1.2	2.65	1.97	0.89	5	mg/kg	40.9
Sodium	162	57.4	1225	1550	52.2	10200	mg/kg	3680
Strontium	162	91.4	61.2	59.8	7.8	398	mg/kg	242
Thallium	161	5	0.97	0.15	0.23	1.2	mg/kg	4.1
Tin	160	21.3	34	14.7	6.6	91	mg/kg	441
Vanadium	162	100	27.3	13.9	3	82.2	mg/kg	283
Zinc	162	100	42.1	36.8	7.2	340	mg/kg	486

Note: Summary statistics were calculated using one-half times the detection limit as a replacement value for nondetects. However, statistics calculated for analytes having less than a 20-percent detection rate are of dubious value.

Background maximum values are from Background Geochemical Characterization Report (DOE, 1993).

N/A = not applicable.

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Table A-10 OU 4 Subsurface (Borehole) Soils: Results of Statistical Tests and UTL Comparisons for Metals

Analyte	Site		Bkgnd		Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	Bkgnd 99/99 UTL	Units	No. of Exceed.
	N	% Det	N	% Det								
Aluminum	162	100.0	98	99.0	0.9443	1.0000	0.8235	0.9390	N	45100	mg/kg	0
Antimony	148	0.7	66	15.2	0.2050	1.0000	N/A	N/A	N	N/A	mg/kg	N/A
Arsenic	162	95.7	99	70.7	0.0430	1.0000	N/A	N/A	Y	16.2	mg/kg	1
Barium	162	98.8	99	88.9	0.2923	0.6207	0.4271	0.2060	N	372	mg/kg	2
Beryllium	162	15.4	99	81.8	>0.9999	1.0000	N/A	N/A	N	18.3	mg/kg	0
Cadmium	161	21.1	81	7.4	0.0001	<0.0001	N/A	N/A	Y	N/A	mg/kg	N/A
Calcium	162	100.0	99	99.0	<0.0001	0.0206	<0.0001	<.0001	Y	53210	mg/kg	33
Cesium	161	0.0	95	1.1	0.8550	1.0000	N/A	N/A	N	N/A	mg/kg	N/A
Chromium	162	96.9	99	84.9	0.9997	1.0000	0.9984	0.9932	N	89.1	mg/kg	0
Cobalt	162	80.3	99	22.2	0.7388	1.0000	N/A	N/A	N	26.4	mg/kg	2
Copper	162	99.4	99	95.0	0.4943	1.0000	0.0360	0.5884	Y	49	mg/kg	1
Iron	162	100.0	99	100.0	0.9767	1.0000	0.9420	0.9547	N	52350	mg/kg	0
Lead	161	100.0	99	99.0	0.5490	0.6192	0.7306	0.5321	N	31	mg/kg	2
Lithium	162	87.7	99	61.6	0.0245	1.0000	N/A	N/A	Y	34.2	mg/kg	6
Magnesium	162	100.0	99	96.0	0.8178	1.0000	0.8965	0.9160	N	12100	mg/kg	0
Manganese	162	100.0	99	100.0	0.9034	1.0000	0.7387	0.6493	N	1194	mg/kg	2
Mercury	160	21.9	86	25.6	0.9997	1.0000	N/A	N/A	N	1.18	mg/kg	1
Molybdenum	160	1.3	99	50.5	0.9998	1.0000	N/A	N/A	N	41.1	mg/kg	0
Nickel	162	89.5	96	85.4	0.9967	1.0000	N/A	N/A	N	78.7	mg/kg	1
Potassium	162	96.3	98	52.0	0.0163	0.6231	N/A	0.9768	Y	7270	mg/kg	4
Selenium	161	4.3	82	2.4	0.9838	1.0000	N/A	N/A	N	N/A	mg/kg	N/A
Silicon	108	100.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	mg/kg	N/A
Silver	162	1.2	83	39.8	>0.9999	1.0000	N/A	N/A	N	33.1	mg/kg	0
Sodium	162	57.4	99	17.2	<0.0001	0.0017	N/A	N/A	Y	N/A	mg/kg	N/A
Strontium	162	91.4	99	36.4	0.0004	1.0000	N/A	N/A	Y	185	mg/kg	8
Thallium	161	5.0	75	4.0	0.2362	1.0000	N/A	N/A	N	N/A	mg/kg	N/A
Tin	160	21.3	92	27.2	0.9987	1.0000	N/A	N/A	N	383	mg/kg	0
Vanadium	162	100.0	99	98.0	0.9237	1.0000	0.6731	0.9140	N	113	mg/kg	0
Zinc	162	100.0	98	92.9	0.0150	1.0000	0.0496	0.1645	Y	183	mg/kg	1

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data are from the Background Geochemical Characterization Report (DOE, 1993). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate.

N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

Table A-11 PCOCs in OU 4 Subsurface (Borehole) Soils: Results of Statistical Tests and UTL Comparisons for Metals

Analyte	Site		Bkgrnd		Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	Bkgrnd 99/99 UTL	Units	No. of Exceed.
	N	% Det	N	% Det								
Cadmium	161	21.1	81	7.4	0.0001	<0.0001	N/A	N/A	Y	N/A	mg/kg	N/A
Lithium	162	87.7	99	61.6	0.0245	1.0000	N/A	N/A	Y	34.2	mg/kg	6
Strontium	162	91.4	99	36.4	0.0004	1.0000	N/A	N/A	Y	185	mg/kg	8
Zinc	162	100.0	98	92.9	0.0150	1.0000	0.0496	0.1645	Y	183	mg/kg	1

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data are from the Background Geochemical Characterization Report (DOE, 1993). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate.  
N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

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Table A-12 OU 4 Subsurface (Borehole) Soils: Summary Statistics for Radionuclides and Cyanide, Nitrate, Sulfide, and pH

Analyte	N	%Detect	Mean	Std Dev	Min	Max	Units	Bkgd Max
Americium-241	109	100	0.272	0.82	-0.005	6.1	pCi/g	0.01
Cesium-134	91	100	0.041	0.049	-0.032	0.15	pCi/g	N/A
Cesium-137	99	100	0.02	0.068	-0.038	0.42	pCi/g	0.2
Gross alpha	133	100	19.05	14.96	-0.498	116.7	pCi/g	48
Gross beta	145	100	26.32	9.3	10	55	pCi/g	44
Plutonium-239/240	108	100	0.409	1.998	-0.004	20	pCi/g	0.03
Radium-226	86	100	1.32	1.19	0.37	6.84	pCi/g	1.3
Radium-228	94	100	1.59	0.54	0.63	3.5	pCi/g	2.2
Strontium-89/90	99	100	0.285	0.2	-0.09	0.84	pCi/g	1.2
Tritium	135	100	7824	12444	-12	62000	pCi/g	440
Uranium-233/234	144	100	2.38	3.45	0.242	21	pCi/g	8.9
Uranium-235	144	100	0.094	0.124	-0.023	0.87	pCi/g	0.2
Uranium-238	144	100	1.82	2.03	0.297	11.48	pCi/g	3.2
Cyanide	94	0	N/A	N/A	N/A	N/A	mg/kg	N/A
Nitrate/Nitrite	127	97.6	346	859	0	6100	mg/kg	1
Sulfide	108	10.2	5.7	3.9	1	21.2	mg/kg	5
pH	26	100	8.32	0.41	7.6	9.12	pH	9.7

Note: Summary statistics were calculated using one-half times the detection limit as a replacement value for nondetects for nitrate/nitrite, sulfide, and pH. However, statistics calculated for analytes with less than a 20-percent detection rate are of dubious value. Radionuclide data treated as 100-percent detected, per DOE Order 5400.1. Background maximum values are from the Background Geochemical Characterization Report (DOE, 1993). N/A = not applicable.

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Table A-13 OU 4 Subsurface (Borehole) Soils: Results of Statistical Tests and UTL Comparisons for Radionuclides and Water-Quality Parameters

Analyte	Site		Bkgrnd % Det	Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	Bkgrnd 99/99 UTL	Units	No. of Exceed.
	N	% Det									
Americium-241	109	100	28	<0.0001	<0.0001	0.0007	0.0004	Y	0.022	pCi/g	45
Cesium-134	91	100	N/A	N/A	N/A	N/A	N/A	N/A	N/A	pCi/g	N/A
Cesium-137	99	100	99	<0.0001	0.1231	0.0001	0.1602	Y	0.13	pCi/g	7
Gross alpha	133	100	99	>.9999	0.0338	0.9999	0.9998	Y	51.4	pCi/g	4
Gross beta	145	100	99	0.3089	0.0048	0.0208	0.0528	Y	42.02	pCi/g	11
Plutonium-239/240	108	100	99	<0.0001	<0.0001	<0.0001	0.0187	Y	0.025	pCi/g	44
Radium-226	86	100	83	0.0003	<0.0001	0.0032	<0.0001	Y	1.42	pCi/g	25
Radium-228	94	100	83	0.0105	0.0014	0.0016	0.0021	Y	2.33	pCi/g	10
Strontium-89/90	99	100	99	<0.0001	1.0000	0.1882	<0.0001	Y	1.05	pCi/g	0
Tritium	135	100	99	<0.0001	<0.0001	<0.0001	<0.0001	Y	503	pCi/g	96
Uranium-233/234	144	100	99	<0.0001	0.0047	<0.0001	<0.0001	Y	3.44	pCi/g	20
Uranium-235	144	100	99	<0.0001	0.0009	0.1825	<0.0001	Y	0.15	pCi/g	18
Uranium-238	144	100	99	<0.0001	0.0001	<0.0001	<0.0001	Y	1.81	pCi/g	29
Nitrate/Nitrite	127	97.6	98	<0.0001	<0.0001	<0.0001	N/A	Y	56.7	mg/kg	48
Sulfide	108	10.2	89	0.0413	1.0000	N/A	N/A	Y	N/A	mg/kg	N/A
pH	26	100	97	0.0294	0.2114	0.6187	0.0021	Y	9.98	pH	0

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data are from the Background Geochemical Characterization Report (DOE, 1993). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate. N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

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Table A-14 PCOCs in OU4 Subsurface (Borehole) Soils: Results of Statistical Tests and UTL Comparisons for Radionuclides and Water-Quality Parameters

Analyte	Site		Bkgrnd		Gehan P-Value	Slippage P-Value	Quantile P-Value	T-Test P-Value	Any Test Significant?	Bkgrnd 99/99 UTL	Units	No. of Exceed.
	N	% Det	N	% Det								
Americium-241	109	100	28	100	<0.0001	<0.0001	0.0007	0.0004	Y	0.022	pCi/g	45
Plutonium-239/240	108	100	99	100	<0.0001	<0.0001	<0.0001	0.0187	Y	0.025	pCi/g	44
Radium-226	86	100	83	100	0.0003	<0.0001	0.0032	<0.0001	Y	1.42	pCi/g	25
Radium-228	94	100	83	100	0.0105	0.0014	0.0016	0.0021	Y	2.33	pCi/g	10
Tritium	135	100	99	100	<0.0001	<0.0001	<0.0001	<0.0001	Y	503	pCi/g	96
Uranium-233/234	144	100	99	100	<0.0001	0.0047	<0.0001	<0.0001	Y	3.44	pCi/l	20
Uranium-235	144	100	99	100	<0.0001	0.0009	0.1825	<0.0001	Y	0.15	pCi/g	18
Uranium-238	144	100	99	100	<0.0001	0.0001	<0.0001	<0.0001	Y	1.81	pCi/g	29
Nitrate/Nitrite	127	97.6	98	39.8	<0.0001	<0.0001	<0.0001	N/A	Y	56.7	mg/kg	48

Note: Statistical significance is taken at the 5-percent level; therefore, if the p-value is less than 0.05, the test indicates a significant difference between the site and background populations. Background data are from the Background Geochemical Characterization Report (DOE, 1993). Upper tolerance limits (UTLs) were not calculated for background analytes having less than a 20-percent detection rate.

N/A - Test not applicable because conditions for test were not met or the analyte is not in the background data set.

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## Appendix B

### Estimating the Intake Factor

## B.1 ESTIMATING THE CONCENTRATION TERM

In accordance with EPA guidance (EPA, 1989; 1992a; EPA Region VIII, 1994), the 95% upper confidence limit (95% UCL) on the mean is used as the exposure-point concentration for calculating the central tendency (CT) and reasonable maximum risk in Superfund risk assessments. The 95% UCL is an estimate of the upper limit of the true population mean for a given concentration in an exposure area. The 95% UCL is used instead of the mean, in order to account for the uncertainty in calculating the true mean from the sample population mean and standard deviation calculated from a small data set.

This appendix contains (1) a discussion of the statistical methods that were used to test the distribution of the data (normal or lognormal) and to calculate the concentration term and (2) tables showing all sample results used in the calculations.

### B.1.1 GENERAL STATISTICAL METHODS

For normally distributed data, the 95% UCL is calculated according to:

$$UCL_{1-\alpha} = \mu + \frac{t_{1-\alpha, n-1}}{\sqrt{(n-1)}} \quad (B-1)$$

For lognormally distributed data, the following equation is used:

$$UCL_{1-\alpha} = \exp \left( \bar{y} + 0.5s_y^2 + \frac{s_y H_{1-\alpha}}{\sqrt{(n-1)}} \right) \quad (B-2)$$

where

- $\mu$  = mean of original data
- $s$  = standard deviation of original data
- $y$  = mean of the log-transformed data
- $s_y$  = standard deviation of the log-transformed data
- $n$  = sample size
- $t$  = Student  $t$  value at significance level of  $\alpha$  (0.05) with  $(n-1)$  degrees of freedom
- $H$  = H statistic at a significance level of  $\alpha$

It is not always possible to correctly identify the distribution of a small sample ( $n = 20$  to  $50$ ), although this size is indicative of many environmental data sets (Hahn and Shapiro, 1967; Shumway et al., 1989). Distributions other than normal or lognormal are also possible. However, the normal and lognormal distributions were used here because (1) risk assessment guidance recommends using the normal and lognormal distributions and (2) methods to test distributions other than normal or lognormal are not readily available.

Distribution testing and calculating summary statistics for the original or the log-transformed data were performed using statistical procedures recommended by EPA (1989) or generally accepted in engineering practices. The following standard statistical methods were applied, depending on the characteristics of the data set:

- Wilk-Shapiro test for normality (EPA, 1992b)
- Probability plotting test for normality (EPA, 1992b)

The proportion of nondetects for each analyte in each medium ranges from 0 to 96.55 percent. As specified in DOE Order 5400.1, all radionuclide results are treated as detects, in that the actual value of the result, rather than a replacement value, is used in all statistical calculations. The detection rates and results of distributional testing for all COCs are provided in Tables B-1 through B-3. Because one-half the detection limit was used as a replacement value for each nondetect record, the proportion of nondetects affects the reliability of the calculation of central tendency in each case. It is up to the user to be cognizant of the increased uncertainty associated with increased nondetect rates.

For radionuclide data, which include some zero and negative values for the analytical results, no log-transformations were performed; rather, calculations defaulted to the normal 95% UCL. A satisfactory method for treatment of the zero and negative activities reported for radionuclides has not been agreed upon by various statisticians working for DOE.

Some data sets include only three observations: americium-241, plutonium-239/240, and radium-226 in subsurface soils of AOC No. 2. Again, the user should be cognizant of the uncertainties of distributional testing and estimation of the mean, inherent in calculations for such small sample sizes.

In summary, the user of these results must apply professional judgment in deciding which value (the  $UCL_{95}$  or the maximum detected concentration) to use for assessing risk. Tables B-1 through B-3 also show analytical results used in the calculations.

## B.2 ESTIMATING CHEMICAL INTAKES

As stated in Section 3.3 of the OU 4 HHRA, chemical intakes are based on reasonable estimates of body weight, inhalation volume, ingestion rates, soil matrix effects, frequency and duration of exposure, and chemical concentration (exposure point concentration). This section of Appendix B presents the intake equations for each pathway evaluated in the risk assessment and also includes discussions on the concepts of averaging time, age-adjusted ingestion rates, the area averaging factor, and chemical-specific matrix effects and adsorption factors.

The variable "averaging time" in the following intake equations is expressed in days to calculate daily intake. For noncarcinogenic chemicals, intakes are calculated by averaging over the exposure duration to yield an average daily intake for the period of exposure. For carcinogens, intakes are calculated by averaging the total intake over a 70-year lifetime, yielding "lifetime average daily intake." Different averaging times are used for carcinogens and noncarcinogens because it is thought that their effects occur by different mechanisms. The approach for carcinogens is based on the scientific opinion and EPA policy that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime, and that even very low doses of carcinogens have the potential to cause cancer. Therefore, the average daily intake of a carcinogen is estimated over a 70-year lifetime (EPA, 1989). Intake of noncarcinogens is averaged only over the period of exposure in order to compare an estimate of daily dose to a reference dose considered to be without appreciable risk of adverse effects during long-term exposure.

Omitting chemical concentration from the intake equation yields an "intake factor" for each exposure pathway/receptor combination. The intake factor can then be multiplied by the concentration of each chemical to obtain the pathway/receptor-specific intake of that chemical. Intake factors were calculated for each potentially exposed receptor and exposure pathway identified in Appendix C. Except for soil ingestion, intake rates are approximately proportional to body weight, and therefore adult exposure parameters are considered adequately protective for calculating chemical doses used in estimating risk for all exposed populations, including children. Although body surface area is not exactly proportional to body weight and age-specific ratios of inhalation rate to body weight may differ, these differences are assumed to be negligible in estimating potential risk. Therefore, child intakes are not estimated for any exposure pathway except ingestion of soil, because children age 0 to 6 are thought to ingest considerably more soil and dust per kilogram body weight than adults. Childhood intake of soil is estimated for the open-space recreational user only, because adults would typically be the only receptors in the other scenarios.

## B.2.1 AREA WEIGHTING FACTOR FOR CURRENT ONSITE WORKER

A site-specific OU 4 weighting factor of 0.06 was used to estimate the fraction of time that a current RFETS worker (security personnel) would spend in OU 4 compared to the rest of RFETS. This factor is used to account for the fact that the worker spends only a fraction of the work day in contact with contaminated media in OU 4. A factor of 0.004 was initially derived by dividing the area of OU 4 by the total area of the RFETS property: 28 acres/6,550 acres = 0.004; where the 28 acres is the total acreage of OU 4 minus the acreage of the ponds (39 acres - 11 acres = 28 acres) and 6,550 acres is the total area of RFETS. The factor of 0.004 is equivalent to about 2 minutes based on an 8-hour work day, which equates to a very small amount of time. Therefore, to be conservative, it was assumed that a security worker would spend a maximum of 30 minutes in the surveillance of OU 4 and the resulting factor of 0.06 was obtained when backcalculating the equation using 30 minutes rather than 2 minutes. This weighting factor was applied in both the CT and RME scenarios developed for the current onsite worker for all pathways. Although this factor appears in the risk assessment tables in Appendix C, it is not shown in the exposure factor tables in this appendix.

## B.2.2 PATHWAY-SPECIFIC INTAKE EQUATIONS

The following equations were used to estimate intake of chemicals and radionuclides for the exposure scenarios evaluated in the risk assessment. Numerical values for the exposure factors for each receptor are shown on the Exposure Factors Tables (Tables B-4 through B-7) following the equations.

### B.2.2.1 Soil Ingestion

Chemical intake from soil ingestion is estimated using

$$\text{Intake} = \frac{C \times IR \times FC \times ME \times EF \times ED \times CF}{BW \times AT} \quad (\text{B-3})$$

where

- Intake = chemical intake, mg/kg-day
- C = chemical concentration in soil, mg/kg
- IR = soil ingestion rate, mg/day
- FC = fraction contaminated, unitless
- ME = soil matrix effect, unitless
- EF = exposure frequency, days/year
- ED = exposure duration, years
- CF = conversion factor,  $10^{-6}$  kg/mg
- BW = body weight, kg

AT = averaging time, days.

### Age-Adjusted IRs

Both child and adult soil ingestion rates were evaluated in the open-space use exposure scenario. For noncarcinogens, child and adult soil ingestion were evaluated separately, using the equation shown above and parameter values listed in Table B-4. This approach yields separate hazard indexes (HIs) for children and adults for the soil ingestion exposure route. The separate HI for children is a more protective estimate of potential noncarcinogenic hazard for this age group because it accounts for the greater amount of soil ingested by children relative to body weight.

For carcinogens, a combined child and adult weighted ingestion rate was calculated, combining the soil IR, BW, EF, and ED for both age groups. It is not necessary to calculate separate cancer risk estimates for children and adults because, according to theories of carcinogenesis currently advocated by EPA, a higher dose of a potential carcinogen over a short period of time is thought to have the same carcinogenic potential as a lower dose over a longer period of time. The calculation of age-adjusted soil ingestion rates for carcinogenic chemicals and radionuclides is shown in the risk calculation tables in Appendix C.

### Matrix Effect

The soil matrix effect (ME) describes the reduced bioavailability of a chemical bound to a soil matrix compared to the same chemical in solution. For Aroclor-1254, which has toxicity factors that were derived from studies in which the agent was administered in solution, a soil ME of 0.5 was used in calculating intake for risk assessment. The ME is used to account for decreased bioavailability of ingested compounds bound to a solid matrix relative to their bioavailability from drinking water or other solutions such as corn oil. Adjustments of this type may be necessary if "the medium of exposure in the site exposure assessment differs from the medium of exposure assumed by the toxicity value" (EPA, 1989). The EPA guidance further states that "a substance might be more completely absorbed following exposure to contaminated drinking water than following exposure to contaminated food or soil (e.g., if the substance does not desorb from soil in the gastrointestinal tract)."

There are several EPA precedents for assuming decreased bioavailability of inorganics from soil compared to that in water. For example, cadmium has two oral reference doses (RfDs), one for ingestion in food or other solid media, and one for ingestion in water. In deriving media-specific RfDs for cadmium, EPA assumed that 5 percent of cadmium ingested in water is bioavailable, compared to 2.5 percent for cadmium ingested in food (EPA, 1995). The corresponding matrix effect for cadmium ingested in food is 0.5. For the remaining COCs, where the critical toxicity study was dietary but no

vehicle was indicated in Integrated Risk Information System (IRIS), a default matrix effect of 1 was used.

For radionuclides, ingestion slope factors were calculated using gastrointestinal absorption factors ( $f_1$ ) for soluble forms of each radionuclide; consequently, it would be appropriate to consider matrix effects as well as mineralized form to estimate carcinogenic effects from ingestion of radionuclides in a soil matrix (Nelson, 1995). However, the reduction in potential toxic effects cannot be quantified simply using a matrix effect because the adjustment must account for differential effects on target organs. Therefore, a matrix effect of 1 has been adopted for radionuclides in the present risk assessment, even though this factor probably overestimates the effects of radionuclides ingested in soil.

#### B.2.2.2 Inhalation of Airborne Particulate Matter

$$\text{Intake} = \frac{C \times IR \times ET \times EF \times ED}{BW \times AT} \quad (\text{B-4})$$

Chemical intake through inhalation exposure routes is estimated using

where

- Intake = chemical intake, mg/kg-day
- C = chemical concentration in air, mg/m<sup>3</sup>
- IR = inhalation rate, m<sup>3</sup>/hr
- ET = exposure time, hr/day
- EF = exposure frequency, days/year
- ED = exposure duration, years
- BW = body weight, kg.
- AT = averaging time, days.

#### B.2.2.3 Soil Dermal Contact

Chemical intake through absorption of organic chemicals through skin is estimated using

$$\text{Intake} = \frac{C \times SA \times SAF \times AF \times FC \times EF \times ED \times CF}{BW \times AT} \quad (\text{B-5})$$

where

Intake	=	chemical intake, mg/kg-day
C	=	chemical concentration in soil, mg/kg
SA	=	surface area, cm <sup>2</sup> /day
SAF	=	skin absorption factor, unitless (chemical-specific)
AF	=	soil adherence factor, mg/cm <sup>2</sup>
FC	=	fraction contacted that is contaminated, unitless
EF	=	exposure frequency, days/year
ED	=	exposure duration, years
CF	=	conversion factor, kg soil/mg soil
BW	=	body weight, kg
AT	=	averaging time, days.

### Absorption Factors

The parameter AB is a chemical-specific value describing the fraction of organic chemical in soil that is absorbed by the skin. Dermal absorption of metals from contact with soil is not considered a significant uptake route, because metals bind strongly to soil, which greatly reduces their bioavailability. Most metals form strong bonds with other soil constituents and, because of polarity and solubility, metals are not absorbed well across the skin (EPA, 1991). Therefore, dermal uptake of metals was considered negligible and was not evaluated in this risk assessment. Likewise for radionuclides, EPA guidance states that "dermal uptake is generally not an important route of uptake for radionuclides, which have small dermal permeability constants" (EPA, 1989). Dermal permeability constants describe the rate at which dissolved (aqueous phase) chemicals permeate the skin. Absorption of radionuclides adhered to soil is also expected to be negligible.

#### B.2.2.4 Calculating Intake of Radionuclides

Exposure to radionuclides was evaluated in two ways. First, the total intake or external irradiation exposure for each radionuclide was calculated and multiplied by the respective carcinogenic slope factor to provide an estimate of lifetime excess cancer risk. The equations for estimating intake of radionuclides and external irradiation exposure are described in this appendix.

Second, the annual radiation dose (more precisely, the annual CEDE) was calculated and compared to annual radiation protection standards. Radiation dose calculations are discussed in Section 5.2.

#### B.2.2.5 Intake of Radionuclides from Ingestion and Inhalation

Intake of radionuclides was calculated using equations similar to those for calculating intake of chemicals. Intake of radionuclides by either ingestion or inhalation is a function of radionuclide

activity concentration, intake rate (or the amount of potentially contaminated medium contacted per unit time or event), and exposure frequency and duration. The only difference between calculating intake for radionuclides and nonradioactive substances is that averaging time and body weight are excluded from the intake equations for radionuclides.

$$\text{Intake} = C \times IR \times FC \times ME \times EF \times ED \quad (\text{B-6})$$

where

- Intake = lifetime internal radionuclide intake via inhalation or ingestion, pCi
- C = activity concentration of a radionuclide at the exposure point, pCi/m<sup>3</sup>, pCi/L, or pCi/kg
- IR = intake rate, m<sup>3</sup>/day, L/day, or kg/day
- FC = fraction contaminated, unitless (soil ingestion pathway only)
- ME = soil matrix effect, unitless (soil ingestion pathway only)
- EF = exposure frequency, days/year
- ED = exposure duration, years.

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

#### B.2.2.6 External Irradiation

For estimating lifetime excess cancer risk, external irradiation exposure is estimated

$$ER = C \times (1 - S_e) \times T_e \times EF \times ED \quad (\text{B-7})$$

where:

- ER = external irradiation exposure, pCi/g soil per year (pCi-yr/g)
- C = mass activity concentration of a radionuclide at the exposure point, pCi/g soil
- S<sub>e</sub> = gamma shielding factor, unitless
- T<sub>e</sub> = gamma exposure time factor, fraction of day (unitless)
- EF = exposure frequency, fraction of year (unitless)
- ED = exposure duration, years.

Excess lifetime cancer risk is then estimated by multiplying ER in pCi-yr/g by the slope factor for external irradiation expressed in risk per pCi-yr/g.

### B.3 REFERENCES

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EPA, 1992b, *Statistical Analysis of Ground-Water Data at RCRA Facilities, Addendum to Interim Final Guidance*, Office of Solid Waste, Waste Management Division, Washington, D.C., July.

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Table B-1 Data Used for Calculation of 95 Percent UCLs for Surface Soil in AOC No. 1

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
40993	BH40201AE	03-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
40993	BH40204AE	03-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
40993	BH40206AE	05-Mar-93	Cadmium	1.11	mg/kg	N/A	U	5	Z
40993	BH40415AE	05-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	JA
40993	BH40416AE	05-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	JA
41593	BH40417AE	06-Apr-93	Cadmium	22.1	mg/kg	N/A		5	V
41593	BH40418AE	06-Apr-93	Cadmium	1.3	mg/kg	N/A	U	5	V
41593	BH40419AE	06-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
41593	BH40424AE	06-Apr-93	Cadmium	1.2	mg/kg	N/A	U	5	V
41693	BH40217AE	22-Feb-93	Cadmium	27.6	mg/kg	N/A	N	1	JA
41693	BH40220AE	22-Feb-93	Cadmium	61.4	mg/kg	N/A	N	1	JA
41793	BH40243AE	19-Feb-93	Cadmium	3.2	mg/kg	N/A	N	1	JA
41793	BH40246AE	22-Feb-93	Cadmium	1.1	mg/kg	N/A	UN	1	JA
41993	BH40062AE	13-Jan-93	Cadmium	1.1	mg/kg	N/A	UN	1	V
41993	BH40065AE	14-Jan-93	Cadmium	1.2	mg/kg	N/A	UN	1	V
42093	BH40103AE	08-Jan-93	Cadmium	1.2	mg/kg	N/A	UN	1	V
42093	BH40483AE	08-Jan-93	Cadmium	1.1	mg/kg	N/A	UN	1	V
42193	BH40086AE	30-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	Z
42193	BH40091AE	30-Mar-93	Cadmium	1.3	mg/kg	N/A	U	5	V
42193	BH40425AE	19-Mar-93	Cadmium	5	mg/kg	N/A		5	V
42193	BH40426AE	19-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42193	BH40427AE	19-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42193	BH40430AE	30-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42193	BH40432AE	19-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42193	BH40433AE	31-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42293	BH40253AE	15-Apr-93	Cadmium	2.1	mg/kg	N/A		5	V
42293	BH40256AE	15-Apr-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42293	BH40258AE	20-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42393	BH40261AE	27-Jan-93	Cadmium	1.1	mg/kg	N/A	U	1	V
42393	BH40264AE	27-Jan-93	Cadmium	1.1	mg/kg	N/A	U	1	V
42493	BH40112AE	23-Mar-93	Cadmium	340	mg/kg	N/A		5	V
42493	BH40438AE	23-Mar-93	Cadmium	362	mg/kg	N/A		5	V
42493	BH40439AE	23-Mar-93	Cadmium	547	mg/kg	N/A		5	V
42493	BH40440AE	23-Mar-93	Cadmium	37.5	mg/kg	N/A		5	V
42493	BH40441AE	23-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42493	BH40445AE	23-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42593	BH40290AE	26-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42593	BH40446AE	16-Mar-93	Cadmium	4.7	mg/kg	N/A		5	JA
42593	BH40447AE	16-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42593	BH40448AE	16-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42593	BH40449AE	16-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42593	BH40450AE	16-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42993	BH40094AE	20-Jan-93	Cadmium	1.2	mg/kg	N/A	U	1	V
42993	BH40141AE	20-Jan-93	Cadmium	1.2	mg/kg	N/A	U	1	V
42993	BH40144AE	20-Jan-93	Cadmium	1.1	mg/kg	N/A	U	1	V
43193	BH40306AE	12-Feb-93	Cadmium	1.2	mg/kg	N/A	UN	1	JA
43193	BH40309AE	15-Feb-93	Cadmium	2.5	mg/kg	N/A	N	1	JA
43393	BH40324AE	18-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
43393	BH40510AE	18-Mar-93	Cadmium	3.6	mg/kg	N/A		5	V
43393	BH40511AE	18-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V

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Table B-1 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
43393	BH40512AE	18-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43393	BH40517AE	18-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
43493	BH40319AE	21-Apr-93	Cadmium	1.5	mg/kg	N/A		5	V
43493	BH40322AE	21-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43493	BH40573AE	21-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43693	BH40518AE	24-Mar-93	Cadmium	48.4	mg/kg	N/A		5	V
43693	BH40519AE	24-Mar-93	Cadmium	1.3	mg/kg	N/A		5	JA
43693	BH40520AE	24-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43693	BH40521AE	25-Mar-93	Cadmium	1	mg/kg	N/A	U	5	V
43693	BH40522AE	25-Mar-93	Cadmium	1	mg/kg	N/A	U	5	V
43693	BH40525AE	25-Mar-93	Cadmium	1.3	mg/kg	N/A		5	JA
43693	BH40563AE	25-Mar-93	Cadmium	1.6	mg/kg	N/A		5	JA
43793	BH40332AE	23-Feb-93	Cadmium	21.7	mg/kg	N/A		5	V
43793	BH40335AE	24-Feb-93	Cadmium	37.6	mg/kg	N/A		5	V
43893	BH40070AE	05-Feb-93	Cadmium	1.2	mg/kg	N/A	U	1	V
43893	BH40073AE	08-Feb-93	Cadmium	1.1	mg/kg	N/A	U	1	V
43993	BH40353AE	10-Feb-93	Cadmium	1.2	mg/kg	N/A	UN	1	JA
44093	BH40348AE	09-Feb-93	Cadmium	1.2	mg/kg	N/A	U	1	V
44093	BH40351AE	10-Feb-93	Cadmium	1.1	mg/kg	N/A	UN	1	JA
46593	BH40700AE	06-Nov-93	Cadmium	63.7	mg/kg	N/A		1	V
46593	BH40702AE	06-Nov-93	Cadmium	0.61	mg/kg	N/A	U	1	V
46593	BH40703AE	06-Nov-93	Cadmium	0.67	mg/kg	N/A	U	1	V
46593	BH40705AE	08-Nov-93	Cadmium	0.66	mg/kg	N/A	U	1	V
46593	BH40711AE	08-Nov-93	Cadmium	0.68	mg/kg	N/A	U	1	V
46593	BH40713AE	08-Nov-93	Cadmium	0.73	mg/kg	N/A	U	1	V
46693	BH40715AE	08-Nov-93	Cadmium	135	mg/kg	N/A		1	V
46693	BH40717AE	08-Nov-93	Cadmium	5.9	mg/kg	N/A		1	JA
46693	BH40718AE	09-Nov-93	Cadmium	3.6	mg/kg	N/A	U	1	JA
46693	BH40726AE	09-Nov-93	Cadmium	0.73	mg/kg	N/A	U	1	V
46693	BH40728AE	09-Nov-93	Cadmium	0.726	mg/kg	N/A	U	1	Z
46793	BH40729AE	10-Nov-93	Cadmium	35.6	mg/kg	N/A		1	V
46793	BH40731AE	10-Nov-93	Cadmium	0.71	mg/kg	N/A	U	1	JA
46793	BH40732AE	10-Nov-93	Cadmium	1.1	mg/kg	N/A	U	1	JA
46793	BH40740AE	10-Nov-93	Cadmium	0.73	mg/kg	N/A	U	1	JA
46793	BH40742AE	10-Nov-93	Cadmium	0.68	mg/kg	N/A	U	1	V
46793	BH40823AE	10-Nov-93	Cadmium	0.713	mg/kg	N/A	U	1	Z
46893	BH40743AE	19-Nov-93	Cadmium	0.71	mg/kg	N/A	U	1	V
46893	BH40745AE	19-Nov-93	Cadmium	0.68	mg/kg	N/A	U	1	V
46893	BH40746AE	19-Nov-93	Cadmium	3.3	mg/kg	N/A	U	1	V
46893	BH40748AE	19-Nov-93	Cadmium	11.4	mg/kg	N/A		1	JA
46893	BH40749AE	19-Nov-93	Cadmium	7	mg/kg	N/A		1	V
46893	BH40754AE	19-Nov-93	Cadmium	4.8	mg/kg	N/A		1	JA
46993	BH40757AE	22-Nov-93	Cadmium	0.64	mg/kg	N/A	U	1	V
46993	BH40759AE	22-Nov-93	Cadmium	1.4	mg/kg	N/A		1	JA
46993	BH40768AE	22-Nov-93	Cadmium	0.71	mg/kg	N/A	U	1	V
46993	BH40770AE	22-Nov-93	Cadmium	0.69	mg/kg	N/A	U	1	V
46993	BH40830AE	22-Nov-93	Cadmium	0.64	mg/kg	N/A	U	1	V
40993	SS40072AE	26-Feb-93	Americium-241	2.6	pCi/g	0.31		0.04	V
41693	SS40410AE	12-Feb-93	Americium-241	12	pCi/g	2.7		0.05	A
41793	SS40069AE	09-Feb-93	Americium-241	11.9	pCi/g	1.22		0	A

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Table B-1 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
41993	SS40009AE	13-Jan-93	Americium-241	0.43	pCi/g	0.042		0.01	A
42093	SS40480AE	08-Jan-93	Americium-241	0.46	pCi/g	0.044		0.01	V
42293	SS40078AE	15-Apr-93	Americium-241	0.059	pCi/g	0.015		0	V
42393	SS40079AE	27-Jan-93	Americium-241	0.21	pCi/g	0.048		0.01	V
42993	SS40056AE	18-Jan-93	Americium-241	0.56	pCi/g	0.06		0.02	V
43493	SS40086AE	21-Apr-93	Americium-241	0.086	pCi/g	0.02		0	V
43793	SS40088AE	12-Feb-93	Americium-241	65	pCi/g	15		0.12	A
43893	SS40010AE	05-Feb-93	Americium-241	1.7	pCi/g	0.34		0.05	V
44093	SS40090AE	09-Feb-93	Americium-241	0.97	pCi/g	0.23		0.06	V
SS400393	SS40019AE	27-May-93	Americium-241	27	pCi/g	2.3		0.6	A
SS400593	SS40021AE	27-May-93	Americium-241	92	pCi/g	6.9		0.5	A
SS400693	SS40022AE	27-May-93	Americium-241	45	pCi/g	4		1	A
SS400793	SS40023AE	29-Dec-92	Americium-241	1.147	pCi/g	0.129		0	A
SS401293	SS40028AE	29-Dec-92	Americium-241	0.044	pCi/g	0.014		0.01	A
SS401693	SS40032AE	30-Dec-92	Americium-241	2.132	pCi/g	0.231		0	A
SS401893	SS40034AE	30-Dec-92	Americium-241	16.43	pCi/g	1.8		0	A
SS402393	SS40039AE	30-Dec-92	Americium-241	1.381	pCi/g	0.154		0	A
SS402893	SS40044AE	27-May-93	Americium-241	130	pCi/g	7.5		0.8	A
SS402993	SS40045AE	27-May-93	Americium-241	3.2	pCi/g	0.44		0.3	A
40993	SS40072AE	26-Feb-93	Plutonium-239/240	7.2	pCi/g	1.6		0.04	V
41693	SS40410AE	12-Feb-93	Plutonium-239/240	4.9	pCi/g	1		0.01	V
41793	SS40069AE	09-Feb-93	Plutonium-239/240	15.04	pCi/g	1.48		0.01	A
42293	SS40078AE	15-Apr-93	Plutonium-239/240	0.322	pCi/g	0.049		0.01	V
42393	SS40079AE	27-Jan-93	Plutonium-239/240	0.37	pCi/g	0.074		0	V
43193	SS40084AE	09-Feb-93	Plutonium-239/240	5.324	pCi/g	0.532		0	A
43493	SS40086AE	21-Apr-93	Plutonium-239/240	0.642	pCi/g	0.079		0.01	V
43793	SS40088AE	12-Feb-93	Plutonium-239/240	17	pCi/g	3.7		0.01	V
43893	SS40010AE	05-Feb-93	Plutonium-239/240	2.1	pCi/g	0.29		0.01	V
44093	SS40090AE	09-Feb-93	Plutonium-239/240	0.39	pCi/g	0.17		0.03	A
SS400793	SS40023AE	29-Dec-92	Plutonium-239/240	0.43	pCi/g	0.071		0.01	A
SS401293	SS40028AE	29-Dec-92	Plutonium-239/240	0.032	pCi/g	0.013		0	V
SS401693	SS40032AE	30-Dec-92	Plutonium-239/240	1.864	pCi/g	0.208		0	V
SS401893	SS40034AE	30-Dec-92	Plutonium-239/240	7.448	pCi/g	0.758		0.01	V
SS402393	SS40039AE	30-Dec-92	Plutonium-239/240	5.329	pCi/g	0.563		0	V
SS402793	SS40043AE	20-May-93	Plutonium-239/240	56	pCi/g	10		0.03	A
40993	SS40072AE	26-Feb-93	Uranium-238	1.2	pCi/g	0.52	B	0.06	A
41693	SS40410AE	12-Feb-93	Uranium-238	2.6	pCi/g	0.6	B	0.03	A
41793	SS40077AE	09-Feb-93	Uranium-238	2.268	pCi/g	0.464		0.07	A
41993	SS40009AE	13-Jan-93	Uranium-238	0.69	pCi/g	0.21		0.1	A
42093	SS40480AE	08-Jan-93	Uranium-238	0.66	pCi/g	0.19		0.1	V
42293	SS40078AE	15-Apr-93	Uranium-238	1.013	pCi/g	0.312		0.07	A
42393	SS40079AE	27-Jan-93	Uranium-238	0.97	pCi/g	0.37	B	0.02	V
42993	SS40056AE	18-Jan-93	Uranium-238	0.93	pCi/g	0.25		0.1	V
43193	SS40084AE	09-Feb-93	Uranium-238	1.797	pCi/g	0.371		0.06	A
43493	SS40086AE	21-Apr-93	Uranium-238	0.969	pCi/g	0.265		0.1	A
43793	SS40088AE	12-Feb-93	Uranium-238	5.5	pCi/g	1.5	B	0.06	A
43893	SS40010AE	05-Feb-93	Uranium-238	5.2	pCi/g	0.95	B	0.03	V
43993	SS40091AE	04-Feb-93	Uranium-238	1.1	pCi/g	0.43	B	0.03	V
44093	SS40090AE	09-Feb-93	Uranium-238	0.78	pCi/g	0.25	B	0.01	A
SS400393	SS40019AE	27-May-93	Uranium-238	2.2	pCi/g	0.41		0.1	V

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Table B-1 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
SS400593	SS40021AE	27-May-93	Uranium-238	8.4	pCi/g	0.89		0.1	V
SS400693	SS40022AE	27-May-93	Uranium-238	0.91	pCi/g	0.26		0.1	V
SS400793	SS40023AE	29-Dec-92	Uranium-238	0.909	pCi/g	0.275		0.06	A
SS401293	SS40028AE	29-Dec-92	Uranium-238	0.75	pCi/g	0.211		0.05	A
SS401693	SS40032AE	30-Dec-92	Uranium-238	1.135	pCi/g	0.316		0.08	A
SS401893	SS40034AE	30-Dec-92	Uranium-238	2.517	pCi/g	0.453		0.05	A
SS402393	SS40039AE	30-Dec-92	Uranium-238	0.948	pCi/g	0.288		0.06	A
SS402793	SS40043AE	20-May-93	Uranium-238	6.3	pCi/g	0.61	B	0.01	V
SS402893	SS40044AE	27-May-93	Uranium-238	4.7	pCi/g	0.56		0.09	V
SS402993	SS40045AE	27-May-93	Uranium-238	1.5	pCi/g	0.35		0.1	V

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Table B-2 Data Used for Calculation of 95 Percent UCLs for Subsurface Soil in  
AOC No. 1

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
40993	BH40201AE	03-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
40993	BH40204AE	03-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
40993	BH40206AE	05-Mar-93	Cadmium	1.11	mg/kg	N/A	U	5	Z
40993	BH40415AE	05-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	JA
40993	BH40416AE	05-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	JA
41593	BH40417AE	06-Apr-93	Cadmium	22.1	mg/kg	N/A		5	V
41593	BH40418AE	06-Apr-93	Cadmium	1.3	mg/kg	N/A	U	5	V
41593	BH40419AE	06-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
41593	BH40424AE	06-Apr-93	Cadmium	1.2	mg/kg	N/A	U	5	V
41693	BH40217AE	22-Feb-93	Cadmium	27.6	mg/kg	N/A	N	1	JA
41693	BH40220AE	22-Feb-93	Cadmium	61.4	mg/kg	N/A	N	1	JA
41793	BH40243AE	19-Feb-93	Cadmium	3.2	mg/kg	N/A	N	1	JA
41793	BH40246AE	22-Feb-93	Cadmium	1.1	mg/kg	N/A	UN	1	JA
41993	BH40062AE	13-Jan-93	Cadmium	1.1	mg/kg	N/A	UN	1	V
41993	BH40065AE	14-Jan-93	Cadmium	1.2	mg/kg	N/A	UN	1	V
42093	BH40103AE	08-Jan-93	Cadmium	1.2	mg/kg	N/A	UN	1	V
42093	BH40483AE	08-Jan-93	Cadmium	1.1	mg/kg	N/A	UN	1	V
42193	BH40086AE	30-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	Z
42193	BH40091AE	30-Mar-93	Cadmium	1.3	mg/kg	N/A	U	5	V
42193	BH40425AE	19-Mar-93	Cadmium	5	mg/kg	N/A		5	V
42193	BH40426AE	19-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42193	BH40427AE	19-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42193	BH40430AE	30-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42193	BH40432AE	19-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42193	BH40433AE	31-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42293	BH40253AE	15-Apr-93	Cadmium	2.1	mg/kg	N/A		5	V
42293	BH40256AE	15-Apr-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42293	BH40258AE	20-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42393	BH40261AE	27-Jan-93	Cadmium	1.1	mg/kg	N/A	U	1	V
42393	BH40264AE	27-Jan-93	Cadmium	1.1	mg/kg	N/A	U	1	V
42493	BH40112AE	23-Mar-93	Cadmium	340	mg/kg	N/A		5	V
42493	BH40438AE	23-Mar-93	Cadmium	362	mg/kg	N/A		5	V
42493	BH40439AE	23-Mar-93	Cadmium	547	mg/kg	N/A		5	V
42493	BH40440AE	23-Mar-93	Cadmium	37.5	mg/kg	N/A		5	V
42493	BH40441AE	23-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42493	BH40445AE	23-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42593	BH40290AE	26-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42593	BH40446AE	16-Mar-93	Cadmium	4.7	mg/kg	N/A		5	JA
42593	BH40447AE	16-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42593	BH40448AE	16-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42593	BH40449AE	16-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
42593	BH40450AE	16-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
42993	BH40094AE	20-Jan-93	Cadmium	1.2	mg/kg	N/A	U	1	V
42993	BH40141AE	20-Jan-93	Cadmium	1.2	mg/kg	N/A	U	1	V
42993	BH40144AE	20-Jan-93	Cadmium	1.1	mg/kg	N/A	U	1	V
43193	BH40306AE	12-Feb-93	Cadmium	1.2	mg/kg	N/A	UN	1	JA
43193	BH40309AE	15-Feb-93	Cadmium	2.5	mg/kg	N/A	N	1	JA
43393	BH40324AE	18-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
43393	BH40510AE	18-Mar-93	Cadmium	3.6	mg/kg	N/A		5	V
43393	BH40511AE	18-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43393	BH40512AE	18-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
43393	BH40517AE	18-Mar-93	Cadmium	1.2	mg/kg	N/A	U	5	V
43493	BH40319AE	21-Apr-93	Cadmium	1.5	mg/kg	N/A		5	V
43493	BH40322AE	21-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43493	BH40573AE	21-Apr-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43693	BH40518AE	24-Mar-93	Cadmium	48.4	mg/kg	N/A		5	V
43693	BH40519AE	24-Mar-93	Cadmium	1.3	mg/kg	N/A		5	JA
43693	BH40520AE	24-Mar-93	Cadmium	1.1	mg/kg	N/A	U	5	V
43693	BH40521AE	25-Mar-93	Cadmium	1	mg/kg	N/A	U	5	V
43693	BH40522AE	25-Mar-93	Cadmium	1	mg/kg	N/A	U	5	V
43693	BH40525AE	25-Mar-93	Cadmium	1.3	mg/kg	N/A		5	JA
43693	BH40563AE	25-Mar-93	Cadmium	1.6	mg/kg	N/A		5	JA
43793	BH40332AE	23-Feb-93	Cadmium	21.7	mg/kg	N/A		5	V
43793	BH40335AE	24-Feb-93	Cadmium	37.6	mg/kg	N/A		5	V
43893	BH40070AE	05-Feb-93	Cadmium	1.2	mg/kg	N/A	U	1	V
43893	BH40073AE	08-Feb-93	Cadmium	1.1	mg/kg	N/A	U	1	V
43993	BH40353AE	10-Feb-93	Cadmium	1.2	mg/kg	N/A	UN	1	JA
44093	BH40348AE	09-Feb-93	Cadmium	1.2	mg/kg	N/A	U	1	V
44093	BH40351AE	10-Feb-93	Cadmium	1.1	mg/kg	N/A	UN	1	JA
46593	BH40700AE	06-Nov-93	Cadmium	63.7	mg/kg	N/A		1	V
46593	BH40702AE	06-Nov-93	Cadmium	0.61	mg/kg	N/A	U	1	V
46593	BH40703AE	06-Nov-93	Cadmium	0.67	mg/kg	N/A	U	1	V
46593	BH40705AE	08-Nov-93	Cadmium	0.66	mg/kg	N/A	U	1	V
46593	BH40711AE	08-Nov-93	Cadmium	0.68	mg/kg	N/A	U	1	V
46593	BH40713AE	08-Nov-93	Cadmium	0.73	mg/kg	N/A	U	1	V
46693	BH40715AE	08-Nov-93	Cadmium	135	mg/kg	N/A		1	V
46693	BH40717AE	08-Nov-93	Cadmium	5.9	mg/kg	N/A		1	JA
46693	BH40718AE	09-Nov-93	Cadmium	3.6	mg/kg	N/A	U	1	JA
46693	BH40726AE	09-Nov-93	Cadmium	0.73	mg/kg	N/A	U	1	V
46693	BH40728AE	09-Nov-93	Cadmium	0.726	mg/kg	N/A	U	1	Z
46793	BH40729AE	10-Nov-93	Cadmium	35.6	mg/kg	N/A		1	V
46793	BH40731AE	10-Nov-93	Cadmium	0.71	mg/kg	N/A	U	1	JA
46793	BH40732AE	10-Nov-93	Cadmium	1.1	mg/kg	N/A	U	1	JA
46793	BH40740AE	10-Nov-93	Cadmium	0.73	mg/kg	N/A	U	1	JA
46793	BH40742AE	10-Nov-93	Cadmium	0.68	mg/kg	N/A	U	1	V
46793	BH40823AE	10-Nov-93	Cadmium	0.713	mg/kg	N/A	U	1	Z
46893	BH40743AE	19-Nov-93	Cadmium	0.71	mg/kg	N/A	U	1	V
46893	BH40745AE	19-Nov-93	Cadmium	0.68	mg/kg	N/A	U	1	V
46893	BH40746AE	19-Nov-93	Cadmium	3.3	mg/kg	N/A	U	1	V
46893	BH40748AE	19-Nov-93	Cadmium	11.4	mg/kg	N/A		1	JA
46893	BH40749AE	19-Nov-93	Cadmium	7	mg/kg	N/A		1	V
46893	BH40754AE	19-Nov-93	Cadmium	4.8	mg/kg	N/A		1	JA
46993	BH40757AE	22-Nov-93	Cadmium	0.64	mg/kg	N/A	U	1	V
46993	BH40759AE	22-Nov-93	Cadmium	1.4	mg/kg	N/A		1	JA
46993	BH40768AE	22-Nov-93	Cadmium	0.71	mg/kg	N/A	U	1	V
46993	BH40770AE	22-Nov-93	Cadmium	0.69	mg/kg	N/A	U	1	V
46993	BH40830AE	22-Nov-93	Cadmium	0.64	mg/kg	N/A	U	1	V
40993	BH40201AE	03-Mar-93	Americium-241	0.25	pCi/g	0.06		0.003	V
40993	BH40204AE	03-Mar-93	Americium-241	0.04	pCi/g	0.03		0.017	V
40993	BH40206AE	05-Mar-93	Americium-241	0	pCi/g	0	U	0.006	V
40993	BH40415AE	05-Mar-93	Americium-241	0	pCi/g	0	U	0.004	V
40993	BH40416AE	05-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.002	V
41593	BH40417AE	06-Apr-93	Americium-241	0.5	pCi/g	0.08		0.005	V

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
41593	BH40418AE	06-Apr-93	Americium-241	0.12	pCi/g	0.05		0.011	V
41593	BH40419AE	06-Apr-93	Americium-241	0.01	pCi/g	0.01	J	0.004	V
41593	BH40424AE	06-Apr-93	Americium-241	0	pCi/g	0.01	U	0.011	V
41693	BH40217AE	22-Feb-93	Americium-241	2.7	pCi/g	0.42		0.005	A
41693	BH40220AE	22-Feb-93	Americium-241	0.28	pCi/g	0.05		0.002	A
41793	BH40243AE	19-Feb-93	Americium-241	2.1	pCi/g	0.39		0.019	A
41793	BH40246AE	22-Feb-93	Americium-241	0.07	pCi/g	0.03		0.015	A
41993	BH40062AE	13-Jan-93	Americium-241	0.23	pCi/g	0.02		0.007	A
41993	BH40065AE	14-Jan-93	Americium-241	0	pCi/g	0.01	U	0.01	A
42093	BH40103AE	08-Jan-93	Americium-241	0.27	pCi/g	0.03		0.008	A
42193	BH40086AE	30-Mar-93	Americium-241	0	pCi/g	0.01	U	0.007	A
42193	BH40091AE	30-Mar-93	Americium-241	0	pCi/g	0.01	U	0.004	A
42193	BH40425AE	19-Mar-93	Americium-241	0.09	pCi/g	0.03		0.007	A
42193	BH40426AE	19-Mar-93	Americium-241	0	pCi/g	0.01	U	0.01	A
42193	BH40427AE	19-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.003	A
42193	BH40430AE	30-Mar-93	Americium-241	0	pCi/g	0	U	0.006	A
42193	BH40432AE	19-Mar-93	Americium-241	0	pCi/g	0	U	0.009	A
42193	BH40433AE	31-Mar-93	Americium-241	0	pCi/g	0.01	U	0.007	A
42293	BH40253AE	15-Apr-93	Americium-241	0.08	pCi/g	0.02		0.002	V
42293	BH40256AE	15-Apr-93	Americium-241	0	pCi/g	0		0.003	V
42293	BH40258AE	20-Apr-93	Americium-241	0.01	pCi/g	0.01		0.003	V
42393	BH40261AE	27-Jan-93	Americium-241	0.69	pCi/g	0.09		0.006	V
42393	BH40264AE	27-Jan-93	Americium-241	0.06	pCi/g	0.02		0.002	V
42493	BH40112AE	23-Mar-93	Americium-241	0.17	pCi/g	0.05		0.016	V
42493	BH40438AE	23-Mar-93	Americium-241	1.1	pCi/g	0.25		0.062	V
42493	BH40439AE	23-Mar-93	Americium-241	0.17	pCi/g	0.04		0.011	V
42493	BH40440AE	23-Mar-93	Americium-241	0.01	pCi/g	0.01	U	0.009	V
42493	BH40441AE	23-Mar-93	Americium-241	0	pCi/g	0.01	U	0.011	V
42493	BH40445AE	23-Mar-93	Americium-241	0.02	pCi/g	0.01	J	0.009	V
42593	BH40290AE	26-Mar-93	Americium-241	0	pCi/g	0	U	0.007	A
42593	BH40446AE	16-Mar-93	Americium-241	0.03	pCi/g	0.01		0.005	V
42593	BH40447AE	16-Mar-93	Americium-241	0	pCi/g	0.01	U	0.005	V
42593	BH40448AE	16-Mar-93	Americium-241	0	pCi/g	0	BJ	0.002	V
42593	BH40449AE	16-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.005	V
42593	BH40450AE	16-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.007	V
43193	BH40306AE	12-Feb-93	Americium-241	0.9	pCi/g	0.12		0.005	A
43193	BH40309AE	15-Feb-93	Americium-241	0.01	pCi/g	0.01	J	0.007	A
43393	BH40324AE	18-Mar-93	Americium-241	0.12	pCi/g	0.48	U	0.68	A
43393	BH40510AE	18-Mar-93	Americium-241	0.02	pCi/g	0.01		0.002	A
43393	BH40511AE	18-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.002	A
43393	BH40512AE	18-Mar-93	Americium-241	0	pCi/g	0	U	0.007	A
43393	BH40517AE	18-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.002	A
43493	BH40319AE	21-Apr-93	Americium-241	0.03	pCi/g	0.01		0.002	V
43493	BH40322AE	21-Apr-93	Americium-241	0.01	pCi/g	0.01		0.005	V
43493	BH40573AE	21-Apr-93	Americium-241	0.04	pCi/g	0.01		0.002	V
43693	BH40518AE	24-Mar-93	Americium-241	2.48	pCi/g	0.27		0.005	A
43693	BH40519AE	24-Mar-93	Americium-241	0.01	pCi/g	0.01		0.005	A
43693	BH40520AE	24-Mar-93	Americium-241	0	pCi/g	0	J	0.005	A
43693	BH40521AE	25-Mar-93	Americium-241	0.01	pCi/g	0.01	U	0.01	V
43693	BH40522AE	25-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.004	V
43693	BH40525AE	25-Mar-93	Americium-241	0.01	pCi/g	0.01	J	0.005	V
43693	BH40563AE	25-Mar-93	Americium-241	0	pCi/g	0.01	U	0.007	V

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
43793	BH40332AE	23-Feb-93	Americium-241	6.1	pCi/g	0.72		0.007	A
43793	BH40335AE	24-Feb-93	Americium-241	0.07	pCi/g	0.03		0.012	A
43893	BH40070AE	05-Feb-93	Americium-241	1.4	pCi/g	0.15	B	0.008	V
43893	BH40073AE	08-Feb-93	Americium-241	0	pCi/g	0.01	BJ	0.002	V
43993	BH40353AE	10-Feb-93	Americium-241	0.26	pCi/g	0.04		0.002	A
44093	BH40348AE	09-Feb-93	Americium-241	1.8	pCi/g	0.19		0.006	V
44093	BH40351AE	10-Feb-93	Americium-241	0	pCi/g	0		0.002	A
46593	BH40700AE	06-Nov-93	Americium-241	0.03	pCi/g	0.01		0.006	A
46593	BH40702AE	06-Nov-93	Americium-241	0.02	pCi/g	0.01		0.004	V
46593	BH40703AE	06-Nov-93	Americium-241	0	pCi/g	0	J	0.006	A
46593	BH40705AE	08-Nov-93	Americium-241	0.01	pCi/g	0.01		0.005	A
46593	BH40711AE	08-Nov-93	Americium-241	0.03	pCi/g	0.01		0.004	A
46593	BH40713AE	08-Nov-93	Americium-241	0.04	pCi/g	0.01		0.004	A
46693	BH40715AE	08-Nov-93	Americium-241	1.8	pCi/g	0.2		0.005	Z
46693	BH40717AE	08-Nov-93	Americium-241	0.16	pCi/g	0.03		0.004	V
46693	BH40718AE	09-Nov-93	Americium-241	0.01	pCi/g	0.01		0.005	A
46693	BH40726AE	09-Nov-93	Americium-241	0.07	pCi/g	0.02		0.004	A
46693	BH40728AE	09-Nov-93	Americium-241	0.03	pCi/g	0.01		0.004	A
46793	BH40729AE	10-Nov-93	Americium-241	0.15	pCi/g	0.03		0.005	V
46793	BH40731AE	10-Nov-93	Americium-241	0.01	pCi/g	0.01		0.006	V
46793	BH40732AE	10-Nov-93	Americium-241	0.02	pCi/g	0.01		0.005	V
46793	BH40740AE	10-Nov-93	Americium-241	0.01	pCi/g	0.01		0.006	V
46793	BH40742AE	10-Nov-93	Americium-241	0.01	pCi/g	0.01		0.006	V
46793	BH40823AE	10-Nov-93	Americium-241	0.05	pCi/g	0.01		0.004	V
46893	BH40743AE	19-Nov-93	Americium-241	0.02	pCi/g	0.01		0.004	V
46893	BH40745AE	19-Nov-93	Americium-241	0.01	pCi/g	0.01		0.004	V
46893	BH40746AE	19-Nov-93	Americium-241	0	pCi/g	0	J	0.002	V
46893	BH40748AE	19-Nov-93	Americium-241	0	pCi/g	0	J	0.002	V
46893	BH40749AE	19-Nov-93	Americium-241	0.01	pCi/g	0		0.002	V
46893	BH40754AE	19-Nov-93	Americium-241	0.05	pCi/g	0.01		0.004	V
46893	BH40825AE	19-Nov-93	Americium-241	0.01	pCi/g	0		0.005	V
46993	BH40757AE	22-Nov-93	Americium-241	0	pCi/g	0	J	0.005	V
46993	BH40759AE	22-Nov-93	Americium-241	0.01	pCi/g	0		0.002	V
46993	BH40768AE	22-Nov-93	Americium-241	0.01	pCi/g	0.01	J	0.009	V
46993	BH40770AE	22-Nov-93	Americium-241	0.01	pCi/g	0		0.003	V
46993	BH40830AE	22-Nov-93	Americium-241	0.05	pCi/g	0.01		0.002	V
40993	BH40201AE	03-Mar-93	Plutonium-239/240	1.6	pCi/g	0.24		0.002	A
40993	BH40204AE	03-Mar-93	Plutonium-239/240	0.04	pCi/g	0.02		0.008	A
40993	BH40206AE	05-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.003	A
40993	BH40415AE	05-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.002	A
40993	BH40416AE	05-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.003	A
41593	BH40417AE	06-Apr-93	Plutonium-239/240	1	pCi/g	0.16		0.002	V
41593	BH40418AE	06-Apr-93	Plutonium-239/240	0.04	pCi/g	0.03		0.017	V
41593	BH40419AE	06-Apr-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.007	V
41593	BH40424AE	06-Apr-93	Plutonium-239/240	0	pCi/g	0	U	0.005	V
41693	BH40217AE	22-Feb-93	Plutonium-239/240	3	pCi/g	0.4		0.004	V
41693	BH40220AE	22-Feb-93	Plutonium-239/240	0.29	pCi/g	0.07		0.008	V
41793	BH40243AE	19-Feb-93	Plutonium-239/240	2.9	pCi/g	0.64		0.037	V
41793	BH40246AE	22-Feb-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.003	V
41993	BH40062AE	13-Jan-93	Plutonium-239/240	0.16	pCi/g	0.03		0.009	A
41993	BH40065AE	14-Jan-93	Plutonium-239/240	0.01	pCi/g	0	J	0.005	A
42093	BH40103AE	08-Jan-93	Plutonium-239/240	1.3	pCi/g	0.1		0.005	A

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
42193	BH40086AE	30-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.003	V
42193	BH40091AE	30-Mar-93	Plutonium-239/240	0	pCi/g	0	J	0.002	V
42193	BH40425AE	19-Mar-93	Plutonium-239/240	0.06	pCi/g	0.03	B	0.004	A
42193	BH40426AE	19-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.004	A
42193	BH40427AE	19-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.005	A
42193	BH40430AE	30-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.002	V
42193	BH40432AE	19-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.005	A
42193	BH40433AE	31-Mar-93	Plutonium-239/240	0	pCi/g	0	J	0.002	V
42293	BH40253AE	15-Apr-93	Plutonium-239/240	0.4	pCi/g	0.06		0.003	A
42293	BH40256AE	15-Apr-93	Plutonium-239/240	0.01	pCi/g	0.01		0.003	A
42293	BH40258AE	20-Apr-93	Plutonium-239/240	0.01	pCi/g	0.01		0.007	V
42393	BH40261AE	27-Jan-93	Plutonium-239/240	0.75	pCi/g	0.13	B	0.003	A
42393	BH40264AE	27-Jan-93	Plutonium-239/240	0.15	pCi/g	0.07	B	0.007	A
42493	BH40112AE	23-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.002	V
42493	BH40438AE	23-Mar-93	Plutonium-239/240	0.11	pCi/g	0.03		0.002	V
42493	BH40439AE	23-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.002	V
42493	BH40440AE	23-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.003	V
42493	BH40441AE	23-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.005	V
42493	BH40445AE	23-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.007	V
42593	BH40290AE	26-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.007	V
42593	BH40446AE	16-Mar-93	Plutonium-239/240	0.29	pCi/g	0.06		0.007	V
42593	BH40447AE	16-Mar-93	Plutonium-239/240	0.05	pCi/g	0.03		0.015	V
42593	BH40448AE	16-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.006	V
42593	BH40449AE	16-Mar-93	Plutonium-239/240	0.02	pCi/g	0.01	J	0.004	V
42593	BH40450AE	16-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	U	0.012	V
43193	BH40306AE	12-Feb-93	Plutonium-239/240	1.3	pCi/g	0.18		0.002	V
43193	BH40309AE	15-Feb-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.002	V
43393	BH40324AE	18-Mar-93	Plutonium-239/240	0	pCi/g	0	BJ	0	A
43393	BH40510AE	18-Mar-93	Plutonium-239/240	0.1	pCi/g	0.03	B	0.002	A
43393	BH40511AE	18-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.004	A
43393	BH40512AE	18-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	BJ	0.005	A
43393	BH40517AE	18-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.019	A
43493	BH40319AE	21-Apr-93	Plutonium-239/240	0.24	pCi/g	0.04		0.003	V
43493	BH40322AE	21-Apr-93	Plutonium-239/240	0.01	pCi/g	0.01		0.007	V
43493	BH40573AE	21-Apr-93	Plutonium-239/240	0.21	pCi/g	0.04		0.007	V
43693	BH40518AE	24-Mar-93	Plutonium-239/240	0.99	pCi/g	0.14		0.006	A
43693	BH40519AE	24-Mar-93	Plutonium-239/240	0	pCi/g	0.01	J	0.019	A
43693	BH40520AE	24-Mar-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.016	A
43693	BH40521AE	25-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.007	V
43693	BH40522AE	25-Mar-93	Plutonium-239/240	0	pCi/g	0	U	0.005	V
43693	BH40525AE	25-Mar-93	Plutonium-239/240	0	pCi/g	0	J	0.002	V
43693	BH40563AE	25-Mar-93	Plutonium-239/240	0	pCi/g	0	J	0.002	V
43793	BH40332AE	23-Feb-93	Plutonium-239/240	4	pCi/g	0.49		0.005	V
43793	BH40335AE	24-Feb-93	Plutonium-239/240	0.03	pCi/g	0.01	J	0.002	V
43893	BH40070AE	05-Feb-93	Plutonium-239/240	0.61	pCi/g	0.1	B	0.002	V
43893	BH40073AE	08-Feb-93	Plutonium-239/240	0.14	pCi/g	0.05	B	0.004	V
43993	BH40353AE	10-Feb-93	Plutonium-239/240	0.14	pCi/g	0.03		0.01	A
44093	BH40348AE	09-Feb-93	Plutonium-239/240	0.05	pCi/g	0.02	B	0.007	A
44093	BH40351AE	10-Feb-93	Plutonium-239/240	0	pCi/g	0.01	J	0.009	A
46593	BH40700AE	06-Nov-93	Plutonium-239/240	0.92	pCi/g	0.12		0.008	A
46593	BH40702AE	06-Nov-93	Plutonium-239/240	0.02	pCi/g	0.01		0.003	V
46593	BH40703AE	06-Nov-93	Plutonium-239/240	0.04	pCi/g	0.02		0.022	A

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
46593	BH40705AE	08-Nov-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.015	A
46593	BH40711AE	08-Nov-93	Plutonium-239/240	0.02	pCi/g	0.02		0.009	A
46593	BH40713AE	08-Nov-93	Plutonium-239/240	0	pCi/g	0.01	J	0.023	A
46693	BH40715AE	08-Nov-93	Plutonium-239/240	0.71	pCi/g	0.12		0.022	V
46693	BH40717AE	08-Nov-93	Plutonium-239/240	0.05	pCi/g	0.02		0.016	V
46693	BH40726AE	09-Nov-93	Plutonium-239/240	0	pCi/g	0.01	J	0.006	A
46693	BH40728AE	09-Nov-93	Plutonium-239/240	0	pCi/g	0.01	J	0.016	A
46793	BH40729AE	10-Nov-93	Plutonium-239/240	0.06	pCi/g	0.02		0.003	V
46793	BH40731AE	10-Nov-93	Plutonium-239/240	0.01	pCi/g	0.01		0.004	V
46793	BH40732AE	10-Nov-93	Plutonium-239/240	0.02	pCi/g	0.01		0.01	V
46793	BH40740AE	10-Nov-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.011	V
46793	BH40742AE	10-Nov-93	Plutonium-239/240	0.01	pCi/g	0.02	J	0.031	V
46793	BH40823AE	10-Nov-93	Plutonium-239/240	0	pCi/g	0.01	J	0.012	V
46893	BH40743AE	19-Nov-93	Plutonium-239/240	0.04	pCi/g	0.01		0.008	A
46893	BH40745AE	19-Nov-93	Plutonium-239/240	0	pCi/g	0	J	0.01	A
46893	BH40746AE	19-Nov-93	Plutonium-239/240	0.01	pCi/g	0.01	J	0.008	A
46893	BH40748AE	19-Nov-93	Plutonium-239/240	0	pCi/g	0	J	0.006	V
46893	BH40749AE	19-Nov-93	Plutonium-239/240	0	pCi/g	0	J	0.006	V
46893	BH40754AE	19-Nov-93	Plutonium-239/240	0	pCi/g	0	J	0.006	V
46893	BH40825AE	19-Nov-93	Plutonium-239/240	0	pCi/g	0	J	0.008	V
46993	BH40757AE	22-Nov-93	Plutonium-239/240	0.08	pCi/g	0.02		0.008	A
46993	BH40759AE	22-Nov-93	Plutonium-239/240	0	pCi/g	0.01	J	0.013	V
46993	BH40768AE	22-Nov-93	Plutonium-239/240	0.01	pCi/g	0.02	J	0.019	A
46993	BH40770AE	22-Nov-93	Plutonium-239/240	0	pCi/g	0	J	0.003	V
46993	BH40830AE	22-Nov-93	Plutonium-239/240	0.01	pCi/g	0.01		0.008	A
40993	BH40201AE	03-Mar-93	Radium-226	1.1	pCi/g	0.3		0.34	V
40993	BH40204AE	03-Mar-93	Radium-226	0.67	pCi/g	0.27		0.36	V
40993	BH40206AE	05-Mar-93	Radium-226	0.4	pCi/g	0.17	J	0.23	V
40993	BH40415AE	05-Mar-93	Radium-226	0.63	pCi/g	0.16		0.21	V
40993	BH40416AE	05-Mar-93	Radium-226	0.93	pCi/g	0.17		0.21	V
41593	BH40417AE	06-Apr-93	Radium-226	0.88	pCi/g	0.33		0.45	V
41593	BH40418AE	06-Apr-93	Radium-226	0.69	pCi/g	0.34		0.49	V
41593	BH40419AE	06-Apr-93	Radium-226	0.59	pCi/g	0.33		0.48	V
41593	BH40424AE	06-Apr-93	Radium-226	0.59	pCi/g	0.26		0.36	V
41693	BH40217AE	22-Feb-93	Radium-226	0.82	pCi/g	0.29		0.37	V
41693	BH40220AE	22-Feb-93	Radium-226	0.38	pCi/g	0.25	J	0.37	V
41793	BH40243AE	19-Feb-93	Radium-226	0.55	pCi/g	0.32		0.48	V
41793	BH40246AE	22-Feb-93	Radium-226	0.49	pCi/g	0.24	J	0.34	V
42193	BH40086AE	30-Mar-93	Radium-226	0.7	pCi/g	0.21		0.28	V
42193	BH40091AE	30-Mar-93	Radium-226	0.89	pCi/g	0.23		0.26	V
42193	BH40425AE	19-Mar-93	Radium-226	1	pCi/g	0.43		0.54	V
42193	BH40426AE	19-Mar-93	Radium-226	0.73	pCi/g	0.26		0.34	V
42193	BH40427AE	19-Mar-93	Radium-226	0.48	pCi/g	0.28	J	0.4	V
42193	BH40430AE	30-Mar-93	Radium-226	0.84	pCi/g	0.24		0.3	V
42193	BH40432AE	19-Mar-93	Radium-226	0.37	pCi/g	0.21	J	0.31	V
42193	BH40433AE	31-Mar-93	Radium-226	0.89	pCi/g	0.24		0.32	V
42393	BH40261AE	27-Jan-93	Radium-226	0.94	pCi/g	0.29		0.39	A
42393	BH40264AE	27-Jan-93	Radium-226	1.1	pCi/g	0.31		0.42	A
42493	BH40112AE	23-Mar-93	Radium-226	0.88	pCi/g	0.29		0.39	V
42493	BH40438AE	23-Mar-93	Radium-226	1.1	pCi/g	0.29		0.35	V
42493	BH40439AE	23-Mar-93	Radium-226	0.86	pCi/g	0.28		0.37	V
42493	BH40440AE	23-Mar-93	Radium-226	0.55	pCi/g	0.31		0.44	V

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
42493	BH40441AE	23-Mar-93	Radium-226	0.53	pCi/g	0.3		0.43	V
42493	BH40445AE	23-Mar-93	Radium-226	0.66	pCi/g	0.25		0.33	V
42593	BH40290AE	26-Mar-93	Radium-226	0.9	pCi/g	0.21		0.26	V
42593	BH40446AE	16-Mar-93	Radium-226	0.93	pCi/g	0.25		0.33	V
42593	BH40447AE	16-Mar-93	Radium-226	0.56	pCi/g	0.25		0.36	V
42593	BH40448AE	16-Mar-93	Radium-226	0.59	pCi/g	0.23		0.32	V
42593	BH40449AE	16-Mar-93	Radium-226	0.62	pCi/g	0.2		0.28	V
42593	BH40450AE	16-Mar-93	Radium-226	0.64	pCi/g	0.26		0.32	V
43193	BH40306AE	12-Feb-93	Radium-226	0.59	pCi/g	0.36		0.55	V
43193	BH40309AE	15-Feb-93	Radium-226	0.65	pCi/g	0.32		0.45	V
43393	BH40324AE	18-Mar-93	Radium-226	0.98	pCi/g	0.31		0.4	V
43393	BH40510AE	18-Mar-93	Radium-226	0.8	pCi/g	0.29		0.38	V
43393	BH40511AE	18-Mar-93	Radium-226	0.54	pCi/g	0.32		0.47	V
43393	BH40512AE	18-Mar-93	Radium-226	0.58	pCi/g	0.29		0.42	V
43393	BH40517AE	18-Mar-93	Radium-226	1.9	pCi/g	0.32		0.36	V
43693	BH40521AE	25-Mar-93	Radium-226	0.59	pCi/g	0.28		0.38	V
43693	BH40522AE	25-Mar-93	Radium-226	0.53	pCi/g	0.33		0.49	V
43693	BH40525AE	25-Mar-93	Radium-226	1	pCi/g	0.31		0.41	V
43693	BH40563AE	25-Mar-93	Radium-226	0.71	pCi/g	0.33		0.46	V
43793	BH40332AE	23-Feb-93	Radium-226	0.85	pCi/g	0.29		0.37	V
43793	BH40335AE	24-Feb-93	Radium-226	0.62	pCi/g	0.25		0.34	V
43893	BH40070AE	05-Feb-93	Radium-226	0.93	pCi/g	0.28		0.37	A
43893	BH40073AE	08-Feb-93	Radium-226	0.49	pCi/g	0.27	J	0.41	A
44093	BH40348AE	09-Feb-93	Radium-226	0.75	pCi/g	0.22		0.3	A
46593	BH40700AE	06-Nov-93	Radium-226	1.82	pCi/g	0.42	X	0.191	V
46593	BH40702AE	06-Nov-93	Radium-226	1	pCi/g	0.4	X	0.379	V
46593	BH40703AE	06-Nov-93	Radium-226	1.59	pCi/g	0.4	X	0.192	V
46593	BH40705AE	08-Nov-93	Radium-226	1.89	pCi/g	0.55	X	0.258	V
46593	BH40711AE	08-Nov-93	Radium-226	1.71	pCi/g	0.49	X	0.228	V
46593	BH40713AE	08-Nov-93	Radium-226	1.95	pCi/g	0.73	X	0.326	V
46693	BH40715AE	08-Nov-93	Radium-226	5.89	pCi/g	0.86	X	0.479	V
46693	BH40717AE	08-Nov-93	Radium-226	1.24	pCi/g	0.39	X	0.319	V
46693	BH40718AE	09-Nov-93	Radium-226	2.11	pCi/g	0.51	X	0.234	V
46693	BH40726AE	09-Nov-93	Radium-226	3.28	pCi/g	0.64	X	0.269	V
46693	BH40728AE	09-Nov-93	Radium-226	2.68	pCi/g	0.62	X	0.229	V
46793	BH40729AE	10-Nov-93	Radium-226	3.07	pCi/g	0.62	X	0.233	A
46793	BH40731AE	10-Nov-93	Radium-226	2.07	pCi/g	0.63	X	0.216	A
46793	BH40732AE	10-Nov-93	Radium-226	2.24	pCi/g	0.55	X	0.198	A
46793	BH40740AE	10-Nov-93	Radium-226	1.92	pCi/g	0.46	X	0.234	A
46793	BH40742AE	10-Nov-93	Radium-226	2.34	pCi/g	0.52	X	0.217	A
46793	BH40823AE	10-Nov-93	Radium-226	2.66	pCi/g	0.62	X	0.226	A
46893	BH40743AE	19-Nov-93	Radium-226	0.92	pCi/g	0.45	X	0.187	A
46893	BH40745AE	19-Nov-93	Radium-226	1.07	pCi/g	0.39	X	0.178	A
46893	BH40746AE	19-Nov-93	Radium-226	0.95	pCi/g	0.36	X	0.162	A
46893	BH40748AE	19-Nov-93	Radium-226	1.62	pCi/g	0.44	X	0.19	A
46893	BH40749AE	19-Nov-93	Radium-226	1.51	pCi/g	0.4	X	0.179	A
46893	BH40754AE	19-Nov-93	Radium-226	2.08	pCi/g	0.56	X	0.241	A
46893	BH40825AE	19-Nov-93	Radium-226	2.21	pCi/g	0.53	X	0.186	A
46993	BH40757AE	22-Nov-93	Radium-226	4.54	pCi/g	0.64	X	0.193	A
46993	BH40759AE	22-Nov-93	Radium-226	2.86	pCi/g	0.52	X	0.181	A
46993	BH40768AE	22-Nov-93	Radium-226	6.84	pCi/g	0.92	X	0.265	A
46993	BH40770AE	22-Nov-93	Radium-226	1.57	pCi/g	0.45	X	0.186	A

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
46993	BH40830AE	22-Nov-93	Radium-226	5.43	pCi/g	0.76	X	0.21	A
40993	BH40201AE	03-Mar-93	Uranium-238	1.7	pCi/g	0.64	B	0.034	A
40993	BH40204AE	03-Mar-93	Uranium-238	0.87	pCi/g	0.42	B	0.034	A
40993	BH40206AE	05-Mar-93	Uranium-238	2.5	pCi/g	0.69	B	0.023	A
40993	BH40415AE	05-Mar-93	Uranium-238	2.2	pCi/g	0.54	B	0.048	A
40993	BH40416AE	05-Mar-93	Uranium-238	1.5	pCi/g	0.59	B	0.057	A
41593	BH40417AE	06-Apr-93	Uranium-238	8.3	pCi/g	1.3	B	0.021	A
41593	BH40418AE	06-Apr-93	Uranium-238	5.7	pCi/g	0.93	B	0.021	A
41593	BH40419AE	06-Apr-93	Uranium-238	4.4	pCi/g	0.8	B	0.014	A
41593	BH40424AE	06-Apr-93	Uranium-238	1.4	pCi/g	0.32	B	0.019	A
41693	BH40217AE	22-Feb-93	Uranium-238	5.1	pCi/g	0.81	B	0.018	A
41693	BH40220AE	22-Feb-93	Uranium-238	1.5	pCi/g	0.36	B	0.013	A
41793	BH40243AE	19-Feb-93	Uranium-238	1.4	pCi/g	0.52	B	0.029	A
41793	BH40246AE	22-Feb-93	Uranium-238	1	pCi/g	0.49	B	0.04	A
41993	BH40062AE	13-Jan-93	Uranium-238	0.77	pCi/g	0.18		0.07	V
41993	BH40065AE	14-Jan-93	Uranium-238	0.52	pCi/g	0.21		0.1	V
42093	BH40103AE	08-Jan-93	Uranium-238	0.83	pCi/g	0.19		0.07	V
42093	BH40483AE	08-Jan-93	Uranium-238	0.8473	pCi/g	0.245		0.051	A
42193	BH40086AE	30-Mar-93	Uranium-238	1.1	pCi/g	0.17	B	0.016	A
42193	BH40091AE	30-Mar-93	Uranium-238	1	pCi/g	0.18	B	0.007	A
42193	BH40425AE	19-Mar-93	Uranium-238	11	pCi/g	1.7	B	0.014	V
42193	BH40426AE	19-Mar-93	Uranium-238	1.1	pCi/g	0.34	B	0.049	V
42193	BH40427AE	19-Mar-93	Uranium-238	1.1	pCi/g	0.46	B	0.051	V
42193	BH40430AE	30-Mar-93	Uranium-238	0.94	pCi/g	0.17	B	0.024	A
42193	BH40432AE	19-Mar-93	Uranium-238	0.93	pCi/g	0.26	B	0.012	V
42193	BH40433AE	31-Mar-93	Uranium-238	1.1	pCi/g	0.18	B	0.007	A
42293	BH40253AE	15-Apr-93	Uranium-238	0.8252	pCi/g	0.315		0.11611	A
42293	BH40256AE	15-Apr-93	Uranium-238	0.9267	pCi/g	0.252		0.04733	A
42293	BH40258AE	20-Apr-93	Uranium-238	0.4895	pCi/g	0.175		0.0487	A
42393	BH40261AE	27-Jan-93	Uranium-238	1.3	pCi/g	0.34	B	0.013	A
42393	BH40264AE	27-Jan-93	Uranium-238	1.1	pCi/g	0.32	B	0.015	A
42493	BH40112AE	23-Mar-93	Uranium-238	0.76	pCi/g	0.29	B	0.019	A
42493	BH40438AE	23-Mar-93	Uranium-238	2.1	pCi/g	0.54	B	0.032	A
42493	BH40439AE	23-Mar-93	Uranium-238	1.3	pCi/g	0.44	B	0.024	A
42493	BH40440AE	23-Mar-93	Uranium-238	1.1	pCi/g	0.38	B	0.054	A
42493	BH40441AE	23-Mar-93	Uranium-238	0.68	pCi/g	0.26	B	0.03	A
42493	BH40445AE	23-Mar-93	Uranium-238	0.69	pCi/g	0.28	B	0.02	A
42593	BH40290AE	26-Mar-93	Uranium-238	0.89	pCi/g	0.17	B	0.008	A
42593	BH40446AE	16-Mar-93	Uranium-238	6.9	pCi/g	1.3		0.033	A
42593	BH40447AE	16-Mar-93	Uranium-238	0.87	pCi/g	0.25		0.021	A
42593	BH40448AE	16-Mar-93	Uranium-238	1.7	pCi/g	0.38		0.013	A
42593	BH40449AE	16-Mar-93	Uranium-238	1.3	pCi/g	0.32		0.012	A
42593	BH40450AE	16-Mar-93	Uranium-238	0.92	pCi/g	0.26		0.02	A
42993	BH40094AE	20-Jan-93	Uranium-238	0.489	pCi/g	0.157		0.021	A
42993	BH40141AE	20-Jan-93	Uranium-238	0.827	pCi/g	0.22		0.022	A
42993	BH40144AE	20-Jan-93	Uranium-238	0.768	pCi/g	0.184		0.016	A
43193	BH40306AE	12-Feb-93	Uranium-238	1.1	pCi/g	0.31	B	0.014	A
43193	BH40309AE	15-Feb-93	Uranium-238	1.7	pCi/g	0.56	B	0.026	A
43393	BH40324AE	18-Mar-93	Uranium-238	1.6	pCi/g	0.45	B	0.03	V
43393	BH40510AE	18-Mar-93	Uranium-238	4.4	pCi/g	0.74	B	0.012	V
43393	BH40511AE	18-Mar-93	Uranium-238	2.3	pCi/g	0.58	B	0.019	V
43393	BH40512AE	18-Mar-93	Uranium-238	3	pCi/g	0.52	B	0.018	V

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Table B-2 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
43393	BH40517AE	18-Mar-93	Uranium-238	2.2	pCi/g	0.47	B	0.013	V
43493	BH40319AE	21-Apr-93	Uranium-238	0.962	pCi/g	0.248		0.07101	A
43493	BH40322AE	21-Apr-93	Uranium-238	0.8978	pCi/g	0.228		0.02927	A
43493	BH40573AE	21-Apr-93	Uranium-238	0.7812	pCi/g	0.223		0.05064	A
43693	BH40518AE	24-Mar-93	Uranium-238	6.266	pCi/g	0.643		0.01864	A
43693	BH40519AE	24-Mar-93	Uranium-238	3.949	pCi/g	0.425		0.01762	A
43693	BH40520AE	24-Mar-93	Uranium-238	2.604	pCi/g	0.295		0.01888	A
43693	BH40521AE	25-Mar-93	Uranium-238	2.6	pCi/g	0.62	B	0.018	A
43693	BH40522AE	25-Mar-93	Uranium-238	4.7	pCi/g	1	B	0.033	A
43693	BH40525AE	25-Mar-93	Uranium-238	1.4	pCi/g	0.44	B	0.021	A
43693	BH40563AE	25-Mar-93	Uranium-238	1.5	pCi/g	0.49		0.074	A
43793	BH40332AE	23-Feb-93	Uranium-238	5.9	pCi/g	0.94	B	0.012	A
43793	BH40335AE	24-Feb-93	Uranium-238	0.72	pCi/g	0.36	B	0.054	A
43893	BH40070AE	05-Feb-93	Uranium-238	1.4	pCi/g	0.47	B	0.039	V
43893	BH40073AE	08-Feb-93	Uranium-238	0.68	pCi/g	0.28	B	0.02	V
43993	BH40353AE	10-Feb-93	Uranium-238	1.083	pCi/g	0.264		0.05308	V
44093	BH40348AE	09-Feb-93	Uranium-238	0.83	pCi/g	0.27	B	0.057	A
44093	BH40351AE	10-Feb-93	Uranium-238	0.6124	pCi/g	0.183		0.05362	V
46593	BH40700AE	06-Nov-93	Uranium-238	1.535	pCi/g	0.449		0.10892	A
46593	BH40702AE	06-Nov-93	Uranium-238	1.4	pCi/g	0.315		0.03158	V
46593	BH40703AE	06-Nov-93	Uranium-238	1.768	pCi/g	0.429		0.07999	A
46593	BH40705AE	08-Nov-93	Uranium-238	1.472	pCi/g	0.371		0.06878	A
46593	BH40711AE	08-Nov-93	Uranium-238	1.237	pCi/g	0.294		0.03282	A
46593	BH40713AE	08-Nov-93	Uranium-238	1.273	pCi/g	0.359		0.07879	A
46693	BH40715AE	08-Nov-93	Uranium-238	5.284	pCi/g	0.984		0.07402	V
46693	BH40717AE	08-Nov-93	Uranium-238	0.938	pCi/g	0.268		0.06729	V
46693	BH40718AE	09-Nov-93	Uranium-238	1.594	pCi/g	0.418		0.07957	A
46693	BH40726AE	09-Nov-93	Uranium-238	1.968	pCi/g	0.466		0.07826	A
46693	BH40728AE	09-Nov-93	Uranium-238	1.59	pCi/g	0.425		0.07725	A
46793	BH40729AE	10-Nov-93	Uranium-238	3.333	pCi/g	0.979		0.15112	A
46793	BH40731AE	10-Nov-93	Uranium-238	0.9931	pCi/g	0.374		0.13211	A
46793	BH40732AE	10-Nov-93	Uranium-238	1.233	pCi/g	0.344		0.07525	A
46793	BH40742AE	10-Nov-93	Uranium-238	1.546	pCi/g	0.479		0.1115	V
46793	BH40823AE	10-Nov-93	Uranium-238	1.123	pCi/g	0.352		0.08341	A
46893	BH40743AE	19-Nov-93	Uranium-238	0.9252	pCi/g	0.292		0.06545	V
46893	BH40745AE	19-Nov-93	Uranium-238	0.7835	pCi/g	0.274		0.08421	V
46893	BH40746AE	19-Nov-93	Uranium-238	0.78	pCi/g	0.247		0.07142	V
46893	BH40748AE	19-Nov-93	Uranium-238	1.578	pCi/g	0.37		0.05178	V
46893	BH40749AE	19-Nov-93	Uranium-238	1.786	pCi/g	0.447		0.04834	V
46893	BH40754AE	19-Nov-93	Uranium-238	1.072	pCi/g	0.303		0.06928	V
46893	BH40825AE	19-Nov-93	Uranium-238	1.531	pCi/g	0.353		0.06449	V
46993	BH40757AE	22-Nov-93	Uranium-238	11.46	pCi/g	1.81		0.07547	V
46993	BH40759AE	22-Nov-93	Uranium-238	4.725	pCi/g	0.903		0.08012	V
46993	BH40768AE	22-Nov-93	Uranium-238	9.288	pCi/g	1.52		0.07012	V
46993	BH40770AE	22-Nov-93	Uranium-238	1.15	pCi/g	0.35		0.09097	V
46993	BH40830AE	22-Nov-93	Uranium-238	11.48	pCi/g	1.72		0.05978	V

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Table B-3 Data Used for Calculating 95 Percent UCLs for Surface Soil in AOC No. 2

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
40093	SS40060AE	13-Jan-93	Beryllium	1.4	mg/kg	N/A	U	1	V
40193	SS40485AE	05-Jan-93	Beryllium	1.4	mg/kg	N/A	U	1	V
40293	SS40042AE	20-Jan-93	Beryllium	1.4	mg/kg	N/A	U	1	V
40393	SS40053AE	28-Jan-93	Beryllium	1.3	mg/kg	N/A	U	1	V
40593	SS40054AE	22-Jan-93	Beryllium	1.3	mg/kg	N/A	U	1	V
40693	SS40057AE	25-Feb-93	Beryllium	1.9	mg/kg	N/A	U	5	V
40793	SS40058AE	25-Feb-93	Beryllium	1.7	mg/kg	N/A	U	5	V
40893	SS40004AE	15-Dec-92	Beryllium	1.2	mg/kg	N/A	U	1.2	V
41193	SS40007AE	28-Jan-93	Beryllium	1.8	mg/kg	N/A	U	2	V
41293	SS40071AE	23-Feb-93	Beryllium	1.5	mg/kg	N/A	U	5	V
42693	SS40080AE	02-Feb-93	Beryllium	1.6	mg/kg	N/A	U	2	V
44893	SS40070AE	14-Jan-93	Beryllium	1.4	mg/kg	N/A	U	1	V
45693	SS40094AE	19-Mar-93	Beryllium	1.5	mg/kg	N/A	U	5	V
45793	SS40015AE	18-Mar-93	Beryllium	1.4	mg/kg	N/A	U	5	V
46193	SS40096AE	24-Mar-93	Beryllium	1.2	mg/kg	N/A	U	5	V
SS400293	SS40018AE	29-Dec-92	Beryllium	1.4	mg/kg	N/A	U	1.4	V
SS400493	SS40020AE	30-Dec-92	Beryllium	1.1	mg/kg	N/A	U	1	V
SS400893	SS40024AE	04-Jan-93	Beryllium	1.3	mg/kg	N/A	U	1	V
SS401193	SS40027AE	30-Dec-92	Beryllium	1.4	mg/kg	N/A	U	1	V
SS401393	SS40029AE	29-Dec-92	Beryllium	1.4	mg/kg	N/A	U	1.4	V
SS401593	SS40031AE	29-Dec-92	Beryllium	1.3	mg/kg	N/A	U	1.3	V
SS402593	SS40041AE	30-Dec-92	Beryllium	1.3	mg/kg	N/A	U	1	V
SS403093	SS40046AE	20-May-93	Beryllium	2.5	mg/kg	N/A		5	V
SS403193	SS40047AE	20-May-93	Beryllium	1.3	mg/kg	N/A	U	5	V
SS403293	SS40048AE	20-May-93	Beryllium	1.5	mg/kg	N/A	U	5	V
SS403393	SS40049AE	20-May-93	Beryllium	1.4	mg/kg	N/A	U	5	V
SS403493	SS40050AE	17-May-93	Beryllium	1.2	mg/kg	N/A	U	5	V
SS403593	SS40051AE	17-May-93	Beryllium	1.1	mg/kg	N/A	U	5	V
SS403693	SS40052AE	17-May-93	Beryllium	1.2	mg/kg	N/A	U	5	V
40093	SS40060AE	13-Jan-93	Cadmium	1.4	mg/kg	N/A	UN	1	V
40193	SS40485AE	05-Jan-93	Cadmium	1.4	mg/kg	N/A	UN	1	V
40293	SS40042AE	20-Jan-93	Cadmium	1.4	mg/kg	N/A	U	1	V
40393	SS40053AE	28-Jan-93	Cadmium	1.3	mg/kg	N/A	U	1	V
40593	SS40054AE	22-Jan-93	Cadmium	1.3	mg/kg	N/A	U	1	V
40693	SS40057AE	25-Feb-93	Cadmium	1.9	mg/kg	N/A	U	5	V
40793	SS40058AE	25-Feb-93	Cadmium	1.7	mg/kg	N/A	U	5	V
40893	SS40004AE	15-Dec-92	Cadmium	3.1	mg/kg	N/A		1.2	JA
41193	SS40007AE	28-Jan-93	Cadmium	8	mg/kg	N/A		2	V
41293	SS40071AE	23-Feb-93	Cadmium	4.3	mg/kg	N/A		5	V
42693	SS40080AE	02-Feb-93	Cadmium	1.6	mg/kg	N/A	U	2	V
44893	SS40070AE	14-Jan-93	Cadmium	1.6	mg/kg	N/A	N	1	JA
45693	SS40094AE	19-Mar-93	Cadmium	1.5	mg/kg	N/A	U	5	V
45793	SS40015AE	18-Mar-93	Cadmium	1.9	mg/kg	N/A		5	V
46193	SS40096AE	24-Mar-93	Cadmium	6.4	mg/kg	N/A		5	V
SS400293	SS40018AE	29-Dec-92	Cadmium	12.5	mg/kg	N/A		1.4	V
SS400493	SS40020AE	30-Dec-92	Cadmium	1.1	mg/kg	N/A	UN	1	V
SS400893	SS40024AE	04-Jan-93	Cadmium	1.3	mg/kg	N/A	UN	1	V
SS401193	SS40027AE	30-Dec-92	Cadmium	1.4	mg/kg	N/A	UN	1	V
SS401393	SS40029AE	29-Dec-92	Cadmium	2.1	mg/kg	N/A		1.4	JA
SS401593	SS40031AE	29-Dec-92	Cadmium	1.5	mg/kg	N/A		1.3	JA
SS402593	SS40041AE	30-Dec-92	Cadmium	1.3	mg/kg	N/A	UN	1	V
SS403093	SS40046AE	20-May-93	Cadmium	382	mg/kg	N/A		5	V

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Table B-3 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
SS403193	SS40047AE	20-May-93	Cadmium	1.9	mg/kg	N/A		5	JA
SS403293	SS40048AE	20-May-93	Cadmium	2.5	mg/kg	N/A		5	JA
SS403393	SS40049AE	20-May-93	Cadmium	1.4	mg/kg	N/A	U	5	V
SS403493	SS40050AE	17-May-93	Cadmium	1.2	mg/kg	N/A	U	5	V
SS403593	SS40051AE	17-May-93	Cadmium	1.1	mg/kg	N/A	U	5	V
SS403693	SS40052AE	17-May-93	Cadmium	1.3	mg/kg	N/A		5	JA
40093	SS40060AE	13-Jan-93	Americium-241	0.04	pCi/g	0.02		0	V
40193	SS40485AE	05-Jan-93	Americium-241	0.05	pCi/g	0.02		0	V
40293	SS40042AE	20-Jan-93	Americium-241	0.03	pCi/g	0.02		0.01	V
40393	SS40053AE	28-Jan-93	Americium-241	0.08	pCi/g	0.03		0.01	V
40593	SS40054AE	22-Jan-93	Americium-241	0.04	pCi/g	0.02		0	V
40693	SS40057AE	25-Feb-93	Americium-241	0.58	pCi/g	0.1		0.02	V
40793	SS40058AE	25-Feb-93	Americium-241	2.1	pCi/g	0.24		0.02	V
40893	SS40004AE	15-Dec-92	Americium-241	1.4	pCi/g	0.16		0.01	V
41193	SS40007AE	28-Jan-93	Americium-241	4.5	pCi/g	0.7		0.03	V
41293	SS40071AE	23-Feb-93	Americium-241	2	pCi/g	0.44	B	0.01	A
42693	SS40080AE	02-Feb-93	Americium-241	0.34	pCi/g	0.05		0.01	V
44893	SS40070AE	14-Jan-93	Americium-241	0.05	pCi/g	0.02		0	V
45693	SS40094AE	19-Mar-93	Americium-241	0.16	pCi/g	0.04		0.01	A
45793	SS40015AE	18-Mar-93	Americium-241	1.5	pCi/g	0.32		0.06	V
46193	SS40096AE	24-Mar-93	Americium-241	0.58	pCi/g	0.1		0.01	A
SS400293	SS40018AE	29-Dec-92	Americium-241	2.78	pCi/g	0.3		0	A
SS400493	SS40020AE	30-Dec-92	Americium-241	0.71	pCi/g	0.09		0	A
SS400893	SS40024AE	04-Jan-93	Americium-241	0.2	pCi/g	0.03		0	A
SS401193	SS40027AE	30-Dec-92	Americium-241	0.03	pCi/g	0.01		0	A
SS401393	SS40029AE	29-Dec-92	Americium-241	0.22	pCi/g	0.04		0	A
SS401593	SS40031AE	29-Dec-92	Americium-241	0.98	pCi/g	0.12		0.01	A
SS402593	SS40041AE	30-Dec-92	Americium-241	0.04	pCi/g	0.01		0	A
SS403093	SS40046AE	20-May-93	Americium-241	7.5	pCi/g	0.87		0.01	V
SS403193	SS40047AE	20-May-93	Americium-241	0.45	pCi/g	0.08		0.01	V
SS403293	SS40048AE	20-May-93	Americium-241	0.93	pCi/g	0.15		0.01	V
SS403393	SS40049AE	20-May-93	Americium-241	0.2	pCi/g	0.05		0.01	V
SS403493	SS40050AE	17-May-93	Americium-241	0.05	pCi/g	0.02		0	V
SS403593	SS40051AE	17-May-93	Americium-241	0.05	pCi/g	0.02		0	V
SS403693	SS40052AE	17-May-93	Americium-241	0.25	pCi/g	0.06		0.01	V
40093	SS40060AE	13-Jan-93	Plutonium-239/240	0.01	pCi/g	0.01		0.01	A
40193	SS40485AE	05-Jan-93	Plutonium-239/240	0.08	pCi/g	0.04		0	A
40293	SS40042AE	20-Jan-93	Plutonium-239/240	0.04	pCi/g	0.02		0	A
40393	SS40053AE	28-Jan-93	Plutonium-239/240	0.09	pCi/g	0.05		0.02	A
40593	SS40054AE	22-Jan-93	Plutonium-239/240	0.06	pCi/g	0.02		0	A
40693	SS40057AE	25-Feb-93	Plutonium-239/240	1	pCi/g	0.15		0	V
40793	SS40058AE	25-Feb-93	Plutonium-239/240	3.3	pCi/g	0.65		0.03	V
41193	SS40007AE	28-Jan-93	Plutonium-239/240	3.4	pCi/g	0.57		0.01	V
41293	SS40071AE	23-Feb-93	Plutonium-239/240	1.9	pCi/g	0.52		0.04	A
42693	SS40080AE	02-Feb-93	Plutonium-239/240	0.31	pCi/g	0.06		0.01	V
44893	SS40070AE	14-Jan-93	Plutonium-239/240	0.03	pCi/g	0.01		0.01	A
45693	SS40094AE	19-Mar-93	Plutonium-239/240	0.16	pCi/g	0.05	B	0	A
45793	SS40015AE	18-Mar-93	Plutonium-239/240	4.9	pCi/g	1.2		0.02	A
46193	SS40096AE	24-Mar-93	Plutonium-239/240	1.2	pCi/g	0.22	B	0.02	A
SS400293	SS40018AE	29-Dec-92	Plutonium-239/240	5.53	pCi/g	0.58		0.01	A
SS400493	SS40020AE	30-Dec-92	Plutonium-239/240	0.82	pCi/g	0.11		0.01	V
SS400893	SS40024AE	04-Jan-93	Plutonium-239/240	0.34	pCi/g	0.06		0.01	A

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Table B-3 (continued)

Location	Sample	Date	Analyte	Result	Units	Error	Qual	Detect	Val
SS401193	SS40027AE	30-Dec-92	Plutonium-239/240	0.05	pCi/g	0.02		0	A
SS401393	SS40029AE	29-Dec-92	Plutonium-239/240	0.19	pCi/g	0.03		0.01	A
SS401593	SS40031AE	29-Dec-92	Plutonium-239/240	3.08	pCi/g	0.33		0.01	V
SS402593	SS40041AE	30-Dec-92	Plutonium-239/240	0.03	pCi/g	0.01	J	0	A
SS403093	SS40046AE	20-May-93	Plutonium-239/240	19	pCi/g	3.2		0.02	A
SS403193	SS40047AE	20-May-93	Plutonium-239/240	0.5	pCi/g	0.06		0	V
SS403293	SS40048AE	20-May-93	Plutonium-239/240	2.1	pCi/g	0.22		0	V
SS403393	SS40049AE	20-May-93	Plutonium-239/240	0.46	pCi/g	0.06		0	V
SS403493	SS40050AE	17-May-93	Plutonium-239/240	0.12	pCi/g	0.02		0.01	V
SS403593	SS40051AE	17-May-93	Plutonium-239/240	0.08	pCi/g	0.02		0.01	V
SS403693	SS40052AE	17-May-93	Plutonium-239/240	0.16	pCi/g	0.03		0.01	V
40093	SS40060AE	13-Jan-93	Uranium-238	1.04	pCi/g	0.24		0.02	A
40193	SS40485AE	05-Jan-93	Uranium-238	0.98	pCi/g	0.22		0.02	A
40293	SS40042AE	20-Jan-93	Uranium-238	1.2	pCi/g	0.35	B	0.02	A
40393	SS40053AE	28-Jan-93	Uranium-238	1.2	pCi/g	0.29	B	0.02	A
40593	SS40054AE	22-Jan-93	Uranium-238	0.82	pCi/g	0.31		0.06	A
40693	SS40057AE	25-Feb-93	Uranium-238	1.9	pCi/g	0.36	B	0.04	A
40793	SS40058AE	25-Feb-93	Uranium-238	1.1	pCi/g	0.28	B	0.01	A
40893	SS40004AE	15-Dec-92	Uranium-238	0.7	pCi/g	0.16		0.06	V
41193	SS40007AE	28-Jan-93	Uranium-238	0.89	pCi/g	0.36	B	0.04	V
41293	SS40071AE	23-Feb-93	Uranium-238	1.1	pCi/g	0.28	B	0.02	A
42693	SS40080AE	02-Feb-93	Uranium-238	1.2	pCi/g	0.38	B	0.05	V
44893	SS40070AE	14-Jan-93	Uranium-238	1.12	pCi/g	0.31		0.04	A
45693	SS40094AE	19-Mar-93	Uranium-238	1.9	pCi/g	0.53	B	0.02	V
45793	SS40015AE	18-Mar-93	Uranium-238	2.3	pCi/g	0.47		0.01	A
46193	SS40096AE	24-Mar-93	Uranium-238	4.1	pCi/g	0.67	B	0.01	V
SS400293	SS40018AE	29-Dec-92	Uranium-238	1.47	pCi/g	0.4		0.1	A
SS400493	SS40020AE	30-Dec-92	Uranium-238	0.86	pCi/g	0.23		0.04	A
SS400893	SS40024AE	04-Jan-93	Uranium-238	0.98	pCi/g	0.26		0.03	A
SS401193	SS40027AE	30-Dec-92	Uranium-238	0.78	pCi/g	0.23		0.02	A
SS401393	SS40029AE	29-Dec-92	Uranium-238	3.57	pCi/g	0.61		0.04	A
SS401593	SS40031AE	29-Dec-92	Uranium-238	0.74	pCi/g	0.23		0.06	A
SS402593	SS40041AE	30-Dec-92	Uranium-238	1.23	pCi/g	0.29		0.03	A
SS403093	SS40046AE	20-May-93	Uranium-238	27	pCi/g	2.3	B	0.01	V
SS403193	SS40047AE	20-May-93	Uranium-238	3.3	pCi/g	0.29	B	0.02	V
SS403293	SS40048AE	20-May-93	Uranium-238	2	pCi/g	0.24	B	0.01	V
SS403393	SS40049AE	20-May-93	Uranium-238	2.3	pCi/g	0.29	B	0.02	V
SS403493	SS40050AE	17-May-93	Uranium-238	1.5	pCi/g	0.23	B	0.02	V
SS403593	SS40051AE	17-May-93	Uranium-238	1.2	pCi/g	0.2	B	0.01	V
SS403693	SS40052AE	17-May-93	Uranium-238	1.3	pCi/g	0.2	B	0.01	V

**Table B-4 Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment Soil/Dust Ingestion**

Factors for Potentially Complete Routes of Exposure		Potentially Exposed Receptors			
		Current Onsite Security Worker	Future Onsite Office Worker	Future Onsite Construction Worker	Future Onsite Open-Space Recreational User
Ingestion Rate-Child (mg/day or mg/visit)	RME	N/A	N/A	N/A	100
	CT	N/A	N/A	N/A	50
Ingestion Rate-Adult (mg/day or mg/visit)	RME	50	50	480	50
	CT	10	5	95	25
Fraction Ingested from Contaminated Source	RME	1.0	1.0	1.0	N/A
	CT	0.9	0.9	0.9	N/A
Matrix Effect in GI Tract (Absorption Factor)	RME	CS	CS	CS	CS
	CT	CS	CS	CS	CS
Exposure Frequency (days/yr or visits/yr)	RME	250	250	30	25
	CT	219	219	30	10
Exposure Duration-Child/Adult (years)	RME	25	25	1	6/24
	CT	4	4	1	2/7
Body Weight-Child/Adult (kg)	RME	70	70	70	15/70
	CT	70	70	70	15/70
Averaging Time-Noncarcinogenic Child/Adult (days)	RME	9125	9125	365	2190/8760
	CT	1460	1460	365	730/2555
Averaging Time-Carcinogenic Child/Adult (days)	RME	25550	25550	25550	25550
	CT	25550	25550	25550	25550

Source: Exposure factors taken from Rocky Flats Site-specific Exposure Factors for Quantitative Human Health Risk Assessment developed by DOE, EPA, CDPHE, and EG&G, dated May 18, 1995.

N/A Not applicable because the exposure pathway is incomplete.

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

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**Table B-5 Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment Soil/Dust Inhalation**

Factors for Potentially Complete Foutes of Exposure		Potentially Exposed Receptors			
		Current Onsite Security Worker	Future Onsite Office Worker	Future Onsite Construction Worker	Future Onsite Open-Space Recreational User
Inhalation Rate (m <sup>3</sup> /hr)	RME	0.83	0.83	1.4	1.4
	CT	0.83	0.63	1.25	0.83
Respirable Fraction (PM <sub>10</sub> )	RME	1.0	1.0	1.0	1.0
	CT	1.0	1.0	1.0	1.0
Exposure Time (hr/day or hr/visit)	RME	8	8	8	5
	CT	7.2	7.2	7.2	1.5
Exposure Frequency (days/yr or visits/yr)	RME	250	250	30	25
	CT	219	219	30	10
Exposure Duration- (years)	RME	25	25	1	30
	CT	4	4	1	9
Body Weight- (kg)	RME	70	70	70	70
	CT	70	70	70	70
Averaging Time: Noncarcinogenic (days)	RME	9125	9125	365	10,950
	CT	1460	1460	365	3285
Averaging Time: Carcinogenic (days)	RME	25,550	25,550	25,550	25,550
	CT	25,550	25,550	25,550	25,550

Source: Exposure factors taken from Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment developed by DOE, EPA, CDPHE, and EG&G, dated May 18, 1995.

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**Table B-6 Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment Soil/Dust Dermal Contact**

Factors for Potentially Complete Routes of Exposure		Potentially Exposed Receptors			
		Current Onsite Security Worker	Future Onsite Office Worker	Future Onsite Construction Worker	Future Onsite Open-Space Recreational User
Exposed Skin	RME	3400	2100	4700	5300
Surface (cm <sup>2</sup> /day)	CT	3400	2100	4700	2000
Fraction Contacted from Contaminated Source	RME	1.0	1.0	1.0	1.0
	CT	0.9	0.9	0.9	0.5
Soil Adherence to Skin (mg/cm <sup>2</sup> )	RME	1.0	1.0	1.0	1.0
	CT	0.2	0.2	0.2	0.2
Skin Absorption Factor	RME	CS	CS	CS	CS
	CT	CS	CS	CS	CS
Exposure Frequency (days/yr or visits/yr)	RME	250	250	30	25
	CT	219	219	30	10
Exposure Duration-(years)	RME	25	25	1	30
	CT	4	4	1	9
Body Weight-(kg)	RME	70	70	70	70
	CT	70	70	70	70
Averaging Time: Noncarcinogenic (days)	RME	9125	9125	365	10,950
	CT	1460	1460	365	3285
Averaging Time: Carcinogenic (days)	RME	25,550	25,550	25,550	25,550
	CT	25,550	25,550	25,550	25,550

Source: Exposure factors taken from Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment developed by DOE, EPA, CDPHE, and EG&G, dated May 18, 1995.

CS Chemical-specific exposure parameter determined from quantitative analysis

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**Table B-7 Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment External Irradiation**

Factors for Potentially Complete Routes of Exposure		Potentially Exposed Receptors			
		Current Onsite Security Worker	Future Onsite Office Worker	Future Onsite Construction Worker	Future Onsite Open-Space Recreational User
Gamma Exposure	RME	0.3	0.3	0.3	0.2
Time Factor (T <sub>e</sub> )	CT	0.3	0.3	0.3	0.1
Gamma Shielding Factor (1-S <sub>e</sub> )	RME	0.8	0.8	1.0	1.0
	CT	0.5	0.5	0.8	0.8
Exposure Frequency Ratio (unitless)	RME	0.7	0.7	0.1	0.07
	CT	0.6	0.6	0.1	0.03
Exposure Duration-(years)	RME	25	25	1	30
	CT	4	4	1	9

Source: Exposure factors taken from Rocky Flats Site-Specific Exposure Factors for Quantitative Human Health Risk Assessment developed by DOE, EPA, CDPHE, and EG&G, dated May 18, 1995.

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**Table C-1**  
**Human Health Risk Assessment Summary for**  
**Current Onsite Security Worker in OU4 AOC No.1**

Media/Pathway	Average Exposure (CT)		Reasonable Maximum Exposure (RME)	
	Cancer Risk	Chronic Hazard Index	Cancer Risk	Chronic Hazard Index
<u>Surface Soil</u>				
Ingestion	1.16E-08	0.001	4.59E-07	0.01
Inhalation of Particulates	1.64E-10	-	1.30E-09	-
Dermal Contact	3.74E-09	*	1.48E-07	*
External Irradiation	1.64E-08	-	1.92E-07	-
<u>Pond Liner Materials</u>				
External Irradiation	2.11E-09	-	2.47E-08	-
<b>Total</b>	<b>3E-08</b>	<b>0.001</b>	<b>8E-07</b>	<b>0.01</b>

\*Dermal absorption of metals and radionuclides is considered insignificant. Risk for this pathway estimated for Aroclor-1254 only.  
-Exposure pathway cannot be quantified for COCs (e.g., COCs have either slope factors or RfDs, but not both).

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**Table C-2**  
**Estimated Risk to Current Onsite Security Worker from**  
**Ingestion of Surface Soil in OU4 AOC No.1**

Chemical Intake Factor =  $(IR \times ED \times EF \times ME \times AW \times FC \times CF) / (BW \times AT)$

Radionuclide Intake Factor =  $IR \times ED \times EF \times FC \times ME \times AW \times CF$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Ingestion Rate (IR)	mg/day	10	50
Conversion Factor - Chemical (CF)	kg/mg	1.00E-06	1.00E-06
Conversion Factor - Radionuclides (CF)	g/mg	1.00E-03	1.00E-03
Fraction from Contaminated Source (FC)	unitless	0.9	1.0
Chemical-specific Matrix Effect (ME)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Frequency (EF)	days/year	219	250
Exposure Duration (ED)	years	4	25
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	1460	9125

**CARCINOGENIC RISK FOR NONRADIONUCLIDES**

(CR = CxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Aroclor-1254	0.45	1.32E-10	5.95E-11	7.70E+00	4.58E-10
Beryllium	2.34	2.64E-10	6.19E-10	4.30E+00	2.66E-09
TOTAL					3.12E-09

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Aroclor-1254	0.45	5.24E-09	2.36E-09	7.70E+00	1.82E-08
Beryllium	2.34	1.05E-08	2.45E-08	4.30E+00	1.05E-07
TOTAL					1.24E-07

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**Table C-2 (continued)**  
**Estimated Risk to Current Onsite Security Worker from**  
**Ingestion of Surface Soil in OU4 AOC No.1**

**CARCINOGENIC RISK FOR RADIONUCLIDES**

(CR = AxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	130	4.73E-01	6.15E+01	3.28E-10	2.02E-08
Plutonium-239/240	56	4.73E-01	2.65E+01	3.16E-10	8.37E-09
Uranium-238	3.09	4.73E-01	1.46E+00	6.20E-11	9.06E-11
<b>TOTAL</b>					<b>8.46E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	130	1.88E+01	2.44E+03	3.28E-10	8.00E-07
Plutonium-239/240	56	1.88E+01	1.05E+03	3.16E-10	3.32E-07
Uranium-238	3.09	1.88E+01	5.79E+01	6.20E-11	3.59E-09
<b>TOTAL</b>					<b>3.35E-07</b>

**NONCARCINOGENIC EFFECTS**

(HQ = CxIF/RfD)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Aroclor-1254	0.45	2.31E-09	1.04E-09	2.00E-05	0.0001
Beryllium	2.34	4.63E-09	1.08E-08	5.00E-03	0.000002
Cadmium	231.55	2.31E-09	5.36E-07	5.00E-04	0.001
<b>HAZARD INDEX</b>					<b>0.001</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Aroclor-1254	0.45	1.47E-08	6.60E-09	2.00E-05	0.0003
Beryllium	2.34	2.94E-08	6.87E-08	5.00E-03	0.00001
Cadmium	231.55	1.47E-08	3.40E-06	5.00E-04	0.01
<b>HAZARD INDEX</b>					<b>0.01</b>

- (1) The chemical-specific matrix effect used for Aroclor-1254 and cadmium is 0.5 (EPA, 1995); 1 is used for all other chemicals. Also see Appendix B.
- (2) See Appendix B for explanation.

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**Table C-3**  
**Estimated Risk to Current Onsite Security Worker from**  
**Particulate Inhalation of Surface Soil in OU4 AOC No.1**

Chemical Intake Factor = (IRxRFxAWxETxEFxED)/(BWxAT)

Radionuclide Intake Factor = IRxRFxAWxETxEFxEDxCF

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Inhalation Rate (IR)	m <sup>3</sup> /hr	0.83	0.83
Respirable Fraction (RF) <sup>(1)</sup>	unitless	1	1
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Time (ET)	hr/day	7.2	8
Exposure Frequency (EF)	days/year	219	250
Exposure Duration (ED)	years	4	25
Conversion Factor (CF)	g/kg	1000	1000
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	1460	9125

**CARCINOGENIC RISK FOR NONRADIONUCLIDES**

(CR = ACxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Air Concentration (AC) <sup>(3)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Beryllium	5.05E-10	1.76E-04	8.88E-14	8.40E+00	7.46E-13
Cadmium	5.00E-08	1.76E-04	8.78E-12	6.30E+00	5.53E-11
				TOTAL	5.61E-11

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Air Concentration (AC) <sup>(3)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Beryllium	5.05E-10	1.39E-03	7.04E-13	8.40E+00	5.91E-12
Cadmium	5.00E-08	1.39E-03	6.96E-11	6.30E+00	4.39E-10
				TOTAL	4.45E-10

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**Table C-3 (continued)**  
**Estimated Risk to Current Onsite Security Worker from**  
**Particulate Inhalation of Surface Soil in OU4 AOC No.1**

**CARCINOGENIC RISK FOR RADIONUCLIDES**

(CR = AxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Air Activity (A) <sup>(3)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	2.81E-08	3.14E+05	8.82E-03	3.85E-08	3.40E-10
Plutonium-239/240	1.21E-08	3.14E+05	3.80E-03	2.78E-08	1.06E-10
Uranium-238	6.67E-10	3.14E+05	2.10E-04	1.24E-08	2.60E-12
				<b>TOTAL</b>	<b>1.08E-10</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Air Activity (A) <sup>(3)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	2.81E-08	2.49E+06	6.99E-02	3.85E-08	2.69E-09
Plutonium-239/240	1.21E-08	2.49E+06	3.01E-02	2.78E-08	8.37E-10
Uranium-238	6.67E-10	2.49E+06	1.66E-03	1.24E-08	2.06E-11
				<b>TOTAL</b>	<b>8.58E-10</b>

- (1) The Air Concentration is calculated by multiplying the soil concentration by 1/4630000000; 4.63E+9 m<sup>3</sup>/kg is the particulate emission factor. The RF of 1 was chosen because the air concentration is already assumed to represent the PM<sub>10</sub> fraction; the RF was included in the calculations for the PEF (see EPA, 1991).
- (2) See Appendix B for explanation.
- (3) See (1) above.

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**Table C-4**  
**Estimated Risk to Current Onsite Security Worker from**  
**Dermal Contact with Surface Soil in OU4 AOC No.1**

Chemical Intake Factor = (SAxFCxAFxSAFxAWxEFxEDxCF)/(BWxAT)

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Skin Surface Area (SA)	cm <sup>2</sup>	3400	3400
Conversion Factor (CF)	kg/mg	1.00E-06	1.00E-06
Soil Adherence Factor (AF)	mg/cm <sup>2</sup>	0.2	1.0
Contaminated Source Fraction (FC)	unitless	0.9	1
Skin Absorption Factor (SAF)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Frequency (EF)	days/year	219	250
Exposure Duration (ED)	years	4	25
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	1460	9125

**CARCINOGENIC RISK** (CR = CxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Absorbed Dose (mg/kg-day)	Slope Factor (SF) (1/mg/kg-day)	Carcinogenic Risk (CR)
Aroclor-1254	0.45	1.08E-09	4.86E-10	7.70E+00	3.74E-09
<b>TOTAL</b>					<b>3.74E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Absorbed Dose (mg/kg-day)	Slope Factor (SF) (1/mg/kg-day)	Carcinogenic Risk (CR)
Aroclor-1254	0.45	4.28E-08	1.92E-08	7.70E+00	1.48E-07
<b>TOTAL</b>					<b>1.48E-07</b>

(1) The skin absorption factor used for Aroclor-1254 is 0.06 (EPA, 1992).

(2) See Appendix B for explanation.

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**Table C-5**  
**Estimated Risk to Current Onsite Security Worker from**  
**External Irradiation from Surface Soil in OU4 AOC No.1**

Radionuclide Intake Factor =  $EF \times AW \times ED \times (1 - S_e) \times T_e$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Percent of Year Exposed (EF)	unitless <sup>(1)</sup>	0.6	0.7
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Duration (ED)	years	4	25
Gamma Shielding Factor (1-S <sub>e</sub> )	unitless	0.5	0.8
Gamma Time Factor (T <sub>e</sub> )	unitless	0.3	0.3

**CARCINOGENIC RISK** (CR = IA x IF x SF)

**CENTRAL TENDENCY:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	130	2.16E-02	2.81E+00	4.59E-09	1.29E-08
Plutonium-239/240	56	2.16E-02	1.21E+00	1.87E-11	2.26E-11
Uranium-238	3.09	2.16E-02	6.67E-02	5.25E-08	3.50E-09
<b>TOTAL</b>					<b>1.64E-08</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	130	2.52E-01	3.28E+01	4.59E-09	1.50E-07
Plutonium-239/240	56	2.52E-01	1.41E+01	1.87E-11	2.64E-10
Uranium-238	3.09	2.52E-01	7.79E-01	5.25E-08	4.09E-08
<b>TOTAL</b>					<b>1.92E-07</b>

- (1) The exposure frequency for the external irradiation pathway is expressed as a factor rather than as days/year in order to have the units cancel properly. To calculate days/year, multiply the factor presented in the table by 365.
- (2) See Appendix B for explanation.

**Table C-6**  
**Estimated Risk to Current Onsite Security Worker from**  
**External Irradiation from Pond Liner Materials in OU4 AOC No.1**

Radionuclide Intake Factor =  $EF \times AW \times ED \times (1 - S_e) \times T_e$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Percent of Year Exposed (EF)	unitless <sup>(1)</sup>	0.6	0.7
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Duration (ED)	years	4	25
Gamma Shielding Factor (1-S <sub>e</sub> )	unitless	0.5	0.8
Gamma Time Factor (T <sub>e</sub> )	unitless	0.3	0.3

**CARCINOGENIC RISK** (CR = IAxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	1.73	2.16E-02	3.74E-02	4.59E-09	1.72E-10
Plutonium-239/240	3.13	2.16E-02	6.76E-02	1.87E-11	1.26E-12
Uranium-233/234	2.38	2.16E-02	5.14E-02	2.14E-11	1.10E-12
Uranium-238	1.71	2.16E-02	3.69E-02	5.25E-08	1.94E-09
<b>TOTAL</b>					<b>2.11E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	1.73	2.52E-01	4.36E-01	4.59E-09	2.00E-09
Plutonium-239/240	3.13	2.52E-01	7.89E-01	1.87E-11	1.47E-11
Uranium-233/234	2.38	2.52E-01	6.00E-01	2.14E-11	1.28E-11
Uranium-238	1.71	2.52E-01	4.31E-01	5.25E-08	2.26E-08
<b>TOTAL</b>					<b>2.47E-08</b>

- (1) The exposure frequency for the external irradiation pathway is expressed as a factor rather than as days/year in order to have the units cancel properly. To calculate days/year, multiply the factor presented in the table by 365.
- (2) See Appendix B for explanation.

**Table C-7**  
**Human Health Risk Assessment Summary for**  
**Future Onsite Office Worker in OU4 AOC No. 1**

Media/Pathway	Average Exposure (CT)		Reasonable Maximum Exposure (RME)	
	Cancer Risk	Chronic Hazard Index	Cancer Risk	Chronic Hazard Index
<u>Surface Soil</u>				
Ingestion	2.65E-07	0.01	1.57E-05	0.1
Inhalation of Particulates	2.08E-09	-	2.17E-08	-
Dermal Contact	3.85E-08	*	3.85E-08	*
External Irradiation	2.74E-07	-	3.19E-06	-
<b>Total</b>	<b>6E-07</b>	<b>0.01</b>	<b>2E-05</b>	<b>0.1</b>

\*Dermal absorption of metals and radionuclides is considered insignificant. Risk for this pathway estimated for Aroclor-1254 only.

-Exposure pathway cannot be quantified for COCs (e.g., COCs have either slope factors or RfDs, but not both).

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**Table C-8**  
**Estimated Risk to Future Onsite Office Worker from**  
**Ingestion of Surface Soil in OU4 AOC No. 1**

Chemical Intake Factor =  $(IR \times ED \times EF \times ME \times FC \times CF) / (BW \times AT)$

Radionuclide Intake Factor =  $IR \times ED \times EF \times FC \times ME \times CF$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Ingestion Rate (IR)	mg/day	5	50
Conversion Factor - Chemical (CF)	kg/mg	1.00E-06	1.00E-06
Conversion Factor - Radionuclides (CF)	g/mg	1.00E-03	1.00E-03
Fraction from Contaminated Source (FC)	unitless	0.9	1.0
Chemical-specific Matrix Effect (ME)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Exposure Frequency (EF)	days/year	219	250
Exposure Duration (ED)	years	4	25
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	1460	9125

**CARCINOGENIC RISK FOR NONRADIONUCLIDES**

(CR = CxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Aroclor-1254	0.45	1.10E-09	4.96E-10	7.70E+00	3.82E-09
Beryllium	2.34	2.20E-09	5.16E-09	4.30E+00	2.22E-08
				<b>TOTAL</b>	<b>2.60E-08</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Aroclor-1254	0.45	8.74E-08	3.93E-08	7.70E+00	3.03E-07
Beryllium	2.34	1.75E-07	4.09E-07	4.30E+00	1.76E-06
				<b>TOTAL</b>	<b>2.06E-06</b>

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**Table C-8 (continued)**  
**Estimated Risk to Future Onsite Office Worker from**  
**Ingestion of Surface Soil in OU4 AOC No. 1**

**CARCINOGENIC RISK FOR RADIONUCLIDES**

(CR = AxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	130	3.94E+00	5.12E+02	3.28E-10	1.68E-07
Plutonium-239/240	56	3.94E+00	2.21E+02	3.16E-10	6.98E-08
Uranium-238	3.09	3.94E+00	1.22E+01	6.20E-11	7.55E-10
<b>TOTAL</b>					<b>2.39E-07</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	130	3.13E+02	4.06E+04	3.28E-10	1.33E-05
Aroclor-1254	0.45	8.74E-08	3.93E-08	7.70E+00	3.03E-07
Uranium-238	3.09	3.13E+02	9.66E+02	6.20E-11	5.99E-08
<b>TOTAL</b>					<b>1.37E-05</b>

**NONCARCINOGENIC EFFECTS**

(HQ = CxIF/RfD)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Aroclor-1254	0.45	1.93E-08	8.68E-09	2.00E-05	0.0004
Beryllium	2.34	3.86E-08	9.03E-08	5.00E-03	0.00002
Cadmium	231.55	1.93E-08	4.47E-06	5.00E-04	0.01
<b>HAZARD INDEX</b>					<b>0.01</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Aroclor-1254	0.45	2.45E-07	1.10E-07	2.00E-05	0.006
Beryllium	2.34	4.89E-07	1.14E-06	5.00E-03	0.0002
Cadmium	231.55	2.45E-07	5.66E-05	5.00E-04	0.1
<b>HAZARD INDEX</b>					<b>0.1</b>

(1) The chemical-specific matrix effect used for Aroclor-1254 and cadmium is 0.5 (EPA, 1995); 1 is used for all other chemicals.

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Table C-9  
Estimated Risk to Future Onsite Office Worker from  
Particulate Inhalation of Surface Soil in OU4 AOC No. 1

Chemical Intake Factor = (IRxRFxETxEFxED)/(BWxAT)

Radionuclide Intake Factor = IRxRFxETxEFxEDxCF

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Inhalation Rate (IR)	m <sup>3</sup> /hr	0.63	0.83
Respirable Fraction (RF) <sup>(1)</sup>	unitless	1	1
Exposure Time (ET)	hr/day	7.2	8
Exposure Frequency (EF)	days/year	219	250
Exposure Duration (ED)	years	4	25
Conversion Factor (CF)	g/kg	1000	1000
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550

**CARCINOGENIC RISK FOR NONRADIONUCLIDES**

(CR = ACxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	5.05E-10	2.22E-03	1.12E-12	8.40E+00	9.43E-12
Cadmium	5.00E-08	2.22E-03	1.11E-10	6.30E+00	7.00E-10
				TOTAL	7.09E-10

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	5.05E-10	2.32E-02	1.17E-11	8.40E+00	9.85E-11
Cadmium	5.00E-08	2.32E-02	1.16E-09	6.30E+00	7.31E-09
				TOTAL	7.41E-09

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**Table C-9 (continued)**  
**Estimated Risk to Future Onsite Office Worker from**  
**Particulate Inhalation of Surface Soil in OU4 AOC No. 1**

**CARCINOGENIC RISK FOR RADIONUCLIDES**

(CR = AxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	2.81E-08	3.97E+06	1.12E-01	3.85E-08	4.30E-09
Plutonium-239/240	1.21E-08	3.97E+06	4.81E-02	2.78E-08	1.34E-09
Uranium-238	6.67E-10	3.97E+06	2.65E-03	1.24E-08	3.29E-11
				<b>TOTAL</b>	<b>1.37E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	2.81E-08	4.15E+07	1.17E+00	3.85E-08	4.49E-08
Plutonium-239/240	1.21E-08	4.15E+07	5.02E-01	2.78E-08	1.40E-08
Uranium-238	6.67E-10	4.15E+07	2.77E-02	1.24E-08	3.43E-10
				<b>TOTAL</b>	<b>1.43E-08</b>

(1) The Air Concentration is calculated by multiplying the soil concentration by 1/4630000000; 4.63E+9 m<sup>3</sup>/kg is the particulate emission factor. The RF of 1 was chosen because the air concentration is already assumed to represent the PM<sub>10</sub> fraction; the RF was included in the calculations for the PEF (see EPA, 1991).

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**Table C-10**  
**Estimated Risk to Future Onsite Office Worker from**  
**Dermal Contact with Surface Soil in OU4 AOC No. 1**

Chemical Intake Factor = (SAxFCxAFxSAFxEFxEDxCF)/(BWxAT)

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Skin Surface Area (SA)	cm <sup>2</sup>	2100	2100
Conversion Factor (CF)	kg/mg	1.00E-06	1.00E-06
Soil Adherence Factor (AF)	mg/cm <sup>2</sup>	0.2	1.0
Contaminated Source Fraction (FC)	unitless	0.9	1.0
Skin Absorption Factor (SAF)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Exposure Frequency (EF)	days/year	219	250
Exposure Duration (ED)	years	4	25
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550

**CARCINOGENIC RISK** (CR = CxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Absorbed Dose (mg/kg-day)	Slope Factor (SF) (1/mg/kg-day)	Carcinogenic Risk (CR)
Aroclor-1254	0.45	1.11E-08	5.00E-09	7.70E+00	3.85E-08
				<b>TOTAL</b>	<b>3.85E-08</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Absorbed Dose (mg/kg-day)	Slope Factor (SF) (1/mg/kg-day)	Carcinogenic Risk (CR)
Aroclor-1254	0.45	4.40E-07	1.98E-07	7.70E+00	1.53E-06
				<b>TOTAL</b>	<b>3.85E-08</b>

(1) The skin absorption factor used for Aroclor-1254 is 0.06 (EPA, 1992).

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**Table C-11**  
**Estimated Risk to Future Onsite Office Worker from**  
**External Irradiation from Surface Soil in OU4 AOC No. 1**

Radionuclide Intake Factor =  $EF \times ED \times (1 - S_e) \times T_e$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Percent of Year Exposed (EF)	unitless <sup>(1)</sup>	0.6	0.7
Exposure Duration (ED)	years	4	25
Gamma Shielding Factor (1-S <sub>e</sub> )	unitless	0.5	0.8
Gamma Time Factor (T <sub>e</sub> )	unitless	0.3	0.3

**CARCINOGENIC RISK** (CR = IA x IF x SF)

**CENTRAL TENDENCY:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	130	3.60E-01	4.68E+01	4.59E-09	2.15E-07
Plutonium-239/240	56	3.60E-01	2.02E+01	1.87E-11	3.77E-10
Uranium-238	3.09	3.60E-01	1.11E+00	5.25E-08	5.84E-08
				<b>TOTAL</b>	<b>2.74E-07</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	130	4.20E+00	5.46E+02	4.59E-09	2.51E-06
Plutonium-239/240	56	4.20E+00	2.35E+02	1.87E-11	4.40E-09
Uranium-238	3.09	4.20E+00	1.30E+01	5.25E-08	6.81E-07
				<b>TOTAL</b>	<b>3.19E-06</b>

(1) The exposure frequency for the external irradiation pathway is expressed as a factor rather than as days/year in order to have the units cancel properly. To calculate days/year, multiply the factor presented in the table by 365.

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**Table C-12**  
**Human Health Risk Assessment Summary for**  
**Future Onsite Construction Worker in OU4 AOC No.1**

Media/Pathway	Average Exposure (CT)		Reasonable Maximum Exposure (RME)	
	Cancer Risk	Chronic Hazard Index	Cancer Risk	Chronic Hazard Index
<u>Subsurface Soils</u>				
Ingestion	2.07E-09	0.003	1.16E-08	0.02
Inhalation	9.76E-12	-	6.51E-12	-
Dermal Contact	*	*	*	*
External Irradiation	2.54E-07	-	3.17E-07	-
<b>Total</b>	<b>3E-07</b>	<b>0.003</b>	<b>3E-07</b>	<b>0.02</b>

<u>Pond Liner Materials</u>				
Ingestion	1.74E-07	0.01	9.76E-07	0.04
Dermal Contact	*	*	*	*
External Irradiation	2.35E-09	-	2.93E-09	-
<b>Total</b>	<b>2E-07</b>	<b>0.01</b>	<b>1E-06</b>	<b>0.04</b>

\*Dermal absorption of metals and radionuclides is considered insignificant; no organic compounds were assessed for this pathway.

-Exposure pathway cannot be quantified for COCs (e.g., COCs have either slope factors or RfDs, but not both).

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**Table C-13**  
**Estimated Risk to Future Onsite Construction Worker from**  
**Ingestion of Subsurface Soil in OU4 AOC No.1**

Chemical Intake Factor = (IRxEDxEFxMExFCxCF)/(BWxAT)

Radionuclide Intake Factor = IRxEDxEFxFCxMExCF

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Ingestion Rate (IR)	mg/day	95	480
Conversion Factor - Chemical (CF)	kg/mg	1.00E-06	1.00E-06
Conversion Factor - Radionuclides (CF)	g/mg	1.00E-03	1.00E-03
Fraction from Contaminated Source (FC)	unitless	0.9	1.0
Chemical-specific Matrix Effect (ME)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Exposure Frequency (EF)	days/year	30	30
Exposure Duration (ED)	years	1	1
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	365	365

**CARCINOGENIC RISK**

(CR = AxlFxFSF)

**CENTRAL TENDENCY:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	0.3	2.57E+00	7.70E-01	3.28E-10	2.52E-10
Plutonium-239/240	0.29	2.57E+00	7.44E-01	3.16E-10	2.35E-10
Radium-226	1.55	2.57E+00	3.98E+00	2.96E-10	1.18E-09
Uranium-238	2.57	2.57E+00	6.59E+00	6.20E-11	4.09E-10
TOTAL					2.07E-09

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	0.3	1.44E+01	4.32E+00	3.28E-10	1.42E-09
Plutonium-239/240	0.29	1.44E+01	4.18E+00	3.16E-10	1.32E-09
Radium-226	1.55	1.44E+01	2.23E+01	2.96E-10	6.61E-09
Uranium-238	2.57	1.44E+01	3.70E+01	6.20E-11	2.29E-09
TOTAL					1.16E-08

**Table C-13 (continued)**  
**Estimated Risk to Future Onsite Construction Worker from**  
**Ingestion of Subsurface Soil in OU4 AOC No.1**

NONCARCINOGENIC EFFECTS (HQ = CxIF/RfD)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Cadmium	31.7	5.02E-08	1.59E-06	5.00E-04	0.003
HAZARD INDEX					<b>0.003</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Cadmium	31.7	2.8E-07	8.93E-06	5.00E-04	0.02
HAZARD INDEX					<b>0.02</b>

(1) The chemical-specific matrix effect used for cadmium is 0.5 (EPA, 1995); 1 is used for all other chemicals.

Table C-14  
Estimated Risk to Future Onsite Construction Worker from  
Particulate Inhalation of Subsurface Soil in OU4 AOC No.1

Chemical Intake Factor = (IRxRFxETxEFxED)/(BWxAT)

Radionuclide Intake Factor = IRxRFxETxEFxEDxCF

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Inhalation Rate (IR)	m <sup>3</sup> /hr	1.25	1.4
Respirable Fraction (RF) <sup>(1)</sup>	unitless	1	1
Exposure Time (ET)	hr/day	7.2	8
Exposure Frequency (EF)	days/year	30	30
Exposure Duration (ED)	years	1	1
Conversion Factor (CF)	g/kg	1000	1000
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	365	365

**CARCINOGENIC RISK FOR NONRADIONUCLIDES**

(CR = ACxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Cadmium	6.85E-09	1.51E-04	1.03E-12	6.30E+00	6.51E-12
				TOTAL	6.51E-12

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Cadmium	6.85E-09	1.88E-04	1.29E-12	6.30E+00	8.10E-12
				TOTAL	8.10E-12

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**Table C-14 (continued)**  
**Estimated Risk to Future Onsite Construction Worker from**  
**Particulate Inhalation of Subsurface Soil in OU4 AOC No.1**

**CARCINOGENIC RISK FOR RADIONUCLIDES**

(CR = AxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	6.48E-11	2.70E+05	1.75E-05	3.85E-08	6.74E-13
Plutonium-239/240	6.26E-11	2.70E+05	1.69E-05	2.78E-08	4.70E-13
Radium-226	3.35E-10	2.70E+05	9.04E-05	2.75E-09	2.49E-13
Uranium-238	5.55E-10	2.70E+05	1.50E-04	1.24E-08	1.86E-12
				<b>TOTAL</b>	<b>3.25E-12</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	6.48E-11	3.36E+05	2.18E-05	3.85E-08	8.38E-13
Plutonium-239/240	6.26E-11	3.36E+05	2.10E-05	2.78E-08	5.85E-13
Radium-226	3.35E-10	3.36E+05	1.12E-04	2.75E-09	3.09E-13
Uranium-238	5.55E-10	3.36E+05	1.87E-04	1.24E-08	2.31E-12
				<b>TOTAL</b>	<b>4.05E-12</b>

(1) The Air Concentration is calculated by multiplying the soil concentration by 1/463000000; 4.63E+9 m<sup>3</sup>/kg is the particulate emission factor. The RF of 1 was chosen because the air concentration is already assumed to represent the PM<sub>10</sub> fraction; the RF was included in the calculations for the PEF (see EPA, 1991).

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**Table C-15**  
**Estimated Risk to Future Onsite Construction Worker from**  
**External Irradiation from Subsurface Soil in OU4 AOC No.1**

Radionuclide Intake Factor =  $EF \times ED \times (1 - S_e) \times T_e$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Percent of Year Exposed (EF)	unitless <sup>(1)</sup>	0.1	0.1
Exposure Duration (ED)	years	1.0	1.0
Gamma Shielding Factor (1-S <sub>e</sub> )	unitless	0.8	1.0
Gamma Time Factor (T <sub>e</sub> )	unitless	0.3	0.3

**CARCINOGENIC RISK** (CR = IA<sub>x</sub>IF<sub>x</sub>SF)

**CENTRAL TENDENCY:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	0.3	2.40E-02	7.20E-03	4.59E-09	3.30E-11
Plutonium-239/240	0.29	2.40E-02	6.96E-03	1.87E-11	1.30E-13
Radium-226	1.55	2.40E-02	3.72E-02	6.74E-06	2.51E-07
Uranium-238	2.57	2.40E-02	6.17E-02	5.25E-08	3.24E-09
<b>TOTAL</b>					<b>2.54E-07</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	0.3	3.00E-02	9.00E-03	4.59E-09	4.13E-11
Plutonium-239/240	0.29	3.00E-02	8.70E-03	1.87E-11	1.63E-13
Radium-226	1.55	3.00E-02	4.65E-02	6.74E-06	3.13E-07
Uranium-238	2.57	3.00E-02	7.71E-02	5.25E-08	4.05E-09
<b>TOTAL</b>					<b>3.17E-07</b>

(1) The exposure frequency for the external irradiation pathway is expressed as a factor rather than as days/year in order to have the units cancel properly. To calculate days/year, multiply the factor presented in the table by 365.

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Table C-16  
Estimated Risk to Future Onsite Construction Worker from  
Ingestion of Pond Liner Materials in OU4 AOC No.1

Chemical Intake Factor =  $(IR \times ED \times EF \times ME \times FC \times CF) / (BW \times AT)$

Radionuclide Intake Factor =  $IR \times ED \times EF \times FC \times ME \times CF$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Ingestion Rate (IR)	mg/day	95	480
Conversion Factor - Chemical (CF)	kg/mg	1.00E-06	1.00E-06
Conversion Factor - Radionuclides (CF)	g/mg	1.00E-03	1.00E-03
Fraction from Contaminated Source (FC)	unitless	0.9	1.0
Chemical-specific Matrix Effect (ME)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Exposure Frequency (EF)	days/year	30	30
Exposure Duration (ED)	years	1	1
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	365	365

CARCINOGENIC RISK

(CR = A x I x SF)

CENTRAL TENDENCY:

Radionuclide	Liner Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	1.73	2.57E+00	4.44E+00	3.85E-08	1.71E-07
Plutonium-239/240	3.13	2.57E+00	8.03E+00	3.16E-10	2.54E-09
Uranium-233/234	2.38	2.57E+00	6.10E+00	4.44E-11	2.71E-10
Uranium-238	1.71	2.57E+00	4.39E+00	6.20E-11	2.72E-10
TOTAL					1.74E-07

REASONABLE MAXIMUM EXPOSURE:

Radionuclide	Liner Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	1.73	1.44E+01	2.49E+01	3.85E-08	9.59E-07
Plutonium-239/240	3.13	1.44E+01	4.51E+01	3.16E-10	1.42E-08
Uranium-233/234	2.38	1.44E+01	3.43E+01	4.44E-11	1.52E-09
Uranium-238	1.71	1.44E+01	2.46E+01	6.20E-11	1.53E-09
TOTAL					9.76E-07

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**Table C-16 (continued)**  
**Estimated Risk to Future Onsite Construction Worker from**  
**Ingestion of Pond Liner Materials in OU4 AOC No.1**

NONCARCINOGENIC EFFECTS

(HQ = CxIF/RfD)

CENTRAL TENDENCY:

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Cadmium	69.7	5.02E-08	3.50E-06	5.00E-04	0.01
HAZARD INDEX					0.01

REASONABLE MAXIMUM EXPOSURE:

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Cadmium	69.7	2.82E-07	1.96E-05	5.00E-04	0.04
HAZARD INDEX					0.04

(1) The chemical-specific matrix effect used for cadmium is 0.5 (EPA, 1995); 1 is used for all other chemicals.

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**Table C-17**  
**Estimated Risk to Future Onsite Construction Worker from**  
**External Irradiation from Pond Liner Materials in OU4 AOC No.1**

Radionuclide Intake Factor =  $EF \times ED \times (1 - S_e) \times T_e$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Percent of Year Exposed (EF)	unitless (1)	0.1	0.1
Exposure Duration (ED)	years	1.0	1.0
Gamma Shielding Factor (1-S <sub>e</sub> )	unitless	0.8	1.0
Gamma Time Factor (T <sub>e</sub> )	unitless	0.3	0.3

**CARCINOGENIC RISK** (CR = IA<sub>x</sub>IF<sub>x</sub>SF)

**CENTRAL TENDENCY:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	1.73	2.40E-02	4.15E-02	4.59E-09	1.91E-10
Plutonium-239/240	3.13	2.40E-02	7.51E-02	1.87E-11	1.40E-12
Uranium-233/234	2.38	2.40E-02	5.71E-02	2.14E-11	1.22E-12
Uranium-238	1.71	2.40E-02	4.10E-02	5.25E-08	2.15E-09
				<b>TOTAL</b>	<b>2.35E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	1.73	3.00E-02	5.19E-02	4.59E-09	2.38E-10
Plutonium-239/240	3.13	3.00E-02	9.39E-02	1.87E-11	1.76E-12
Uranium-233/234	2.38	3.00E-02	7.14E-02	2.14E-11	1.53E-12
Uranium-238	1.71	3.00E-02	5.13E-02	5.25E-08	2.69E-09
				<b>TOTAL</b>	<b>2.93E-09</b>

- (1) The exposure frequency for the external irradiation pathway is expressed as a factor rather than as days/year in order to have the units cancel properly. To calculate days/year, multiply the factor presented in the table by 365.

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**Table C-18**  
**Human Health Risk Assessment Summary for**  
**Current Onsite Security Worker in OU4 AOC No.2**

Media/Pathway	Average Exposure (CT)		Reasonable Maximum Exposure (RME)	
	Cancer Risk	Chronic Hazard Index	Cancer Risk	Chronic Hazard Index
<u>Surface Soil</u>				
Ingestion	2.51E-09	0.0003	9.96E-08	0.002
Inhalation	6.49E-13	-	9.29E-12	-
Dermal Contact	*	*	*	*
External Irradiation	4.80E-09	-	5.60E-08	-
<b>Total</b>	<b>7E-09</b>	<b>0.0003</b>	<b>2E-07</b>	<b>0.002</b>

\*Dermal absorption of metals and radionuclides is considered insignificant; no organic compounds were assessed for this pathway.

-Exposure pathway cannot be quantified for COCs (e.g., COCs have either slope factors or RfDs, but not both).

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Table C-19  
Estimated Risk to Current Onsite Security Worker from  
Ingestion of Surface Soil in OU4 AOC No.2

Chemical Intake Factor =  $(IR \times ED \times EF \times ME \times AW \times FC \times CF) / (BW \times AT)$   
Radionuclide Intake Factor =  $IR \times ED \times EF \times FC \times ME \times AW \times CF$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Ingestion Rate (IR)	mg/day	10	50
Conversion Factor - Chemical (CF)	kg/mg	1.00E-06	1.00E-06
Conversion Factor - Radionuclides (CF)	g/mg	1.00E-03	1.00E-03
Fraction from Contaminated Source (FC)	unitless	0.9	1.0
Chemical-specific Matrix Effect (ME)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Frequency (EF)	days/year	219	250
Exposure Duration (ED)	years	4	25
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550
Noncarcinogenic Averaging Time (AT)	days	1460	9125

**CARCINOGENIC RISK FOR NONRADIONUCLIDES** (CR = CxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	0.87	2.64E-10	2.30E-10	4.30E+00	9.89E-10
TOTAL					9.89E-10

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	0.87	1.05E-08	9.12E-09	4.30E+00	3.92E-08
TOTAL					3.92E-08

Table C-19 (continued)  
Estimated Risk to Current Onsite Security Worker from  
Ingestion of Surface Soil in OU4 AOC No.2

**CARCINOGENIC RISK FOR RADIONUCLIDES**

(CR = AxiFxFSF)

**CENTRAL TENDENCY:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	3.44	4.73E-01	1.63E+00	3.28E-10	5.34E-10
Plutonium-239/240	9.42	4.73E-01	4.46E+00	3.16E-10	1.41E-09
Uranium-238	3.93	4.73E-01	1.86E+00	6.20E-11	1.15E-10
<b>TOTAL</b>					<b>1.52E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	3.44	1.88E+01	6.45E+01	3.28E-10	2.12E-08
Plutonium-239/240	9.42	1.88E+01	1.77E+02	3.16E-10	5.58E-08
Uranium-238	3.93	1.88E+01	7.37E+01	6.20E-11	4.57E-09
<b>TOTAL</b>					<b>6.04E-08</b>

**NONCARCINOGENIC EFFECTS**

(HQ = CxIF/RfD)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Beryllium	0.87	4.63E-09	4.03E-09	5.00E-03	0.0000008
Cadmium	37.5	4.63E-09	1.74E-07	5.00E-04	0.0003
<b>HAZARD INDEX</b>					<b>0.0003</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Beryllium	0.87	2.94E-08	2.55E-08	5.00E-03	0.00001
Cadmium	37.5	2.94E-08	1.10E-06	5.00E-04	0.002
<b>HAZARD INDEX</b>					<b>0.002</b>

- (1) The chemical-specific matrix effect used for cadmium is 0.5 (EPA, 1995); 1 is used for all other chemicals.
- (2) See Appendix B for explanation.

**Table C-20**  
**Estimated Risk to Current Onsite Security Worker from**  
**Particulate Inhalation of Surface Soil in OU4 AOC No.2**

Chemical Intake Factor = (IRxRFxAWxETxEFxED)/(BWxAT)  
Radionuclide Intake Factor = IRxRFxAWxETxEFxEDxCF

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Inhalation Rate (IR)	m <sup>3</sup> /hr	0.83	1.4
Respirable Fraction (RF) <sup>(1)</sup>	unitless	1	1
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Time (ET)	hr/day	1.5	5
Exposure Frequency (EF)	days/year	10	25
Exposure Duration (ED)	years	9	30
Conversion Factor (CF)	g/kg	1000	1000
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550

**CARCINOGENIC RISK FOR NONRADIONUCLIDES** (CR = ACxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	1.88E-10	3.76E-06	7.06E-16	8.40E+00	5.93E-15
Cadmium	8.10E-09	3.76E-06	3.04E-14	6.30E+00	1.92E-13
				<b>TOTAL</b>	<b>1.98E-13</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	1.88E-10	1.76E-04	3.31E-14	8.40E+00	2.78E-13
Cadmium	8.10E-09	1.76E-04	1.43E-12	6.30E+00	8.99E-12
				<b>TOTAL</b>	<b>9.26E-12</b>

**Table C-20 (continued)**  
**Estimated Risk to Current Onsite Security Worker from**  
**Particulate Inhalation of Surface Soil in OU4 AOC No.2**

**CARCINOGENIC RISK FOR RADIONUCLIDES** (CR = AxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	7.43E-10	6.72E+03	5.00E-06	3.85E-08	1.92E-13
Plutonium-239/240	2.03E-09	6.72E+03	1.37E-05	2.78E-08	3.80E-13
Uranium-238	8.49E-10	6.72E+03	5.71E-06	1.24E-08	7.08E-14
				<b>TOTAL</b>	<b>4.51E-13</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	7.43E-10	3.15E+02	2.34E-07	3.85E-08	9.01E-15
Plutonium-239/240	2.03E-09	3.15E+02	6.41E-07	2.78E-08	1.78E-14
Uranium-238	8.49E-10	3.15E+02	2.67E-07	1.24E-08	3.32E-15
				<b>TOTAL</b>	<b>2.11E-14</b>

(1) The Air Concentration is calculated by multiplying the soil concentration by 1/4630000000; 4.63E+9 m<sup>3</sup>/kg is the particulate emission factor. The RF of 1 was chosen because the air concentration is already assumed to represent the PM<sub>10</sub> fraction; the RF was included in the calculations for the PEF (see EPA, 1991).

(2) See Appendix B for explanation.

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Table C-21  
Estimated Risk to Current Onsite Security Worker from  
External Irradiation from Surface Soil in OU4 AOC No.2

Radionuclide Intake Factor =  $EF \times AW \times ED \times (1 - S_e) \times T_e$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Percent of Year Exposed (EF)	unitless <sup>(1)</sup>	0.6	0.7
Area Weighting Factor (AW) <sup>(2)</sup>	unitless	0.06	0.06
Exposure Duration (ED)	years	4	25
Gamma Shielding Factor (1-S <sub>e</sub> )	unitless	0.5	0.8
Gamma Time Factor (T <sub>e</sub> )	unitless	0.3	0.3

**CARCINOGENIC RISK** (CR = IA x IF x SF)

**CENTRAL TENDENCY:**

Radionuclides	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	3.44	2.16E-02	7.43E-02	4.59E-09	3.41E-10
Plutonium-239/240	9.42	2.16E-02	2.03E-01	1.87E-11	3.80E-12
Uranium-238	3.93	2.16E-02	8.49E-02	5.25E-08	4.46E-09
<b>TOTAL</b>					<b>4.80E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclides	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	3.44	2.52E-01	8.67E-01	4.59E-09	3.98E-09
Plutonium-239/240	9.42	2.52E-01	2.37E+00	1.87E-11	4.44E-11
Uranium-238	3.93	2.52E-01	9.90E-01	5.25E-08	5.20E-08
<b>TOTAL</b>					<b>5.60E-08</b>

(1) The exposure frequency for the external irradiation pathway is expressed as a factor rather than as days/year in order to have the units cancel properly. To calculate days/year, multiply the factor presented in the table by 365.

(2) See Appendix B for explanation.

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**Table C-22**  
**Human Health Risk Assessment Summary for**  
**Future Open-space Recreational User in OU4 AOC No.2**

Media/Pathway	Average Exposure (CT)		Reasonable Maximum Exposure (RME)	
	Cancer Risk	Chronic Hazard Index	Cancer Risk	Chronic Hazard Index
<u>Surface Soil</u>				
Ingestion - Carcinogenic	2.54E-08	-	4.05E-07	-
Ingestion by Child*	-	0.003	-	0.02
Ingestion by Adult*	-	0.0004	-	0.002
Inhalation of Particulates	1.08E-11	-	5.07E-10	-
Dermal Contact	**	**	**	**
External Irradiation	4.80E-09	-	9.34E-08	-
<b>Total</b>	<b>3E-08</b>	<b>0.004</b>	<b>5E-07</b>	<b>0.02</b>

\*Noncarcinogenic effects for the ingestion pathway have been estimated separately for the adult and child receptor.

\*\*Dermal absorption of metals and radionuclides is considered insignificant; no organic compounds were assessed for this pathway.

-Exposure pathway cannot be quantified for COCs (e.g., COCs have either slope factors or RfDs, but not both).

Table C-23  
Estimated Risk for Future Open-space Recreational User from  
Ingestion of Surface Soil in OU4 AOC No.2

Chemical Intake Factor =  $[(IR-CxED-C/BW-C)+(IR-AxED-A)/(BW-A)]x(CFxMExEF)/AT$

Radionuclide Intake Factor =  $[(IR-CxED-C)+(IR-AxED-A)]xEFxMExCF$

Exposure Factors Description	Chemical Units	Central Tendency		Reasonable Maximum Exposure	
		Child Exposure	Adult Exposure	Child Exposure	Adult Exposure
Ingestion Rate (IR)	mg/visit	50	25	100	50
Conversion Factor - Chemical (CF)	kg/mg	1.00E-06	1.00E-06	1.00E-06	1.00E-06
Conversion Factor - Radionuclides (CF)	g/mg	1.00E-03	1.00E-03	1.00E-03	1.00E-03
Chemical-specific Matrix Effect (ME)	unitless	CS <sup>(1)</sup>	CS <sup>(1)</sup>	CS <sup>(1)</sup>	CS <sup>(1)</sup>
Exposure Frequency (EF)	visits/year	10	10	25	25
Exposure Duration (ED)	years	2	7	6	24
Body Weight (BW)	kg	15	70	15	70
Carcinogenic Averaging Time (AT)	days	25550	25550	25550	25550
Noncarcinogenic Averaging Time (AT)	days	730	2555	2190	8760

**CARCINOGENIC RISK FOR NONRADIONUCLIDES**

(CR = CxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	0.87	3.59E-09	3.12E-09	4.30E+00	1.34E-08
				TOTAL	1.34E-08

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg day)]	Carcinogenic Risk (CR)
Beryllium	0.87	5.59E-08	4.86E-08	4.30E+00	2.09E-07
				TOTAL	2.09E-07

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**Table C-23 (continued)**  
**Estimated Risk for Future Open-space Recreational User from**  
**Ingestion of Surface Soil in OU4 AOC No.2**

**CARCINOGENIC RISK FOR RADIONUCLIDES**

(CR = A<sub>x</sub>I<sub>F</sub>xSF)

**CENTRAL TENDENCY:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	3.44	2.75E+00	9.46E+00	3.28E-10	3.10E-09
Plutonium-239/240	9.42	2.75E+00	2.59E+01	3.16E-10	8.19E-09
Uranium-238	3.93	2.75E+00	1.08E+01	6.20E-11	6.70E-10
<b>TOTAL</b>					<b>1.20E-08</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Soil Activity (A) (pCi/g)	Intake Factor (IF) (g)	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	3.44	4.50E+01	1.55E+02	3.28E-10	5.08E-08
Plutonium-239/240	9.42	4.50E+01	4.24E+02	3.16E-10	1.34E-07
Uranium-238	3.93	4.50E+01	1.77E+02	6.20E-11	1.10E-08
<b>TOTAL</b>					<b>1.96E-07</b>

**NONCARCINOGENIC EFFECTS – CHILD** (HQ = CxI<sub>F</sub>/RfD)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg- day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Beryllium	0.87	9.13E-08	7.95E-08	5.00E-03	0.00002
Cadmium	37.5	4.57E-08	1.71E-06	5.00E-04	0.003
<b>HAZARD INDEX</b>					<b>0.003</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg- day)	Intake (mg/kg- day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Beryllium	0.87	4.57E-07	3.97E-07	5.00E-03	0.00008
Cadmium	37.5	2.28E-07	8.56E-06	5.00E-04	0.02
<b>HAZARD INDEX</b>					<b>0.02</b>

**Table C-23 (continued)**  
**Estimated Risk for Future Open-space Recreational User from**  
**Ingestion of Surface Soil in OU4 AOC No.2**

**NONCARCINOGENIC EFFECTS -- ADULT** (HQ = CxIF/RfD)

**CENTRAL TENDENCY:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Beryllium	0.87	9.78E-09	8.51E-09	5.00E-03	0.000002
Cadmium	37.5	4.89E-09	1.83E-07	5.00E-04	0.0004
HAZARD INDEX					<b>0.0004</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Soil Concentration (C) (mg/kg)	Intake Factor (IF) (kg/kg-day)	Intake (mg/kg-day)	Oral Reference Dose (RfD) (mg/kg-day)	Hazard Quotient (HQ)
Beryllium	0.87	4.89E-08	4.26E-08	5.00E-03	0.00001
Cadmium	37.5	2.45E-08	9.17E-07	5.00E-04	0.002
HAZARD INDEX					<b>0.002</b>

(1) The chemical-specific matrix effect used for cadmium is 0.5 (EPA, 1995); 1 is used for all other chemicals.

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**Table C-24**  
**Estimated Risk for Future Open-space Recreational User from**  
**Particulate Inhalation of Surface Soil in OU4 AOC No.2**

Chemical Intake Factor = (IRxRFxETxEFxED)/(BWxAT)

Radionuclide Intake Factor = IRxRFxETxEFxEDxCF

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Inhalation Rate (IR)	m <sup>3</sup> /hr	0.83	1.4
Respirable Fraction (RF) <sup>(1)</sup>	unitless	1	1
Exposure Time (ET)	hr/visit	1.5	5
Exposure Frequency (EF)	visits/year	10	25
Exposure Duration (ED)	years	9	30
Conversion Factor (CF)	g/kg	1000	1000
Body Weight (BW)	kg	70	70
Carcinogenic Averaging Time (AT)	days	25550	25550

**CARCINOGENIC RISK FOR NONRADIONUCLIDES** (CR = ACxIFxSF)

**CENTRAL TENDENCY:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Beryllium	1.88E-10	6.27E-05	1.18E-14	8.40E+00	9.89E-14
Cadmium	8.10E-09	6.27E-05	5.07E-13	6.30E+00	3.20E-12
				<b>TOTAL</b>	<b>3.30E-12</b>

**REASONABLE MAXIMUM EXPOSURE:**

Chemical	Air Concentration (AC) <sup>(1)</sup> (mg/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> /kg-day)	Intake (mg/kg-day)	Slope Factor (SF) [1/(mg/kg-day)]	Carcinogenic Risk (CR)
Beryllium	1.88E-10	2.94E-03	5.52E-13	8.40E+00	4.63E-12
Cadmium	8.10E-09	2.94E-03	2.38E-11	6.30E+00	1.50E-10
				<b>TOTAL</b>	<b>1.54E-10</b>

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Table C-24 (continued)  
Estimated Risk for Future Open-space Recreational User from  
Particulate Inhalation of Surface Soil in OU4 AOC No.2

**CARCINOGENIC RISK FOR RADIONUCLIDES** (CR = AxIFxSF)

**CENTRAL TENDENCY:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	7.43E-10	1.12E+05	8.33E-05	3.85E-08	3.21E-12
Plutonium-239/240	2.03E-09	1.12E+05	2.28E-04	2.78E-08	6.34E-12
Uranium-238	8.49E-10	1.12E+05	9.51E-05	1.24E-08	1.18E-12
				<b>TOTAL</b>	<b>7.52E-12</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Air Activity (A) <sup>(1)</sup> (pCi/m <sup>3</sup> )	Intake Factor (IF) (m <sup>3</sup> )	Intake (pCi)	Slope Factor (SF) (Risk/pCi)	Carcinogenic Risk (CR)
Americium-241	7.43E-10	5.25E+06	3.90E-03	3.85E-08	1.50E-10
Plutonium-239/240	2.03E-09	5.25E+06	1.07E-02	2.78E-08	2.97E-10
Uranium-238	8.49E-10	5.25E+06	4.46E-03	1.24E-08	5.53E-11
				<b>TOTAL</b>	<b>3.52E-10</b>

(1) The Air Concentration is calculated by multiplying the soil concentration by 1/4630000000; 4.63E+9 m<sup>3</sup>/kg is the particulate emission factor. The RF of 1 was chosen because the air concentration is already assumed to represent the PM<sub>10</sub> fraction; the RF was included in the calculations for the PEF (see EPA, 1991).

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**Table C-25**  
**Estimated Risk for Future Open-space Recreational User from**  
**External Irradiation from Surface Soil in OU4 AOC No.2**

Radionuclide Intake Factor =  $EF \times ED \times (1 - S_e) \times T_e$

Exposure Factors Description	Chemical Units	Exposure Value	
		Central Tendency	Reasonable Maximum Exposure
Percent of Year Exposed (EF)	unitless <sup>(1)</sup>	0.03	0.07
Exposure Duration (ED)	years	9	30
Gamma Shielding Factor (1-S <sub>e</sub> )	unitless	0.8	1
Gamma Time Factor (T <sub>e</sub> )	unitless	0.1	0.2

**CARCINOGENIC RISK** (CR = IA x IF x SF)

**CENTRAL TENDENCY:**

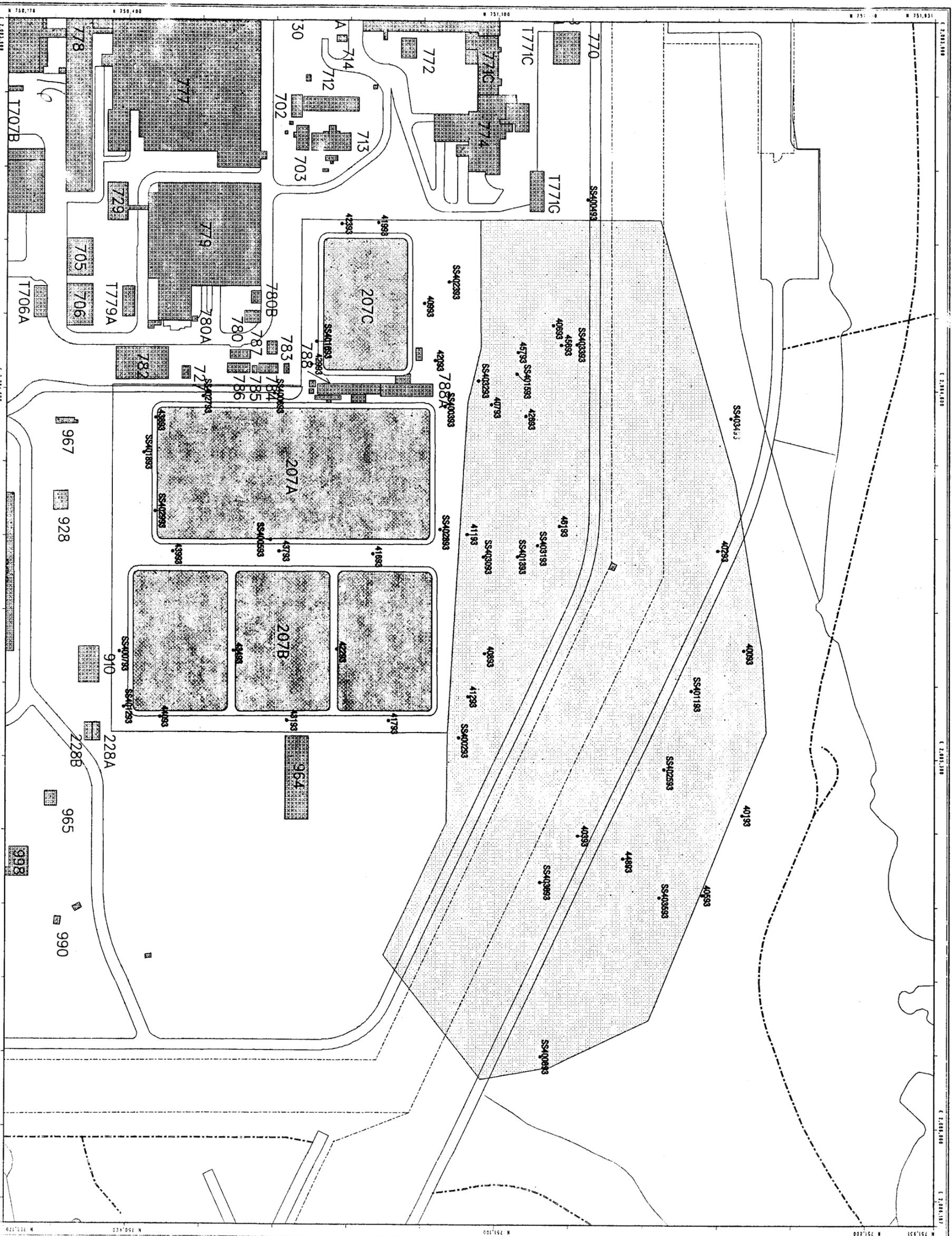
Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	3.44	2.16E-02	7.43E-02	4.59E-09	3.41E-10
Plutonium-239/240	9.42	2.16E-02	2.03E-01	1.87E-11	3.80E-12
Uranium-238	3.93	2.16E-02	8.49E-02	5.25E-08	4.46E-09
				<b>TOTAL</b>	<b>4.80E-09</b>

**REASONABLE MAXIMUM EXPOSURE:**

Radionuclide	Isotope Activity (IA) (pCi/g)	Intake Factor (IF) (years)	Intake (pCi-year/g)	Slope Factor (SF) (1/pCi-yr/g)	Carcinogenic Risk (CR)
Americium-241	3.44	4.20E-01	1.44E+00	4.59E-09	6.63E-09
Plutonium-239/240	9.42	4.20E-01	3.96E+00	1.87E-11	7.40E-11
Uranium-238	3.93	4.20E-01	1.65E+00	5.25E-08	8.67E-08
				<b>TOTAL</b>	<b>9.34E-08</b>

(1) The exposure frequency for the external irradiation pathway is expressed as a factor rather than as days/year in order to have the units cancel properly. To calculate days/year, multiply the factor presented in the table by 365.

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# OU4

## Areas of Concern Surface Soil

Figure 2-1

### EXPLANATION

- Area of Concern 2
- Area of Concern 1
- Surface Soil Sample Locations

### Standard Map Features

- Buildings or other structures
- Lakes and ponds
- Streams, ditches, or other drainage features
- Fence
- Rocky Flats boundary
- == Paved roads
- Dirt roads

*DATA SOURCE:* Data provided by Facilities Eng'g, EG&G Rocky Flats, Inc. - 1974. Hydrology provided by USGS - (date unknown)

Scale = 1 : 2090  
1 inch represents approximately 174.15 feet

State Plane Coordinate Projection  
Colorado Central Zone  
Datum: NAD27

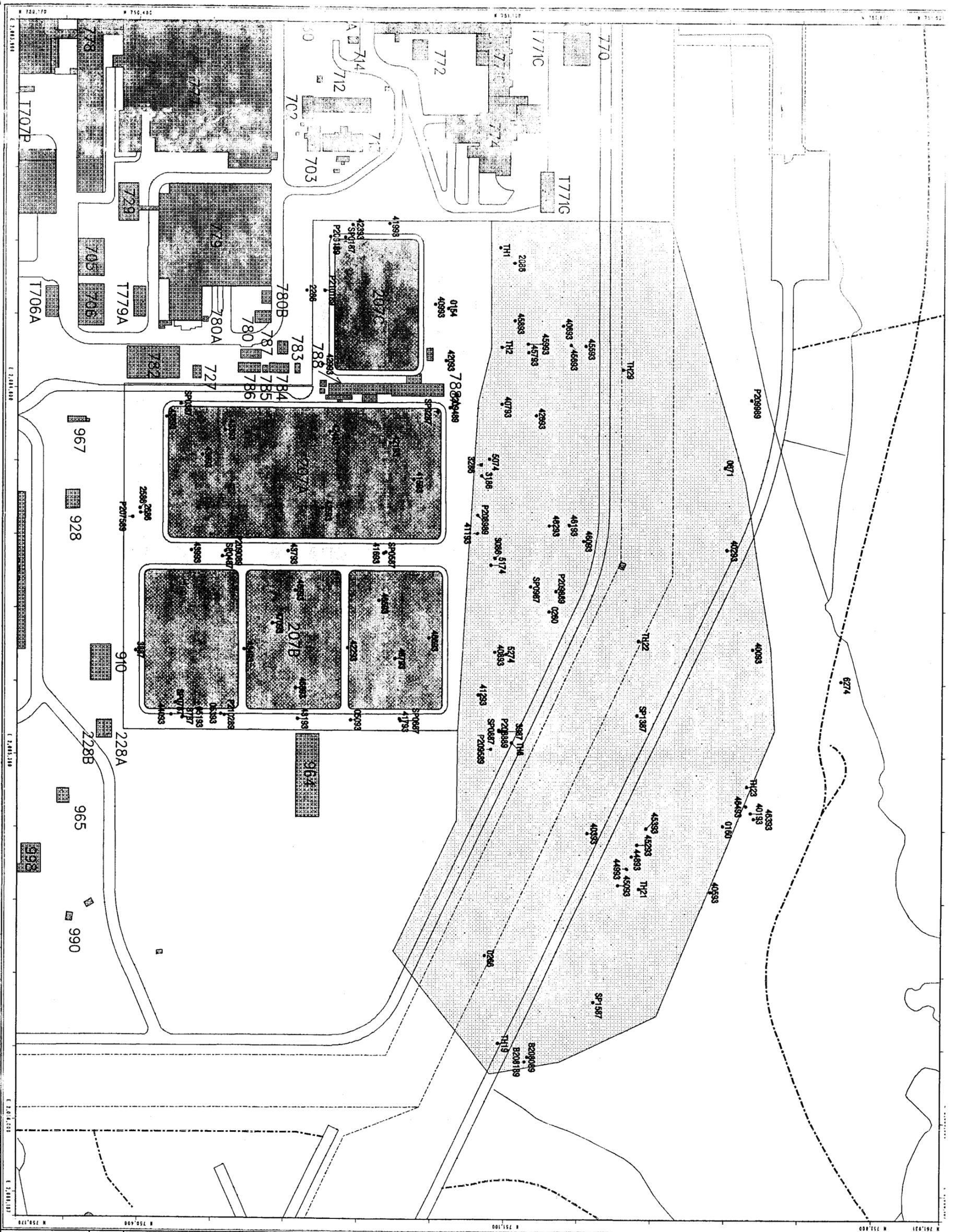
U.S. Department of Energy  
Rocky Flats Environmental Technology Site

Prepared by  
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# OU4

## Areas of Concern Borehole Locations

Figure 2-2



- EXPLANATION**
- ▨ Area of Concern 2
  - ▩ Area of Concern 1
  - Borehole Sampling Locations

- Standard Map Features**
- ▨ Buildings or other structures
  - ▩ Lakes and ponds
  - Streams, ditches, or other drainage features
  - Fences
  - Rocky Flats boundary
  - == Paved roads
  - Dirt roads

**DATA SOURCE**  
Buildings, roads, and fences provided by Facilities Engr, EG&G Rocky Flats, Inc. - 1991.  
Hydrology provided by USGS - (date unknown)

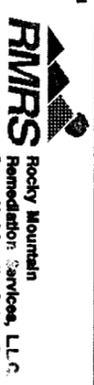


Scale = 1 : 2090  
1 inch represents approximately 174.16 feet



State Plane Coordinate Projection  
Colorado Central Zone  
Datum: NAD27

U.S. Department of Energy  
Rocky Flats Environmental Technology Center



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