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MAR 18 2016

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Mr. Brian Begley
Federal Facility Agreement Manager
Division of Waste Management
Kentucky Department for Environmental Protection
200 Fair Oaks Lane, 2nd Floor
Frankfort, Kentucky 40601

Ms. Julie Corkran
Federal Facility Agreement Manager
U.S. Environmental Protection Agency, Region 4
61 Forsyth Street
Atlanta, Georgia 30303

Dear Mr. Begley and Ms. Corkran:

TRANSMITTAL OF THE ADDENDUM TO THE SOILS OPERABLE UNIT REMEDIAL INVESTIGATION 2 REPORT FOR SOLID WASTE MANAGEMENT UNIT 229 AT THE PADUCAH GASEOUS DIFFUSION PLANT, PADUCAH, KENTUCKY, DOE/LX/07-2306&D2/A1

Please find enclosed for your review the *Addendum to the Soils Operable Unit Remedial Investigation 2 Report for Solid Waste Management Unit 229 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2306&D2/A1.

If you have any questions or require additional information, please contact April Ladd at (270) 441-6843.

Sincerely,

Tracey Duncan
Federal Facility Agreement Manager
Portsmouth/Paducah Project Office

Enclosures:

1. Certification Page
2. *Addendum to the Soils Operable Unit Remedial Investigation 2 Report for Solid Waste Management Unit 229 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-2306&D2/A1

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CERTIFICATION

Document Identification: ***Addendum to the Soils Operable Unit Remedial Investigation 2 Report for Solid Waste Management Unit 229 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,*** **DOE/LX/07-2306&D2/A1**

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Fluor Federal Services, Inc.

Mark J. Duff, Director, Environmental Management

3-17-16
Date Signed

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

U.S. Department of Energy

Jennifer Woodard, Paducah Site Lead
Portsmouth/Paducah Project Office

3/18/16
Date Signed

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Addendum to the Soils Operable Unit Remedial Investigation 2 Report for Solid Waste Management Unit 229 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

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Addendum to the Soils Operable Unit Remedial Investigation 2 Report for Solid Waste Management Unit 229 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

Date Issued—March 2016

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Prepared by
FLUOR FEDERAL SERVICES, INC.,
Paducah Deactivation Project
managing the
Deactivation Project at the
Paducah Gaseous Diffusion Plant
under Task Order DE-DT0007774

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FIGURES

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ACRONYMS

AL	action level
amsl	above mean seal level
AOC	area of concern
AT123D	Analytical Transient 1-,2-,3-Dimensional
BGOU	Burial Grounds Operable Unit
BHHRA	baseline human health risk assessment
BRA	baseline risk assessment
CAS	Chemical Abstract Service
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
COC	contaminant of concern
COE	U.S. Army Corps of Engineers
COPC	chemical or radionuclide of potential concern
COPEC	contaminant of potential ecological concern
cpm	counts per minute
CSOU	Comprehensive Site Operable Unit
D&D	decontamination and decommissioning
DAF	dilution attenuation factor
DMSA	DOE Material Storage Area
DOE	U.S. Department of Energy
DQO	data quality objective
ELCR	excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ESV	ecological screening value
EU	exposure unit
FFA	Federal Facility Agreement
FOE	frequency of exposure
FS	feasibility study
FSP	field sampling plan
GDP	gaseous diffusion plant
GPS	global positioning system
GWOU	Groundwater Operable Unit
GWS	gamma walkover survey
HI	hazard index
HQ	hazard quotient
HU	hydrogeologic unit
LUC	land use control
MARSSIM	Multi-Agency Radiological Survey and Site Investigation Manual
MCL	maximum contaminant level
MDC	minimum detectable concentration
NAL	no action level
NOAA	National Oceanic and Atmospheric Administration
NPL	National Priorities List
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PAL	project action limit
PCB	polychlorinated biphenyl
PGDP	Paducah Gaseous Diffusion Plant
POE	point of exposure
QC	quality control
RAGS	Risk Assessment Guidance for Superfund

RAO	remedial action objective
RCRA	Resource Conservation and Recovery Act
RGA	Regional Gravel Aquifer
RGO	remedial goal option
RI	remedial investigation
RME	reasonable maximum exposure
ROD	Record of Decision
SERA	screening-level ecological risk assessment
SESOIL	Seasonal Soil Compartment Model
SMP	Site Management Plan
SSL	soil screening level
SVOC	semivolatile organic compound
SWMU	solid waste management unit
SWOU	Surface Water Operable Unit
TED	total effective dose
UCRS	Upper Continental Recharge System
USGS	U.S. Geological Survey
VOC	volatile organic compound
WKWMA	West Kentucky Wildlife Management Area
XRF	X-ray fluorescence

EXECUTIVE SUMMARY

The Paducah Gaseous Diffusion Plant (PGDP) is an inactive uranium enrichment facility that is owned by the U.S. Department of Energy (DOE). DOE is conducting environmental restoration activities at PGDP in accordance with the requirements of the Paducah Federal Facility Agreement (FFA), which coordinates Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) cleanup requirements. PGDP was placed on the National Priorities List in 1994. DOE, the U.S. Environmental Protection Agency (EPA), and the Commonwealth of Kentucky (Kentucky) entered into an FFA in 1998 (EPA 1998).

This Remedial Investigation (RI) Report was prepared following the outlines found in Appendix D of the FFA for PGDP (EPA 1998) and is consistent with the elements found in Appendix B of the Soils Operable Unit (OU) RI/Feasibility Study (FS) Work Plan (Work Plan) (DOE 2010), but the outline format was modified to meet specific project requirements.

The original scope of the Soils OU consisted of 86 Solid Waste Management Units (SWMUs)/areas of concern (AOCs). During the RI conducted in 2010, grid-based sampling was conducted at SWMU 229. Sixteen SWMUs/AOCs, including SWMU 229, were determined to require additional characterization subsequent to the Soils OU RI to delineate the extent of contamination. The work performed in this phase of the project was referred to as the Soils OU RI 2 (DOE 2015a). During the course of the Soils OU RI 2 fieldwork, SWMU 229 consistently contained standing water. As stated in the survey plan of the work plan addendum (DOE 2014a), gamma radiological surveys would not be performed in areas of standing water; therefore, the planned activities (i.e., radiological walkover survey and a judgmental grab sample) for this unit could not be completed. After discussion among the FFA parties on December 2, 2014, it was concluded that activities for SWMU 229 would need to be conducted at a later time when the unit was free of standing water and would be reported in an addendum to the Soils OU RI 2 report once field activities were completed. This RI Report, referred to as the Addendum to the Soils OU RI 2 Report, was developed to present results of the field investigation that was conducted in the summer of 2010 and the fall of 2015 for SWMU 229.

Historical data [i.e., data collected during the 2010 investigation (Soils OU RI)] and the 2015 investigation (Soils OU RI 2) were combined to form the entire data set used to evaluate SWMU 229. This Addendum to the Soils OU RI 2 Report documents the nature and extent of contamination, contaminant fate and transport, and risk characterization.[1] Further, this report summarizes the information known about SWMU 229 and describes how the additional investigation fills the data gaps and supports remedial decision making.

PROJECT OBJECTIVES AND GOALS

The goals for this addendum are consistent with those established in the Paducah FFA (EPA 1998) and the Site Management Plan (SMP) (DOE 2015b) negotiated among DOE, EPA, and Commonwealth of Kentucky (Kentucky). The primary objectives for the Soils OU presented in the SMP are to protect human health and the environment by taking actions necessary to prevent both on-site and off-site human

[1] The baseline human health risk assessment (BHHRA) in this report considers residential land use consistent with EPA Region 4 Human Health Risk Assessment Supplemental Guidance. As discussed in the Paducah SMP (DOE 2015a), the Paducah Human Health Risk Methods Document (DOE 2015c), and this Soils OU RI 2 Report Addendum, industrial use, not residential use, is the reasonably anticipated land use for SWMU 229. The risk characterization for the residential scenario will be used in subsequent documents to identify unlimited use/unlimited exposure for no further action determinations and any land use controls appropriate for reasonably anticipated land uses.

exposure that presents an unacceptable risk and to implement actions that provide the greatest opportunities to achieve significant risk reduction before site closure.

The goals of this addendum are as follows:

Goal 1: Characterize Nature and Extent of Source Zone(s);
Goal 2: Determine Surface and Subsurface Transport Mechanisms and Pathways;
Goal 3: Complete a Baseline Risk Assessment for the Soils OU; and
Goal 4: Support Evaluation of Remedial Alternatives.

The Work Plan (DOE 2010) and addendum (DOE 2014a) utilized a compilation of sampling information collected on and around PGDP from 1988 to 2014. During development of the Work Plan, data existing at that time were evaluated relative to the data quality objectives (DQOs) defined in the Work Plan (DOE 2010). The result of the evaluation was the identification of data gaps for each SWMU/AOC. The data collected during the summer of 2010 and the fall of 2015 have addressed those data gaps. Sampling results collected during both Soils OU RIs and historical data of sufficient quality to meet DQOs, per the evaluation in the Work Plan (DOE 2010), have been used (1) to determine nature and extent of contamination, (2) to model the effect contamination may have on groundwater, and (3) to assess potential risks and hazards posed by each SWMU.

This RI Report summarizes the results of the characterization of the sources of SWMU 229, identifies the potential for migration from the soil at SWMU 229 to groundwater or runoff to adjacent drainage ways, and summarizes potential risks/hazards associated with SWMU 229 (Goals 1–3). These form the basis for supporting an evaluation of potential actions in an FS (Goal 4).

SWMU 229 was evaluated based on the criteria in the FFA for a reasonable maximum exposure (RME) for both current and future land use for excess lifetime cancer risks (ELCRs) of 1E-06 or hazard index (HI) greater than 1 and for adverse environmental impacts (EPA 1998).

The Baseline Human Health Risk Assessment (BHHRA) characterized cancer risks and noncancer hazards by exposure unit for all chemicals or radionuclides of potential concern (COPCs) for the following scenarios:

- Current Industrial Worker[2]
- Future Industrial Worker [see footnote (2)]
- Outdoor Worker
- Excavation Worker
- Recreational User
- Future Hypothetical Rural Resident

Likely scenarios for the SWMU 229 are discussed in Chapter 5 and include that of the future industrial worker because SWMU 229 is located inside the Limited Area. Additionally, a hypothetical residential scenario and an excavation worker scenario were assessed.

[2] The "future industrial worker" reflects default assumptions (i.e., 250 days/year for 25 years). A "current industrial worker" scenario has been added to the default scenario to be more reflective of current site conditions and practices with a lower exposure frequency (i.e., 14 days/years for 25 years) (DOE 2015c).

CHARACTERIZE NATURE AND EXTENT OF SOURCE ZONE (GOAL 1)

The conceptual site model for SWMU 229 represents no migration of contamination as the expected condition. The scenario that contaminants have impacted surface water and the groundwater underlying these sources through vertical infiltration in the soil is unlikely.

SWMU 229, the location of former DOE Material Storage Area (DMSA) outside (OS)-18, is located north of C-764-F in the northwest portion of the plant site (Figure ES.1). SWMU 229 is approximately 35,112 ft^2. There is no direct connection between the SWMU and surface water. This area was established soon after plant construction to store excess railroad supplies, parts, components, etc. Later, SWMU 229 became an area for storing various excess materials, including the following:

scrap metal	railroad ties	road signs
concrete	fans	manhole covers
fireproof safes	chain link fencing	scaffolding
portable work platform	two small buildings	circuit boards
empty trash cans	light bulbs	fuses
empty 55-gal drums	oils	batteries
miscellaneous equipment and parts	parts from railroad cars	

In 2001, DOE began characterization and remediation of the materials in DMSAs. RCRA-regulated items have been removed from the SWMU and placed in proper storage. This DMSA now qualifies as a Phase 3 DMSA because it has been characterized fully and contains no fissionable material (DOE 2003a).

Analysis of SWMU 229 indicates the presence of inorganic compounds, organic compounds, and radionuclides above screening levels. Soil sampling results were compared to the appropriate no action levels (NALs) and background concentrations to identify the list of potential contaminants to be evaluated for the purposes of determining nature and extent of contamination. Consistent with the Work Plan (DOE 2010), which identifies industrial or recreational use as the current and reasonably anticipated future land uses, the horizontal and vertical extent was based on NALs for future industrial workers (inside the Limited Area). For naturally occurring constituents, delineation also is based on comparison with background concentrations.

The prevalent contaminants are metals (including uranium), polycyclic aromatic hydrocarbons (PAHs) [benzo(a)pyrene equivalents], and radionuclides (including uranium radioisotopes).

The lateral extent of contamination has been defined within the constraints of the approved Work Plan (DOE 2010) and addendum (DOE 2014a). Field data were used to assist in delineation.

DETERMINE SURFACE AND SUBSURFACE TRANSPORT MECHANISMS AND PATHWAYS (GOAL 2)

Chapter 5 and Appendix C document the fate and transport modeling used in the evaluation of soil sources impacts on groundwater at SWMU 229.

Previous work has shown that the primary pathway for groundwater flow is vertical migration through the Upper Continental Recharge System (UCRS), followed by lateral migration in the Regional Gravel Aquifer (RGA). Contaminated groundwater could migrate to points of exposure (POEs). The POE evaluated was the RGA at the SWMU boundary.

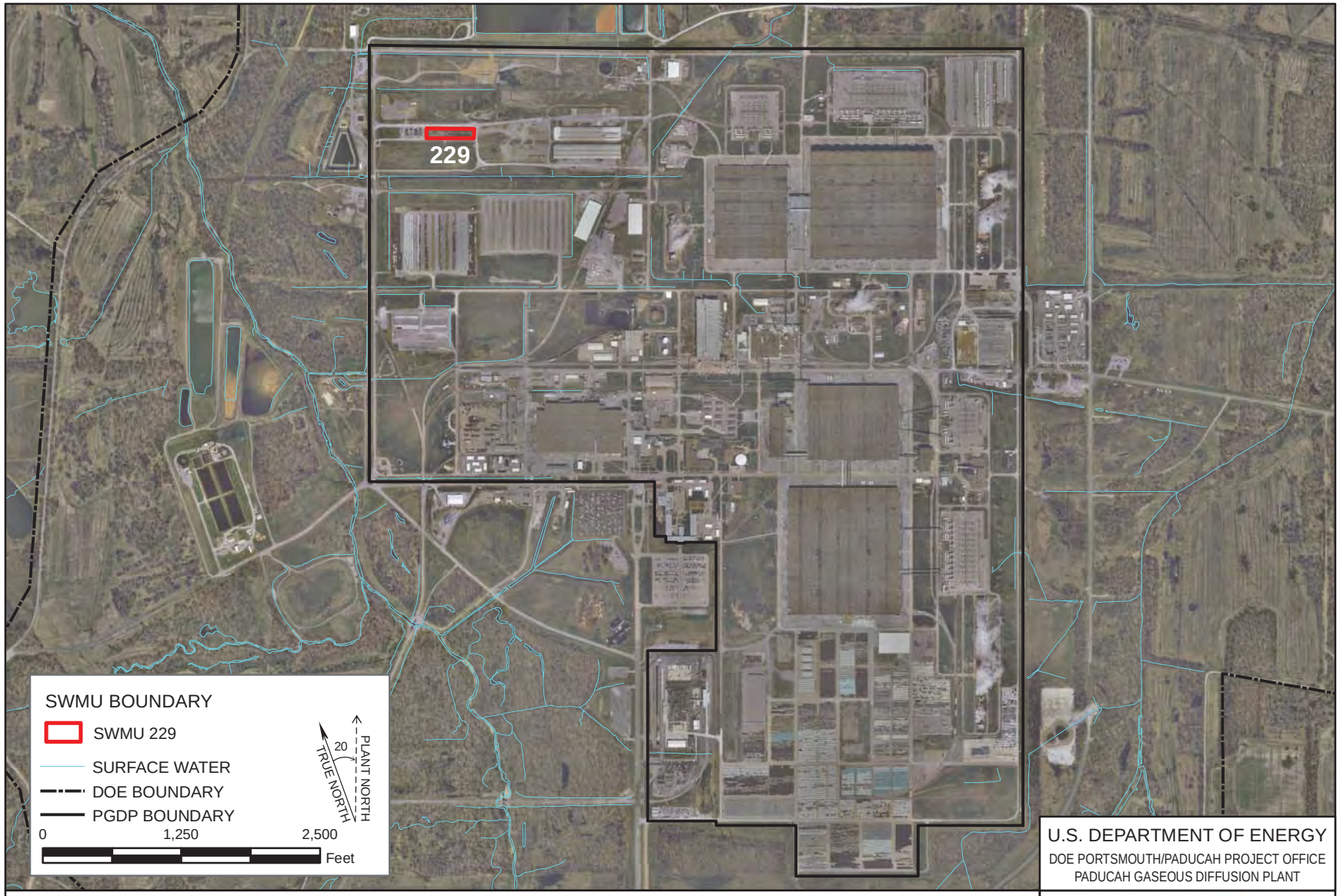

Figure E.1. Location of the Soils OU RI 2 SWMU 229

12/16/2015 G:\GIS\ARCVIEWS\PROJECTS\SoilsOU\RI Report\RI2 D1\229_E1 SWMU location.mxd

Impacts on groundwater in the RGA were evaluated for those soil constituents that had the potential to cause an exceedance of a primary drinking water standard [maximum contaminant level (MCL)] or health based/risk based level (if no MCL was available) at the SWMU boundary.

Soil contaminant screening identified technetium-99 (Tc-99) at SWMU 229 as potentially impacting RGA groundwater quality. This SWMU contaminant scenario was subject to groundwater modeling to bound the potential for impacts to RGA groundwater. Seasonal Soil Compartment Model (SESOIL) and Analytical Transient 1-,2-,3-Dimensional Model (AT123D) simulation results are summarized in Table ES.1.

Table ES.1. SESOIL and AT123D Maximum Predicted Groundwater Concentrations

SWMU	Groundwater Constituent	Maximum RGA Groundwater Concentration at SWMU Boundary (µg/L)	Predicted Time to Reach SWMU Boundary (years)
229	Tc-99	2.0E-2 (340 pCi/L)	32.6

Consistent with the Soils OU RI Report (DOE 2013), 900 pCi/L was the criterion used in screening to determine if the SWMU would be modeled for Tc-99 transport. The incremental contributions of Tc-99 currently present in soil at SWMU 229 do not have the potential to impact the RGA groundwater at the SWMU boundary at a concentration (340 pCi/L) that exceeds the screening criterion of 900 pCi/L (DOE 2013). Consistent with the Soils OU RI Report (DOE 2013), 900 pCi/L was the criterion used in screening to determine if the SWMU was modeled for Tc-99 transport. The model predicts that the Tc-99 associated with the vadose zone at SWMU 229 will leach to the RGA; however, the mass flux of Tc-99 from the vadose zone to the RGA is insufficient to cause RGA groundwater concentrations to exceed the 900 pCi/L screening criterion. Model predictions indicate that, for SWMU 229, dissolved Tc-99 reaches the underlying saturated zone at 32.06 years and the SWMU boundary at 32.6 years. The peak predicted Tc-99 concentration occurs at 37.5 years.

COMPLETE A BASELINE RISK ASSESSMENT FOR THE SOILS OU (GOAL 3)

PGDP is an industrial facility surrounded by a state-maintained wildlife refuge and residential property. The current and reasonably anticipated future use of locations within the current Limited Area is industrial. The risk characterization for these current and reasonably anticipated future uses will be used when making risk management decisions in subsequent documents.

Consistent with the Paducah Human Health Risk Methods Document (DOE 2015c), which incorporates both EPA and Kentucky risk assessment guidance, the BHHRA for SWMU 229 characterized risk for a range of reasonably anticipated and hypothetical current and future use scenarios. In developing these scenarios, the concept of RME was used. Additionally, consistent with the results available, the exposure assessment primarily considered exposure to soil (surface and/or subsurface).

To determine use scenarios of concern, risk characterization results for Total HI and Total ELCR were compared to benchmarks of 1.0 and 1E-06, respectively. Use scenarios with Total HI or Total ELCR exceeding either of these benchmarks were deemed use scenarios of concern. To determine contaminants of concern (COC), potential risk characterization results for chemical-specific hazard quotient (HQ) and chemical-specific ELCR over all pathways within a use scenario of concern were compared to

benchmarks of 0.1 and 1E-06, respectively. COPCs within a use scenario of concern exceeding either of these benchmarks were deemed COCs for the use scenario of concern. The COCs are identified in tables in Chapter 5. In addition, priority COCs have been identified in this report. Priority COCs are those COCs with either a chemical-specific HQ or chemical-specific ELCR over all pathways within a use scenario of concern greater than 1 and 1E-04, respectively. Priority COCs are identified to highlight those COCs contributing most to Total HI and Total ELCR.

The following summarizes the baseline risk assessment results for SWMU 229:

- The BHHRA completed as part of this addendum indicates that the cumulative ELCR benchmark of 1E-06 and/or cumulative HI benchmark of 1.0 is exceeded at SWMU 229 (for one or more exposure scenarios evaluated); therefore, as stated in the Work Plan, Decision Rule D1a, an FS is appropriate to address impacted media (i.e., surface and subsurface soil) at SWMU 229 (DOE 2010).

- Two priority COCs [priority COCs are identified as those COCs with a chemical-specific ELCR > 1E-04 or a chemical-specific HQ > 1, to highlight to risk managers the COCs driving Total ELCR or Total HQ], uranium-235 and uranium-238, are associated with the highest Total ELCRs at SWMU 229 exceeding ELCR > 1E-04.

SCREENING ECOLOGICAL RISK ASSESSMENT

Consistent with the Paducah Ecological Risk Methods Document (DOE 2015d), which incorporates both EPA and Kentucky risk assessment guidance, the screening ecological risk assessment (SERA) was limited to a comparison of maximum and exposure point concentrations in surface soils at the SWMU against ecological screening levels in order to identify the chemicals of potential ecological concern (COPECs). The SERA does not consider the limited habitat, SWMU size, or other factors that also need to be considered to characterize ecological risk. The results of the SERA will be used in the future sitewide ecological Baseline Risk Assessment (BRA) that will be conducted as part of the SWOU. Twenty-three COPECs, including metals, semivolatile organic compounds (SVOCs) and radionuclides, were identified in this report.

SUPPORT EVALUATION OF REMEDIAL ALTERNATIVES (GOAL 4)

The representative data set used for SWMU 229 is sufficient to support the evaluation of remedial alternatives in the FS. Other information was gathered in support of the evaluation of remedial alternatives to include infrastructure issues, extent of contamination, and verification of site descriptions. Discussion of possible remedial technologies applicable for SWMU 229 is located in Chapter 5 along with impacts on or by groundwater and surface water.

Remedial goal options (RGOs) were developed individually for each SWMU 229 EU for scenarios analyzed in the BHHRA. RGOs were calculated for each COC as determined by the conclusions of the BHHRA. These RGOs should not be interpreted as being cleanup goals, but as risk-based values that may be used by risk managers to revise preliminary remediation goals to be consistent with the remedial action objectives in the FS and to develop cleanup goals from these revised preliminary remediation goals in the Record of Decision (ROD). The COCs and RGOs consistent with the current and reasonably anticipated future use scenarios (i.e., industrial use, including both the industrial and excavation worker) are presented to evaluate direct contact exposure and can be found in Chapter 6, Table 6.8.

CONCLUSIONS

The risk levels associated with contamination at SWMU 229 meet the criteria to be evaluated further in an FS. Consistent with the FFA, an FS will be developed to evaluate remedial action alternatives to mitigate the potential risks and hazards to human health and the environment and address the potential migration of contaminants from source areas to surface water and groundwater for SWMU 229 that were evaluated in this RI Report.

UNCERTAINTIES/ASSUMPTIONS

The Work Plan identified data gaps on a SWMU-by-SWMU basis that needed to be filled to proceed with the FS (DOE 2010). The Work Plan (DOE 2010) and addendum (DOE 2014a) were implemented to reduce any remaining uncertainties from previous investigations regarding the nature of the source zone, extent of the source zone and secondary sources, surface transport mechanisms, and to support evaluation of remedial technologies in the FS.

Nature of the Source Zone

For SWMU 229, the available historical documentation and soil characterization data are sufficient relative to chemical and physical properties of soil to screen technology types and to conduct detailed alternative analysis. The RI, however, identified several uncertainties that may affect the FS. The potential impact of these source zone uncertainties on alternatives analysis will be documented, as necessary, and evaluated further in the FS (see Section 4.1 for examples). Additional uncertainty exists because of the higher detection limits for the field data used in the risk assessment, which is discussed further in Appendix B.

SWMU 229 has been investigated previously. This addendum uses a combination of historical and current analytical results of soil and groundwater from the area of SWMU 229. The results of previous investigations and the current RI sampling documented and confirmed the presence of metals, SVOCs, and radionuclides in SWMU 229. The associated samples were collected and analyzed over several previous investigations, as well as for this addendum, using several methods. Quality control/quality assurance practices at PGDP, now and previously, limit the uncertainty associated with the sampling and analysis process. Nevertheless, changes have occurred to analytical methods that limit the strict comparison of data (e.g., laboratory reporting limits have varied over time). In some cases, analytical method detection limits are above screening criteria, such as the future industrial worker NAL.

Extent of the Source Zone and Secondary Sources

The RI investigated extent of contamination from ground surface to 10 ft below ground surface (bgs) (DOE 2013). Uncertainties associated with horizontal and vertical extent will be managed in the FS. SWMU 229 was not sampled for volatile organic compounds because none were suspected to be present. Secondary sources of groundwater contamination, such as potential dense nonaqueous-phase liquid source zones, from SWMU 229 were not identified.

Surface and Subsurface Transport Mechanisms

Whether contaminants found in soil could migrate to the point of exposure (i.e., SWMU boundary) via a groundwater pathway was evaluated. Previous work has shown that the primary pathway for groundwater flow and the site-related contaminants is vertical migration through the UCRS, followed by lateral migration in the RGA. Modeling results, which came from the analysis of this primary pathway for

groundwater flow, show that contaminants in soil are not expected to migrate to groundwater and reach concentrations in groundwater above MCLs.

Internal plant ditches are grass-lined and the outfall ditches are grass-lined or otherwise stabilized; therefore, a quantitative analysis in DOE 2008b determined that the contaminants are not likely to be transported attached to suspended soil particles within the ditches and outfalls in the event transport or runoff to a drainageway did occur.

1. INTRODUCTION

The Paducah Gaseous Diffusion Plant (PGDP), located within the Jackson Purchase region of western Kentucky, was an active uranium enrichment complex from 1952 until 2013. The U.S. Department of Energy (DOE) owns the area the enrichment complex operated and is responsible for environmental restoration activities associated with legacy operation of PGDP (CERCLIS #KY8-890-008-982). DOE is the lead agency for response actions, and the U.S. Environmental Protection Agency (EPA) and the Kentucky Department of Environmental Protection have regulatory oversight responsibilities.

In 1988, off-site groundwater contamination was detected in groundwater wells north of PGDP. Consequently, DOE and EPA Region 4 entered into an Administrative Consent Order under Sections 104 and 106 of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). In 1994, PGDP was placed on the National Priorities List (NPL), a list of sites designated by EPA as having the highest priority for site remediation. Additionally, Section 120 of CERCLA requires federally owned NPL sites to enter into a Federal Facility Agreement (FFA) (EPA 1998). An FFA was finalized among DOE, EPA, and the Commonwealth of Kentucky (Kentucky) in 1998.

Source units and areas of contamination at PGDP have been combined into operable units (OUs) for evaluation of remedial actions. These OUs include the Surface Water OU (SWOU), the Burial Grounds OU (BGOU), the Soils OU, the Groundwater OU (GWOU), and the Decontamination and Decommissioning (D&D) OU. Each OU is designed to remediate contaminated media and/or facilities associated with PGDP. After completion of these activities, the Comprehensive Site OU (CSOU) evaluation will be conducted, with implementation of additional actions, as needed, to ensure long-term protectiveness.

The Soils OU is being implemented in a phased approach [i.e., pre-gaseous diffusion plant (GDP) shutdown and post-GDP shutdown] consisting of remedial and removal actions to accomplish the following goals (DOE 2015b):

- Prevent human exposure to contamination presenting an unacceptable risk;
- Prevent or minimize further off-site migration; and
- Reduce, control, or minimize contaminated soil hot spots contributing to off-site contamination.

Additionally, the phased approach allows the site to use information gained in earlier phases of the cleanup to refine and implement subsequent cleanup objectives and actions in support of final cleanup status. Slabs, subsurface structures, and underlying soils left after completing D&D of the operating GDP, will be addressed in subsequent actions. Figure 1.1, adapted from the Site Management Plan (SMP) (DOE 2015b), illustrates the phases and accomplishments of the Soils OU.

The original scope of the Soils OU consisted of 86 solid waste management units (SWMUs)/areas of concern (AOCs). Sixteen SWMUs/AOCs, including SWMU 229, were determined to require additional characterization subsequent to the Soils OU Remedial Investigation (RI) to delineate the extent of contamination. The work performed in this phase of the project was referred to as the Soils OU RI 2 (DOE 2015a). During the course of the Soils OU RI 2 fieldwork, SWMU 229 consistently contained standing water. As stated in the survey plan of the work plan addendum (DOE 2014a), gamma radiological surveys would not be performed in areas of standing water; therefore, the planned activities (i.e., radiological walkover survey and a judgmental grab sample) for this unit could not be completed. After discussion among the FFA parties on December 2, 2014, it was concluded that activities for SWMU 229 would need to be conducted at a later time when the unit was free of standing water and reported in an addendum to the Soils OU RI 2 report once field activities were completed. The location of SWMU 229 is shown on Figure 1.2.

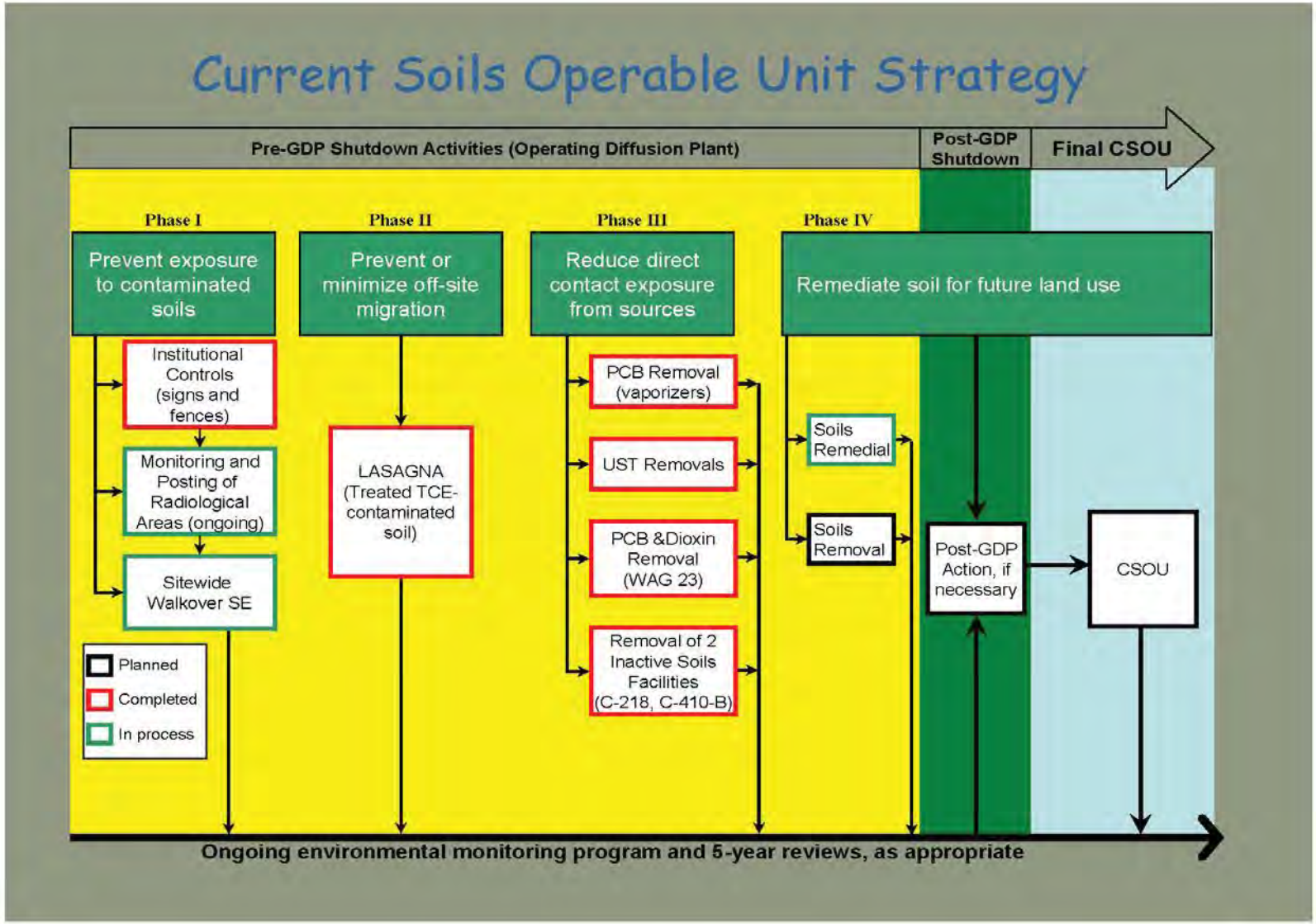

Figure 1.1. Soils OU Paducah Soils Strategy

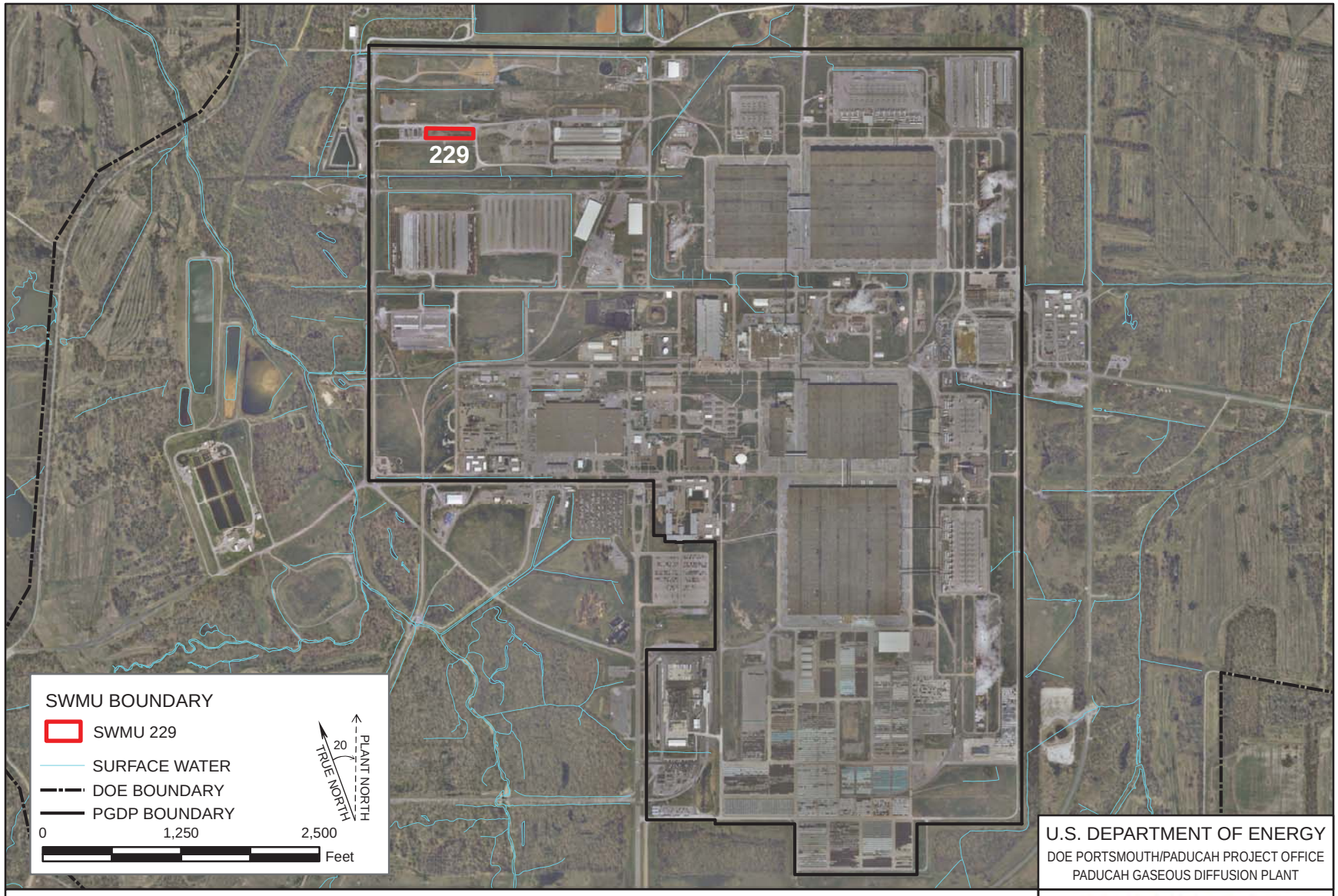

Figure 1.2. Location of the Soils OU RI 2 SWMU 229

11/9/2015 G:\GIS\ARCVIEWS\PROJECTS\SoilsOU\RI Report\RI2 D1\229_E1 SWMU location.mxd

1.1 PURPOSE OF REPORT

The SWMU 229 field investigation followed the investigation outlined in the Soils OU RI Work Plan (DOE 2010) and addendum (DOE 2014a). This report documents the results of the RI, Baseline Human Health Risk Assessment (BHHRA), and Screening Ecological Risk Assessment (SERA) for SWMU 229.

Historical data in addition to data collected during the 2010 investigation (Soils OU RI) and 2015 investigation (Soils OU RI 2) were combined to form the entire data set used to evaluate SWMU 229. This data set will be used in the feasibility study (FS).

The work plan utilized the data quality objective (DQO) process as a planning tool to assist in the identification of environmental problems and to define the data collection process needed to support decisions (DOE 2010).

The problem statement developed through the DQO process and documented in the Work Plan follows (DOE 2010):

> Past releases from the PGDP may have resulted in the contamination of soil found at the SWMUs and AOCs. The nature and extent of contamination has not been adequately defined, nor is it known whether these potential contaminants pose unacceptable risks to current and reasonably anticipated future receptors under some exposure scenarios.

The goals of the RI are (1) characterize nature and extent of source zone; (2) determine surface and subsurface transport mechanisms and pathways; (3) complete a baseline risk assessment (BRA) for the Soils OU; and (4) support evaluation of remedial alternatives. These goals are listed in Table 1.1.

Recommended remedial action objectives (RAOs) will be presented in the forthcoming FS.

Table 1.1. Goals, Decisions, and Questions Identified for the Soils OU

GOAL 1: CHARACTERIZE NATURE AND EXTENT OF SOURCE ZONE
Decisions and questions
1-1: What are the suspected contaminants?
1-2: What are the plant processes that could have contributed to the contamination? When and over what duration did releases occur?
1-3: What are the concentrations and activities at the source?
1-4: What is the area and volume of the source zone? What is the vertical and lateral extent of contamination?
1-5: What are the chemical and physical properties of associated material at the source areas?
1-6: What are the past, current, and potential future migratory paths?
GOAL 2: DETERMINE SURFACE AND SUBSURFACE TRANSPORT MECHANISMS AND PATHWAYS
Decisions and questions
2-1: What are the contaminant migration trends?
2-2: What are the effects of underground pipelines and plant operations on migration pathways including ditches?
2-3: What are the physical and chemical properties of the formations and subsurface matrices?
GOAL 3: COMPLETE A BASELINE RISK ASSESSMENT FOR THE SOILS OU
Decisions and questions
3-1: Where do the contaminant concentrations exceed no action levels (NALs)?
3-2: Are isolated areas of contamination present or is contamination general?
3-3: What are the contaminants of concern (COCs) that define the contamination?
3-4: What are the NALs?
3-5: Are SWMUs/AOCs within the Soils OU similar enough to be addressed in the same manner?

Table 1.1. Goals, Decisions, and Questions Identified for the Soils OU (Continued)

GOAL 4: SUPPORT EVALUATION OF REMEDIAL ALTERNATIVES
Decisions and questions
4-1: What are the possible remedial technologies applicable for this unit?
4-2: What are the physical and chemical properties of media to be remediated?
4-3: Are cultural impediments present?
4-4: What is the extent of contamination (geologic limitations presented by the source zone)?
4-5: What would be the impact of action on and by other sources?
4-6: What would the impact of an action at the source be on the integrator units?
4-7: What are stakeholders' perceptions of contamination at or migrating from source zone?

Table is from Work Plan (DOE 2010).

1.2 PROJECT SCOPE

This addendum is focused on SWMU 229 and the areas immediately surrounding it to determine if the SWMU poses a risk to human health or the environment. As stated in the SMP, a primary objective for this project is to contribute to the protection of on-site workers and off-site residents by addressing sources of soil contamination (DOE 2015b).

The scope of the Soils OU includes potential contaminant migration pathways from the soil to surface water and groundwater, but does not include sampling either the surface water or groundwater. Also, the scope of the Soils OU does not include any drainage ditches bounding the Soils OU SWMUs/AOCs. These ditches are components of the SWOU. The GWOU will address dissolved-phase groundwater contamination in the Regional Gravel Aquifer (RGA) beneath the Soils OU SWMUs/AOCs. The secondary sources of groundwater contamination that are derived from the burial grounds or deep subsurface soil are within the scope of the BGOU or the CSOU. DOE integrates the Natural Resource Damage Assessment values into the CERCLA process. As such, it is the expectation that the sampling data generated by this RI, in addition to the historical data available, will be sufficient to support the Natural Resource Damage Assessment process.

The DQO process was used to focus the sampling strategy on SWMU/AOC-specific media, contamination, and migration pathways, and identify data needs. Data collected during both of the Soils OU RI field efforts, together with historical data presented in the Work Plan (DOE 2010), met project DQOs and were used to determine nature and extent of contamination.

The following list summarizes the activities that were conducted for SWMU 229:

- Gamma radiological walkover survey with judgmental grab sample for radiological constituents;
- Evaluation of nature and extent of contamination based on collected RI samples and historical samples;
- Modeling of contaminant fate and transport and estimation of future contaminant concentrations at selected points of exposure; and
- Determination of potential ecological and human health risks associated with SWMU 229, including the following:
    - On-site future industrial worker (inside the PGDP security fence); and

— Residential scenarios were assessed consistent with the Risk Methods Document (DOE 2015c).

Consistent with the Work Plan (DOE 2010), the nature and extent of surface soils (0–1 ft bgs) within the Soils OU are included in this addendum.

To address uncertainties identified in the Soils OU, the observational approach was used in the design of the sampling strategy for the Soils OU RI/FS Work Plan (DOE 2010). The key concepts are as follows:

- The RI strategy is based on a specified "most probable site condition," which, for the Soils OU RI/FS, assumes that contamination is limited to surface and near surface soil (0–4 ft bgs) and potentially is impacting human health and welfare or the environment adversely.

- Reasonable deviations from the most probable site condition are identified. One reasonable deviation for the Soils OU RI/FS is that no contamination is impacting human health and welfare or the environment adversely. Other reasonable deviations would be that contamination has migrated to depths greater than 4 ft bgs, but still within the Soils OU bound of 10 ft bgs (16 ft bgs at pipelines) and to either the SWOU or GWOU. Site conditions should not differ significantly from the postulated conditions shown in the conceptual models, described in Chapter 3.

- Site assessment factors were identified for observation to detect contamination. These factors included sensory observation of contamination (site walkdowns), field screening, field analyses with portable instruments, geophysical surveys, historical data evaluation, and laboratory analysis of samples.

- The Field Sampling Plan (FSP) included a contingency plan to address deviations from the most probable site conditions.

This field effort provided information to fill data gaps identified for SWMU 229. Data were screened against significant chemicals or radionuclides of potential concern (COPCs) listed in the *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Volume 1: Human Health, Volume 2: Ecological* (DOE 2015c; DOE 2015d). Significant COPCs for the PGDP are listed in Table 1.2.

1.3 SOILS OU SWMU EVALUATION

The scope of the Soils OU includes an RI, BHHRA, SERA, evaluation of remedial alternatives, remedy selection, and implementation of actions [e.g., excavation, land use controls (LUCs)], as necessary, for protection of human health and the environment.

Project uncertainties that could affect the scope and schedule include the amount and scope of RI characterization needed (e.g., field samples, borings) to achieve the RI goals and the remedial action necessary to achieve a final decision.

Table 1.2. Significant Chemicals of Potential Concern at the PGDP[1]

Inorganic Chemicals		Organic Compounds		Radionuclides	
Analyte	**CAS Number**	**Analyte**	**CAS Number**	**Analyte**	**CAS Number**
Aluminum	7429905	Acenaphthene	83329	Americium-241	14596102
Antimony	7440360	Acenaphthylene	208968	Cesium-137+D	10045973
Arsenic	7440382	Acrylonitrile	107131	Neptunium-237+D	13994202
Barium	7440393	Anthracene	120127	Plutonium-238	13981163
Beryllium	7440417	Benzene	71432	Plutonium-239	15117483
Boron	7440428	Bromodichloromethane	75274	Plutonium-240	14119336
Cadmium	7440439	Carbazole	86748	Technetium-99 (Tc-99)	14133767
Chromium III	16065831	Carbon tetrachloride	56235	Thorium-230	14269637
Chromium VI	18540299	Chloroform	67663	Uranium-234	13966295
Cobalt	7440484	1,1-Dichloroethene	75354	Uranium-235+D	15117961
Copper	7440508	1,2-Dichloroethane	107062	Uranium-238+D	7440611
Fluoride	16984488	1,2-Dichloroethene (mixed)	540590		
Iron	7439896	*trans*-1,2-Dichloroethene	156605		
Lead	7439921	*cis*-1,2-Dichloroethene	156592		
Manganese	7439965	Dieldrin	60571		
Mercury	7439976	Ethylbenzene	100414		
Molybdenum	7439987	Fluoranthene	206440		
Nickel	7440020	Fluorene	86737		
Selenium	7782492	Hexachlorobenzene	118741		
Silver	7440224	Naphthalene	91203		
Thallium	7440280	2-Nitroaniline	88744		
Uranium	N/A	N-Nitroso-di-n-propylamine	621647		
Vanadium	7440622	Pentachlorophenol	87865		
Zinc	7440666	Phenanthrene	85018		
		Pyrene	129000		
		Tetrachloroethene	127184		
		1,1,1-Trichloroethane	71556		
		1,1,2-Trichloroethane	79005		
		Trichloroethene	79016		
		Total Dioxins/Furans	1746016		
		2,3,7,8-HpCDD	37871004		
		2,3,7,8-HpCDF	38998753		
		2,3,7,8-HxCDD	34465468		
		2,3,7,8-HxCDF	55684941		
		OCDD	3268879		
		OCDF	39001020		
		2,3,7,8-PeCDD	36088229		
		1,2,3,7,8-PeCDF	57117416		
		2,3,4,7,8-PeCDF	57117314		
		2,3,7,8-TCDD	1746016		
		2,3,7,8-TCDF	5127319		
		Total PAHs	50328		
		Benz(a)anthracene	56553		
		Benzo(a)pyrene	50328		
		Benzo(b)fluoranthene	205992		
		Benzo(k)fluoranthene	207089		
		Chrysene	218019		
		Dibenz(a,h)anthracene	53703		
		Indeno(1,2,3-cd)pyrene	193395		
		Total PCBs	1336363		
		Aroclor 1016	12674112		
		Aroclor 1221	11104282		
		Aroclor 1232	11141165		
		Aroclor 1242	53469219		
		Aroclor 1248	12672296		
		Aroclor 1254	11097691		
		Aroclor 1260	11096825		
		Vinyl chloride	75014		
		Xylenes (Mixture)	1330207		
		p-Xylene	106423		
		m-Xylene	108383		
		o-Xylene	95476		

CAS = Chemical Abstract Service

[1] This list of chemicals, compounds, and radionuclides was compiled from COPCs retained as COCs in BRAs performed at PGDP between 1990 and 2013 (DOE 2015b).

One objective of this investigation is to determine the nature and extent of contamination in the soils to a depth of 10 ft bgs. For all source units, the initial focus of the investigation was surface and subsurface soil contamination to a depth of 4 ft bgs. If contamination at 4 ft bgs was found, then the subsurface soil to a depth of 10 ft bgs was investigated. Any contamination that was found to extend past the depths specified in this investigation will be addressed by another OU.

Remedial alternatives will be screened at the time the RAOs for the Soils OU are developed.

1.4 PROJECT SCHEDULE

Table 1.3 provides a planning schedule for the Soils OU. This schedule is an estimate for planning and is included here for informational purposes only and is not intended to establish enforceable schedules or milestones. Enforceable milestones are contained in Appendix C of the FFA or Appendix 5 of the SMP (DOE 2015b).

Table 1.3. Project Schedule for Soils OU RI and FS[1]

Activity	Milestone
Issue D1 RI 2 RI Report Addendum	March 25, 2016
Issue D1 FS	3rd quarter 2025
Issue D1 Proposed Plan	1st quarter 2026
Issue D1 Record of Decision (ROD)	3rd quarter 2026
Issue D1 Remedial Action Completion Report	September 30, 2030

[1] These are general planning dates for submittal of the CERCLA decision documents. Any extensions will impact the schedule. This schedule is included in this document for information purposes only and is not intended to establish enforceable schedules or milestones. Enforceable milestones, if any, will be established in the FFA or SMP and will be updated in accordance with Sections XXIX and/or XXXIX of the FFA.

1.5 REPORT ORGANIZATION

This addendum to the Soils OU RI 2 report was prepared following guidance found in Appendix D of the FFA for PGDP (EPA 1998) and is consistent with the elements found in Appendix B of the Work Plan (DOE 2010), but was modified to meet specific project requirements.

Chapter 1—Introduction
Chapter 2—Study Area Investigation
Chapter 3—Physical Characteristics of the Study Area
Chapter 4—Evaluation Approach
Chapter 5—SWMU 229

Following the outline of the preceding Soils OU RI 2 Report (DOE 2013), Chapter 5 contains the following information on SWMU 229:

- Background
- Fieldwork Summary
- Nature and Extent of Contamination—Surface Soils
- Nature and Extent of Contamination—Subsurface Soils
- Fate and Transport
- Baseline Human Health Risk Assessment

- Screening Ecological Risk Assessment
- Summary
- Conclusions

Chapter 6—Conclusions for the Soils OU Remedial Investigation
Chapter 7—References

Additionally, the following appendices are included to support the information presented in the text.

Appendix A—Technical Memorandum for Field Activities
Appendix B—Data Quality Analysis
Appendix C—Fate and Transport Modeling
Appendix D—Baseline Human Health Risk Assessment
Appendix E—Screening Ecological Risk Assessment
Appendix F—Analytical Data (CD)

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2. STUDY AREA INVESTIGATION

This section includes descriptions of field activities associated with site characterization of SWMU 229, which was conducted in accordance with the approved Work Plan (DOE 2010) and Addendum (DOE 2014a). A technical memorandum documenting details of field activities is included in Appendix A.

2.1 SOIL INVESTIGATIONS

When the Work Plan was being developed, existing/historical sampling information collected at and around PGDP over the course of the last several years was compiled and a searchable database of soil analytical results was included in Appendix B of the Soils OU RI Work Plan (DOE 2010) on a compact disk. Historical data were compiled from the resources listed in Table 2.1.

Table 2.1. Summary of Historical Information[1]

Year	Reference	Title
2003	DOE 2003a	Final Inventory/Characterization Report for the OS-18 Department of Energy Material Storage Area at the Paducah Gaseous Diffusion Plant

[1] Table adapted from DOE 2010.

A review of historical data for SWMU 229 was used to determine the following:

- SWMU COPCs,
- Extent and quality of existing data, and
- Sufficiency of data to support an FS for remedial options.

Where data were absent or insufficient to characterize the nature and extent of contamination and to support remedy selection, specific data gaps were identified. These data gaps were the basis for additional sampling. Contamination has been defined as concentrations exceeding background or any detected concentration if instrument reporting limits are higher than background values (DOE 2010). Sampling for SWMU 229 included a gamma radiological walkover and grid-based composite sampling.

Historical data, in addition to data collected during the 2010 investigation (Soils OU RI) and the 2015 investigation (Soils OU RI 2), were combined to form the entire data set used to evaluate SWMU 229. This data set will be used in the FS.

At SWMU 229 for which additional sampling was performed, one five-point composite over each 45-ft grid was collected for surface soils (0–1 ft bgs) and shallow subsurface soils (1–4 ft bgs). One grab sample was collected from the center of each grid with four additional grab samples collected 15 ft from the center point in each cardinal direction (north, south, east, and west) to make up the five-point composite. On alternating grids, grab samples were collected from the center of the grid and four additional grab samples collected 15 ft from the center point in each secondary direction (northeast, northwest, southeast, southwest) to make up the five-point composite.

Soil samples were collected from 0–1 ft and 1–4 ft in order to identify potential contaminant migration and exposure pathways, as directed by the Work Plan (DOE 2010). Soil samples then were analyzed by the field laboratory to determine if contingency samples were needed by comparing the field laboratory

results to the project action levels (PALs) listed in Table 2.2. The PALs were developed as a benchmark for contingency sampling only. Additional depth (4–7 ft and 7–10 ft bgs) and/or horizontal extent (step-out grid) sampling was required if the field laboratory results exceeded these levels. Locations of these soil samples are shown in figures for SWMU 229, along with summary tables of data in Chapter 5 of this addendum. Acreage and number of collected samples for SWMU 229 are found in Table 2.3.

Table 2.2. Field Analysis and Limits for Grid Sampling

Analyte	Project Quantitation Limit (mg/kg)	Industrial Worker ELCR = 1E-5 (mg/kg)[a]	Industrial Worker HI = 1 (mg/kg)[a]	PGDP Background (mg/kg)[b]	Project Action Limit (mg/kg)[c]
Arsenic	11	9.99	160	7.9	11
Chromium (total)	85	1,980	32,300	16	1,980
Copper	35	N/A	14,300	19	14,300
Iron	100	N/A	100,000[d]	28,000	100,000
Lead	13	N/A	800[e]	23	800
Manganese	85	N/A	515	820	820
Mercury (inorganic)	10	N/A	9	0.13	10
Molybdenum	15	N/A	1,790	N/A	1,790
Nickel	65	100,000[d]	430	21	430
Selenium	20	N/A	1,790	0.7	1,790
Silver	10	N/A	108	2.3	108
Uranium	20	224[f]	1,070	4.6	224
Vanadium	70	N/A	108	37	108
Zinc	25	N/A	100,000[d]	60	100,000
Total PCBs	5	28.6	N/A	N/A	28.6

N/A = not applicable.

[a] ELCR and hazard index (HI) values are derived from values presented in Table A.4 of the Risk Methods Document (DOE 2014b) and updated for use of the Kentucky-preferred dermal absorption values [Table B.5 (DOE 2014b)].

[b] PGDP background values are taken from Table A.12 of the Risk Methods Document (DOE 2014b), the lesser of surface and subsurface is presented.

[c] The PAL is the greater of background and the lesser of the ELCR-based and the HI-based value, unless unachievable by the quantitation limit. If unachievable, the project quantitation limit is used as the PAL.

[d] The screening value was reduced to an upper limit value (100,000 mg/kg) to remain consistent with the Risk Methods Document (DOE 2014b).

[e] The value for lead is the NAL presented in Table A.4 of the Risk Methods Document (DOE 2014b), this value was not adjusted to ELCR=1E-5 or HI=1, for the on-site industrial worker.

[f] The ELCR=1E-5 for uranium was calculated from the ELCR=1E-5 for U-238 (DOE 2014b) (i.e., 74.8 pCi/g × 3). The isotope of uranium with the greatest mass abundance in natural uranium metal is U-238 (99.3%). A common conversion to determine the mass of uranium metal present, when the uranium is at or near the isotopic abundance in natural uranium, is to multiply the U-238 activity concentration by 3. This conversion factor is based upon the specific activity of U-238 (3.3E5 pCi/g).

Table 2.3. SWMU 229 Composite Samples Collected

Composite Samples Collected*	Acres
36	0.849

*Total number of composite samples collected under both the Soils OU RI and Soils OU RI 2 field efforts. Radiological judgmental grab sample is not included in this table.

Split samples and replicates were obtained from the composite as necessary. Analyses for each composite sample consisted of field analysis of Resource Conservation and Recovery Act (RCRA) metals, plus uranium, by X-ray fluorescence (XRF) and Total PCB by PCB test kits. Ten percent of the samples had

fixed-base laboratory confirmation splits. The 10% included at least one surface and one shallow subsurface that was sampled. These fixed-base laboratory samples were randomly selected from all sample locations within the SWMU.

2.2 RECTIFICATION FROM ORIGINALLY PLANNED SAMPLE LOCATIONS

Site conditions did not necessitate modifications of the sampling strategy for SWMU 229.

2.3 QUALITY ASSURANCE/QUALITY CONTROL

Quality control (QC) was monitored throughout the RI process. QC included field sampling, laboratory analysis, and data management. QC for this addendum was evaluated in Chapter 2 of the Soils OU RI 2 Report (DOE 2015a). A review of data collected during the summer of 2010 as part of the Soils OU RI is included in Appendix B.

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3. PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This chapter presents the physical and ecological characteristics of PGDP and the region surrounding it. The discussion focuses on region- and PGDP-wide characteristics to support subsequent evaluations of the nature and extent and the fate and transport of contaminants exiting at SWMU 229.

This RI field effort focused on collection and analysis of soil samples to address deficiencies in the existing characterization of the nature and extent of contamination. These sampling and analytical activities yielded additional data for the soils in SWMU 229. The results of those activities have been incorporated into the SWMU-specific discussion.

3.1 SURFACE FEATURES

PGDP is located on a 3,556-acre DOE site approximately 10 miles west of Paducah, Kentucky, and 3.5 miles south of the Ohio River in the western part of McCracken County (Figure 3.1). The PGDP industrial area occupies approximately 650 acres of the DOE site, surrounded by an additional 689-acre buffer zone. DOE licenses most of the remaining acreage to the Commonwealth of Kentucky as part of the West Kentucky Wildlife Management Area (WKWMA). Tennessee Valley Authority (TVA) Shawnee Fossil Plant borders the DOE site to the northeast, between PGDP and the Ohio River.

Three small communities are situated within three miles of the DOE property boundary: Heath and Grahamville to the east and Kevil to the southwest. The next closest municipality is Metropolis, Illinois, five miles to the northeast of PGDP on the north side of the Ohio River.

The dominant topographic features in the area of PGDP are nearly level to gently sloping dissected plains and the flood plain of the Ohio River. Local elevations range from 290 ft above mean sea level (amsl) along the Ohio River to 450 ft amsl southwest of PGDP. Ground surface elevations vary from 360 ft to 390 ft amsl within the PGDP boundary, where SWMU 229 is located. Generally, the topography in the PGDP area slopes toward the Ohio River at an approximate gradient of 27 ft per mile (CH2M HILL 1992).

3.2 METEOROLOGY

The National Weather Service office at Barkley Regional Airport (located four miles to the southeast of PGDP) documents hourly meteorological measurements. Current and historical meteorological information regarding temperature, precipitation, and wind speed/direction are available from the National Oceanic and Atmospheric Administration's (NOAA's) National Climatic Data Center.

The climate of the PGDP region is humid-continental. Summers are warm (July averages 79°F) and winters are moderately cold (January averages 35°F). PGDP experiences a yearly surplus of precipitation versus evapotranspiration. The 30-year average monthly precipitation for the period 1961 through 1990 is 4.11 inches, varying from an average of 3.00 inches in October (the monthly average low) to an average of 5.01 inches in April (the monthly average high). Monthly estimates of evapotranspiration using the Thornthwaite method (Thornthwaite and Mather 1957) equal or exceed average rainfall for the period May through September (season of no net infiltration).

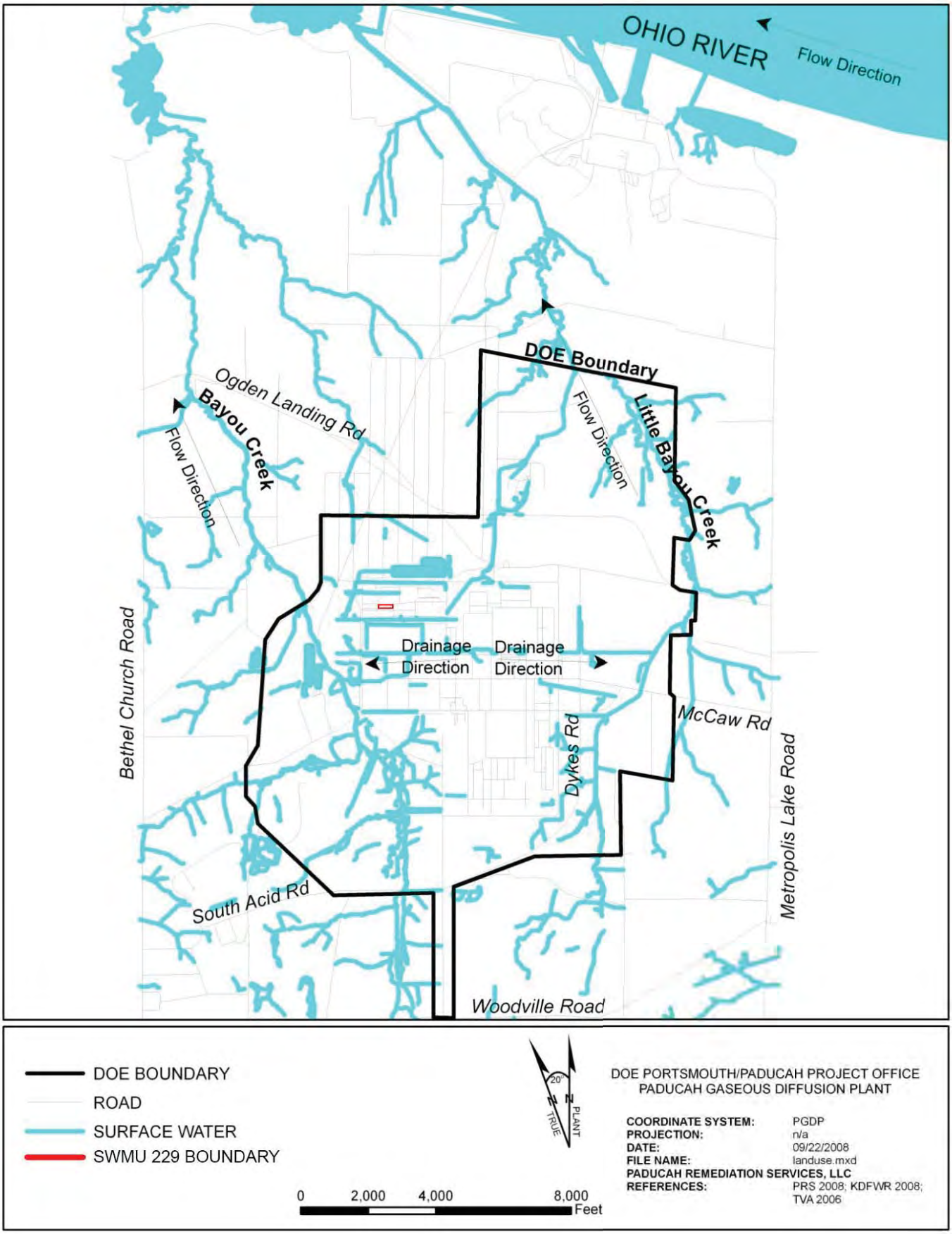

Figure 3.1. Surface Water Features in the Vicinity of the DOE Site

Heavy rainfall associated with thunderstorms or low-pressure systems occurs occasionally at PGDP. Table 3.1 presents the predicted storm recurrence intervals for PGDP (Dupont and Allen 2000).

Table 3.1. Rainfall Intensity as a Function of Recurrence Interval and Storm Duration for Western Kentucky

	Recurrence Interval (years)					
Storm Duration (minutes)	2	5	10	25	50	100
	Precipitation (inches per hour)					
5	11.80	16.69	19.98	24.19	27.33	30.46
10	7.02	9.44	11.05	13.09	14.61	16.11
15	5.20	6.82	7.90	9.25	10.26	11.26
20	4.20	5.43	6.25	7.27	8.04	8.79
30	3.12	3.96	4.52	5.22	5.74	6.25
60	1.89	2.34	2.64	3.02	3.31	3.59
80	1.54	1.89	2.13	2.43	2.65	2.87
100	1.30	1.61	1.81	2.05	2.24	2.43
120	1.15	1.41	1.58	1.80	1.96	2.12
1,440	0.20	0.26	0.30	0.34	0.38	0.41

The prevailing wind is from the south-southwest at approximately 10 miles per hour. Historically, stronger winds are recorded when the winds are from the southwest.

3.3 SURFACE WATER HYDROLOGY

PGDP is situated in the western portion of the Ohio River basin, 15 miles downstream of the confluence of the Ohio River with the Tennessee River and 35 miles upstream of the confluence of the Ohio River with the Mississippi River. The Ohio River is located approximately 3.5 miles north of PGDP. It is the most significant surface water feature in the region, carrying over 25 billion gal/day of water through its channel. A U.S. Geological Survey (USGS) gaging station at Metropolis, Illinois (USGS 03611500), monitors the Ohio River stage near PGDP. River stage typically varies between 290 ft and 328 ft amsl over the course of a year. Water levels on the lower Ohio River generally are highest in winter and early spring and lowest in late summer and early fall. The entire PGDP is above the historical high water floodplain of the Ohio River (CH2M HILL 1991) and above the local 100-year flood elevation of the Ohio River (333 ft). [The highest Ohio River stage recorded at Metropolis, Illinois (February 2, 1937) was 343 ft.]

The plant overlies the divide between Bayou and Little Bayou Creeks (Figure 3.1). Bayou Creek is a perennial stream on the western boundary of the plant that flows generally northward, from approximately 2.5 miles south of the plant site to the Ohio River along a 9-mile course. Little Bayou Creek is an intermittent stream located on the eastern boundary of the plant; its drainage originates within WKWMA and extends northward along a 6.5-mile course, which joins Bayou Creek near the Ohio River. Most of the flow within Bayou and Little Bayou Creeks is from surface water runoff from PGDP. Networks of ditches discharge effluent and surface water runoff from PGDP to the creeks. Any surface water migrating from SWMU 229 would join into Bayou Creek because SWMU 229 is located in the northwest corner of PGDP. Contributions from PGDP comprise approximately 85% of the base flow within Bayou Creek and 100% of the base flow within Little Bayou Creek.

Multiple groundwater aquifers underlie PGDP (see Section 3.6 for a discussion of PGDP hydrogeology). The shallowest aquifers occur in the Continental Deposits and the McNairy Formation, both of which discharge into the Ohio River north of PGDP. (The shallow groundwater system beneath SWMU 229

occurs in the Continental Deposits.) A large, downward, vertical hydraulic gradient within the Upper Continental Deposits, which represents an aquitard, typically limits the amount of groundwater discharge to the ditches of PGDP and adjacent creeks. Gaining reaches in the creeks are found on Bayou Creek south of PGDP and on Little Bayou Creek to the north of PGDP where it meets the Ohio River flood plain. Both creeks have gaining reaches adjacent to the Ohio River.

Other surface water bodies in the vicinity of PGDP include several small ponds, inactive clay and gravel pits, and settling basins scattered throughout the PGDP plant area; a marshy area just south of the confluence of Bayou Creek and Little Bayou Creek; ash settling ponds of the Shawnee Fossil Plant; and Metropolis Lake, located east of the Shawnee Fossil Plant.

3.4 GEOLOGY

PGDP lies within the Jackson Purchase region of western Kentucky, which represents the northern tip of the Mississippi Embayment portion of the Coastal Plain Province. The stratigraphic sequence in the region consists of Cretaceous, Tertiary, and Quaternary sediments unconformably overlying Paleozoic bedrock (Figure 3.2). The following sections describe the primary geologic units of the PGDP region.

3.4.1 Bedrock

Mississippian carbonates, composed of dark gray limestone with some interbedded chert and shale, underlie the entire PGDP area at an approximate depth of 300 ft to 340 ft.

3.4.2 Rubble Zone

Deep soil borings at PGDP commonly encounter a rubble zone of chert gravel at the top of the bedrock. The age and continuity of the rubble zone remain undetermined.

3.4.3 McNairy Formation

The McNairy Formation consists of Upper Cretaceous, fine clastic sediments. At PGDP, the upper and middle members of the McNairy Formation are typically grayish-white to dark-gray, micaceous silt and clay interbedded with gray to yellow, very fine- to fine-grained sand. The middle (Levings) member tends to contain fewer sand interbeds. The basal McNairy member at PGDP is primarily a light gray, very fine to fine sand.

3.4.4 Porters Creek Clay/Porters Creek Terrace Slope

Paleocene age Porters Creek Clay underlies the southern portions of the DOE site and consists of dark gray to black silt with varying amounts of clay and fine-grained, micaceous, commonly glauconitic, sand. The Porters Creek Clay subcrops along a buried terrace slope that extends east–west under the south end of the PGDP industrial area. This subcrop is the northern limit of Porters Creek Clay and the southern limit of the Pleistocene Lower Continental Deposits under PGDP. SWMU 229 lies north of the subcrop of the Porters Creek Clay.

3.4.5 Eocene Sands

Eocene sands occur south of PGDP (and south of SWMU 229) above the Porters Creek Clay. This unit includes undifferentiated quartz sands and interbedded and interlensing silts and clays of the Claiborne Group and Wilcox Formation (Olive 1980). The Eocene sands thicken to the south of PGDP.

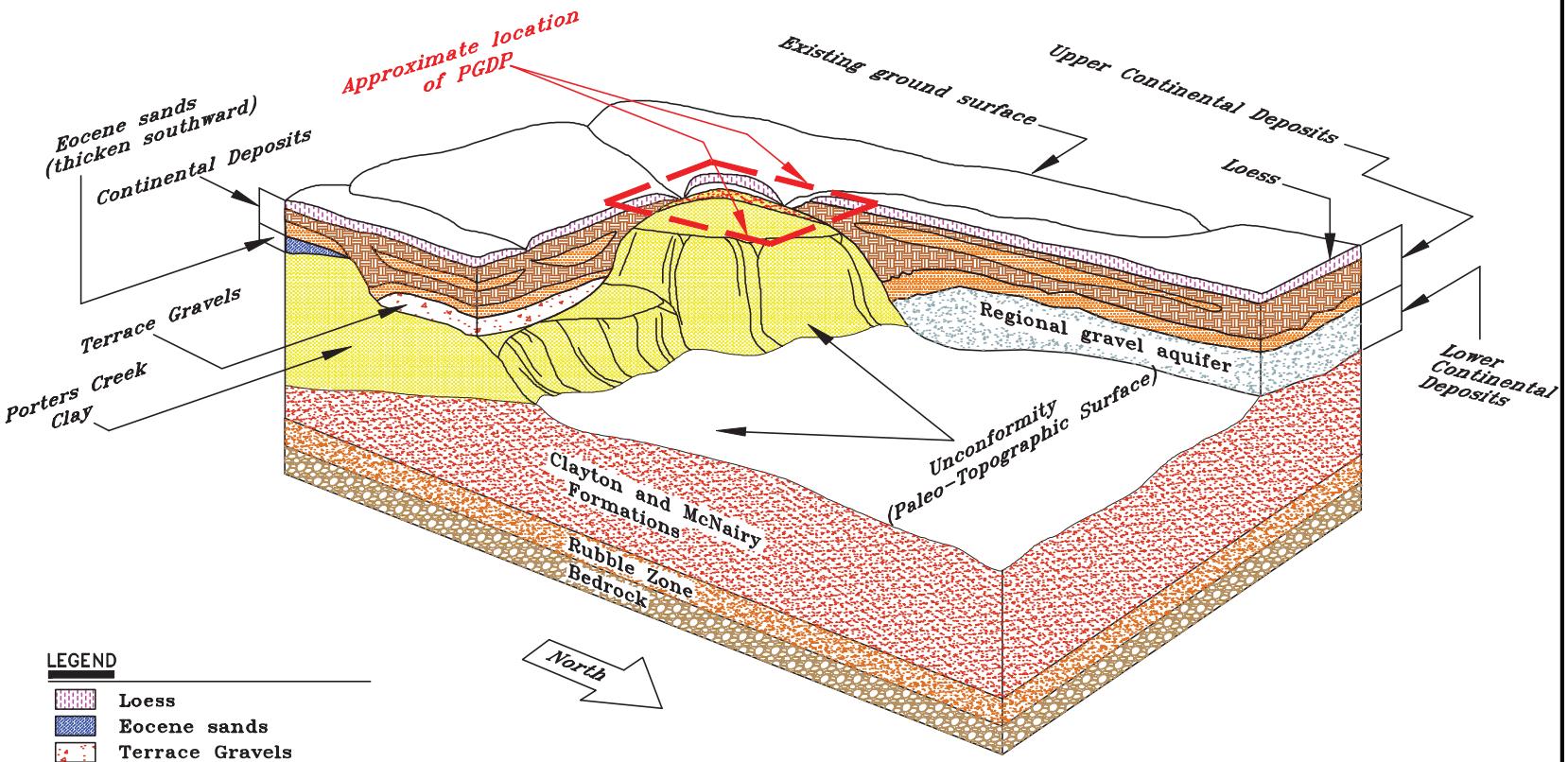

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Figure 3.2. PGDP Stratigraphic Sections

3.4.6 Continental Deposits

Continental sediments [Pliocene(?)[3] to Pleistocene age] unconformably overlie the Cretaceous through Eocene strata throughout the area. These continental sediments were deposited on an irregular erosional surface consisting of several terraces. The thicker Continental Deposits sections represent Pleistocene valley fill sediments that comprise a fining-upward cycle. The continental sediments have been divided into the two distinct facies described below.

(1) Lower Continental Deposits. The Lower Continental Deposits is a gravel facies consisting of chert, ranging from pebbles to cobbles, in a matrix of poorly sorted sand and silt. Gravels of the Lower Continental Deposits overlie three distinct terraces in the PGDP area.

- The upper terrace Lower Continental Deposits consists of Pliocene(?) gravel units, ranging in thickness from near 0 ft to 30 ft, occurring in the southern portion of the DOE site and south of SWMU 229 at elevations greater than 350 ft amsl. This gravel unit overlies the Eocene sands and Porters Creek Clay (where the Eocene sands are missing).

- Pliocene(?) gravels of the Lower Continental Deposits also occur on an intermediate terrace eroded into the Porters Creek Clay at an elevation of approximately 320 ft to 345 ft amsl in the southeastern and eastern portions of the DOE site and southeast of SWMU 229. The thickness of this unit typically ranges from 15 ft to 20 ft.

- The Lower Continental Deposits of the upper and intermediate terraces are collectively referred to as the Terrace Gravel.

- The third and most prominent of the three Lower Continental Deposits members consists of a Pleistocene gravel deposit resting on an erosional surface at an elevation of approximately 280 ft amsl. This gravel underlies SWMU 229 and most of the plant area and the region to the north, but pinches out under the south side of PGDP along the subcrop of the Porters Creek Clay. The Pleistocene member of the Lower Continental Deposits averages approximately 30 ft in thickness. Trends of greater thickness, as much as 50 ft, fill deeper scour channels that trend east–west beneath the site.

(2) Upper Continental Deposits. The Upper Continental Deposits are a Pleistocene age, fine-grained clastics facies that commonly overlies the Lower Continental Deposits. This unit commonly ranges in thickness from 15 ft to 55 ft and is approximately 60 ft-thick beneath SWMU 229. The Upper Continental Deposits includes three general horizons beneath PGDP: (1) an upper silt and clay interval, (2) an intermediate interval of common sand and gravel lenses (sand and gravel content generally diminishes northward), and (3) a lower silt and clay interval. The upper silt and clay interval consists of the Peoria Loess and Roxana Silt (DOE 2003b; WLA 2006). The Peoria Loess and Roxana Silt blanket the entire PGDP area.

3.5 SOILS

The surficial deposits found in the vicinity of PGDP are Pleistocene loess and Holocene alluvium. Both units commonly consist of clayey silt or silty clay and range in color from yellowish-brown to brownish-gray or tan, making field differentiation difficult. The general soil map for Ballard and McCracken Counties delineates three soil associations within the vicinity of PGDP: the Rosebloom-Wheeling-Dubbs association, the Grenada-Calloway association, and the Calloway-Henry association (USDA 1976).

[3] A question mark indicates uncertain age.

In the immediate PGDP area, the predominant soil is the Henry soil series of the Calloway-Henry association, which consists of nearly level, somewhat poorly to poorly drained, medium-textured soils on upland positions. The Henry soil series contains poorly drained, acidic soils that have a fragipan. Henry soils typically have moderate permeability above the fragipan and low permeability within the fragipan. Permeability in the fragipan is less than 0.4 ft/day (DOE 1998). It should be noted that soils within the industrial area of PGDP, including SWMU 229, could be classified as "urban" since they have been impacted by human influence and many of the original characteristics have been lost.

Several other soil groups also occur in limited areas of the region, including the Grenada, Falaya-Collins, Waverly, Vicksburg, and Loring.

3.6 HYDROGEOLOGY

The significant geologic units relative to shallow groundwater flow at PGDP include the Terrace Gravel and Porters Creek Clay (south part of the DOE site) and the Pleistocene Continental Deposits and McNairy Formation (underlying PGDP and adjacent areas to the north). Groundwater flow in the Pleistocene Continental Deposits is a primary pathway for transport of dissolved contamination from PGDP and the SWMU 229 area. The following paragraphs provide the framework of the shallow groundwater flow system at PGDP.

(1) Terrace Gravel Flow System. The Porters Creek Clay is a confining unit to downward groundwater flow south of the PGDP industrial area. A shallow water table flow system is developed in the Terrace Gravel, where it overlies the Porters Creek Clay south of SWMU 229 and the PGDP industrial area. Discharge from this water table flow system provides baseflow to Bayou Creek and underflow to the Pleistocene Continental Deposits to the east of PGDP.

The elevation of the top of the Porters Creek Clay is an important control to the area's groundwater flow trends. A distinct groundwater divide is centered in hills located approximately 9,000 ft southwest of the PGDP industrial area, where the Terrace Gravel and Eocene sands overlie a "high" on the top of the Porters Creek Clay. In adjacent areas where the top of the Porters Creek Clay approaches land surface, as it does south of PGDP and near the subcrop of the Porters Creek Clay to the west of the industrial complex, the majority of groundwater flow is forced to discharge into surface streams (gaining reaches) and little underflow occurs into the Pleistocene Continental Deposits. To the east of PGDP, the Terrace Gravel overlies a lower terrace eroded into the top of the Porters Creek Clay. In this area, a thick sequence of Terrace Gravel occurs adjacent to the Pleistocene Continental Deposits, allowing significant underflow from the Terrace Gravel. Surface drainages in this area are typically loosing reaches. Figure 3.3 presents hydraulic potential trends for the Terrace Gravel flow system.

(2) Upper Continental Recharge System (UCRS). The upper strata, where infiltration of water from the surface occurs and where the uppermost zone of saturation exists, in the Upper Continental Deposits (beneath SWMU 229 and PGDP and the contiguous land to the north) is called the UCRS. Groundwater flow is primarily downward in the Upper Continental Deposits. A plot of elevation of water level versus midpoint of well screen for UCRS wells at PGDP (Figure 3.4) demonstrates that steep vertical hydraulic gradients are characteristic of the UCRS. Vertical hydraulic gradients generally range from 0.5 to 1 ft/ft where measured by wells completed at different depths in the UCRS. Vertical gradients are 1 to 2 orders of magnitude greater than lateral hydraulic gradients. While groundwater flow is predominantly downward, there will be some lateral flow due to heterogeneities in the shallow soils. Water level measurements in MW190, located west of SWMU 229, indicate that vertical gradients may be lower in the area of SWMU 229 than is typical of the UCRS.

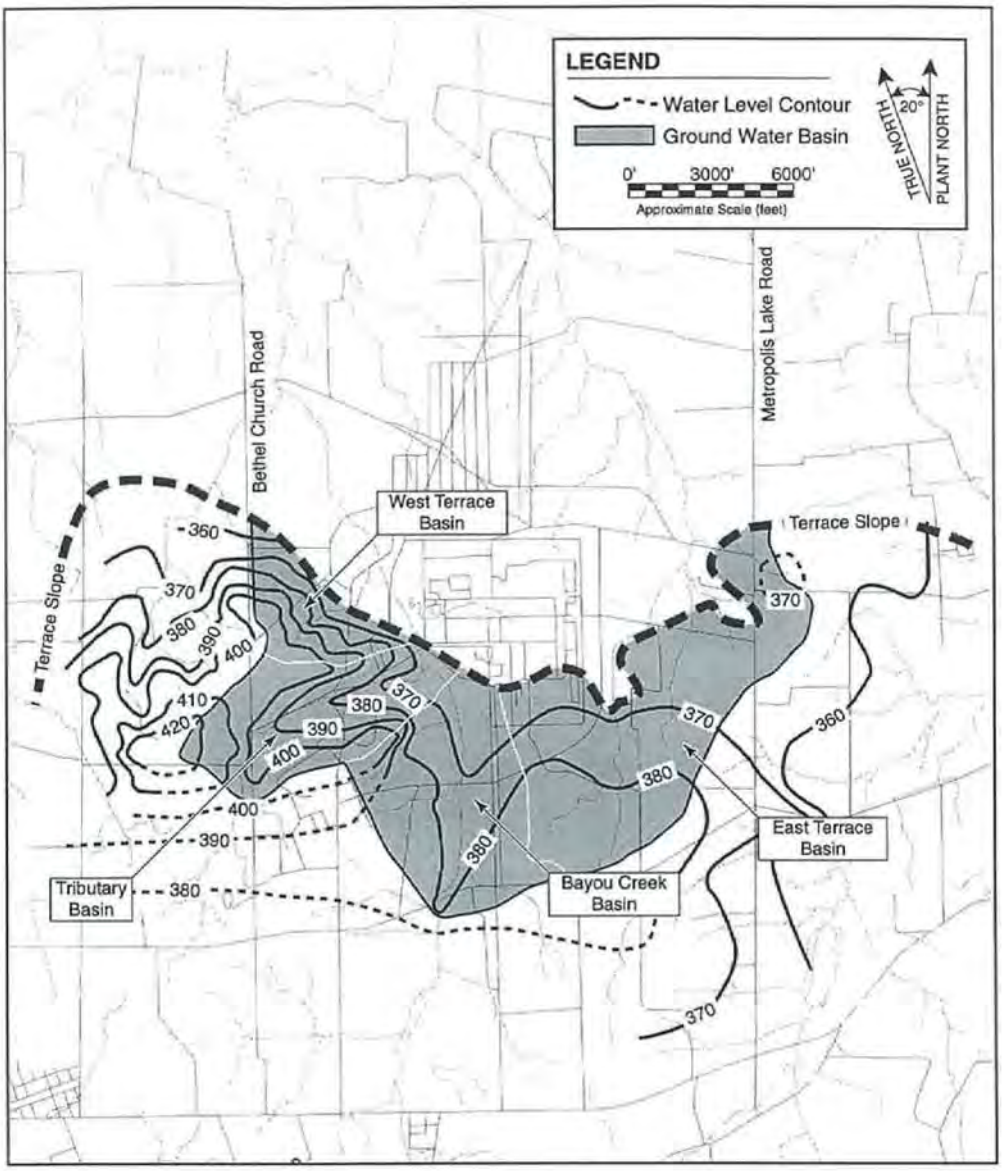

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Figure 3.3. Water Table Trends in the Terrace Deposits South of the PGDP

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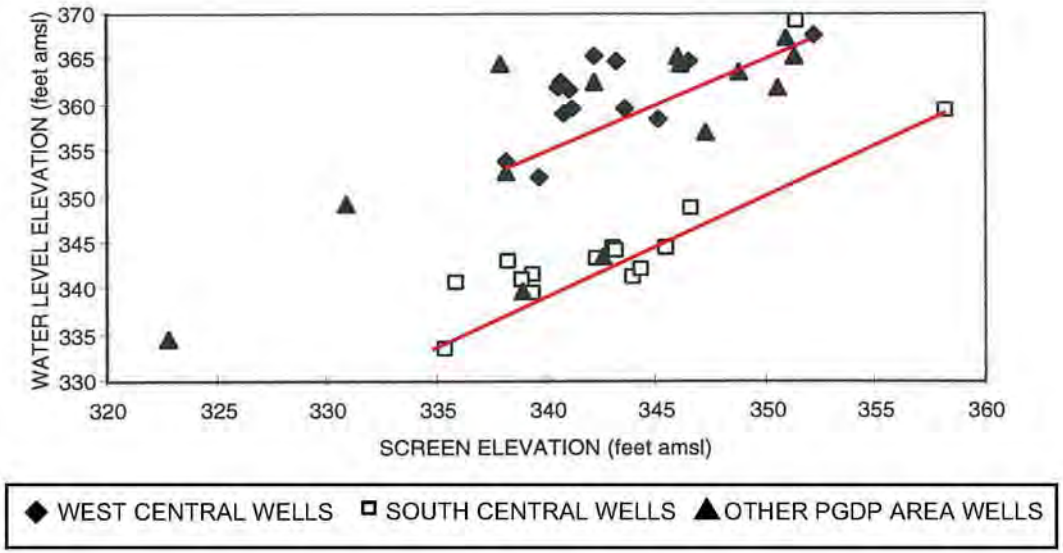

Figure 3.4. Plot of Water Level versus Well Screen for Upper Continental Recharge System Wells

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The infiltration rate for the PGDP area is approximately 6.6 inches/yr based on site-specific groundwater modeling. This 6.6 inches/yr applied over the area of the industrial area of the plant yields approximately 0.4 mgd of recharge to the shallow groundwater system. Leakage from plant water utilities, ditches, lagoons, and cooling tower basins is suspected to be another important source of infiltration at PGDP. Water use for PGDP for calendar year 2006 averaged 13 mgd. Municipal water systems lose as much as 24% of the daily conveyance (Jowitt and Xu 1990). A similar loss of the PGDP system would equal 3.1 mgd. Since the UCRS groundwater flow is predominantly downward, areas with higher anthropogenic recharge create mounding of hydraulic head in the RGA that can affect contaminant transport. Because the hydraulic conductivity in the RGA on-site is relatively large, the mounding is only slight (often less than 1 ft) and difficult to measure.

(3) RGA. Vertically infiltrating water from the UCRS moves downward into a basal sand member of the Upper Continental Deposits and the Pleistocene gravel member of the Lower Continental Deposits and then laterally north toward the Ohio River. This lateral flow system is called the RGA. The RGA is the shallow aquifer beneath SWMU 229 and PGDP and contiguous lands to the north. Groundwater of the RGA meets requirements of a Class II groundwater as delineated in *Guidelines for Ground-Water Classification under the EPA Ground-Water Protection Strategy* (EPA 1988).

Hydraulic potential in the RGA declines toward the Ohio River, which is the control of base level of the region's surface water and groundwater systems. The RGA potentiometric surface gradient beneath PGDP is commonly 10^{-4} ft/ft, but increases by an order of magnitude near the Ohio River. (Vertical gradients are not well documented, but small.)

The hydraulic conductivity of the RGA varies spatially. Pumping tests have documented the hydraulic conductivity of the RGA ranges from 53 ft/day to 5,700 ft/day. East-to-west flow of the ancestral Tennessee River, which laid down the Pleistocene Continental Deposits gravel member, tended to orient permeable gravel and sand lenses east-west. Thus, with the hydraulic head in the RGA generally decreasing northward toward the Ohio River, groundwater flow trends to the northeast and northwest from PGDP in response to the anisotropy of the hydraulic conductivity as well as the anthropogenic recharge, which is greatest in the industrial portion of the plant. Anthropogenic recharge from waterline leaks, lagoons, cooling tower basins, and other sources provides the primary driving force in moving groundwater in northeastern and northwestern flow directions from the industrial plant area. Ambient groundwater flow rates in the more permeable pathways of the RGA commonly range from 1 to 3 ft/day.

Previous work has shown that the primary pathway for groundwater flow and the site-related contaminants is vertical migration through the UCRS, followed by lateral migration in the RGA. The two primary groundwater plume contaminants at PGDP are trichloroethene and Tc-99. Interpretation of the location of these plumes is updated on a regular basis with the addition of groundwater analytical data from various projects at the site. Figures 3.5 and 3.6 illustrate the plume maps presented in the calendar year 2012 plume map update (LATA Kentucky 2013). Monitoring wells used to generate the plume maps are plotted on the figures.

(4) McNairy Flow System. Groundwater flow in the fine sands and silts of the McNairy Formation is called the McNairy Flow System. The overall McNairy groundwater flow direction in the area of PGDP is northward to the Ohio River, similar to that of the RGA. Hydraulic potential is greater in the RGA than in the McNairy Flow System beneath PGDP. Area monitoring well clusters document an average downward vertical gradient of 0.03 ft/ft. Because the RGA has a steeper hydraulic potential slope toward the Ohio River than does the McNairy Flow System, the vertical gradient reverses nearer the Ohio River. [The "hinge line," which is where the vertical hydraulic gradient between the

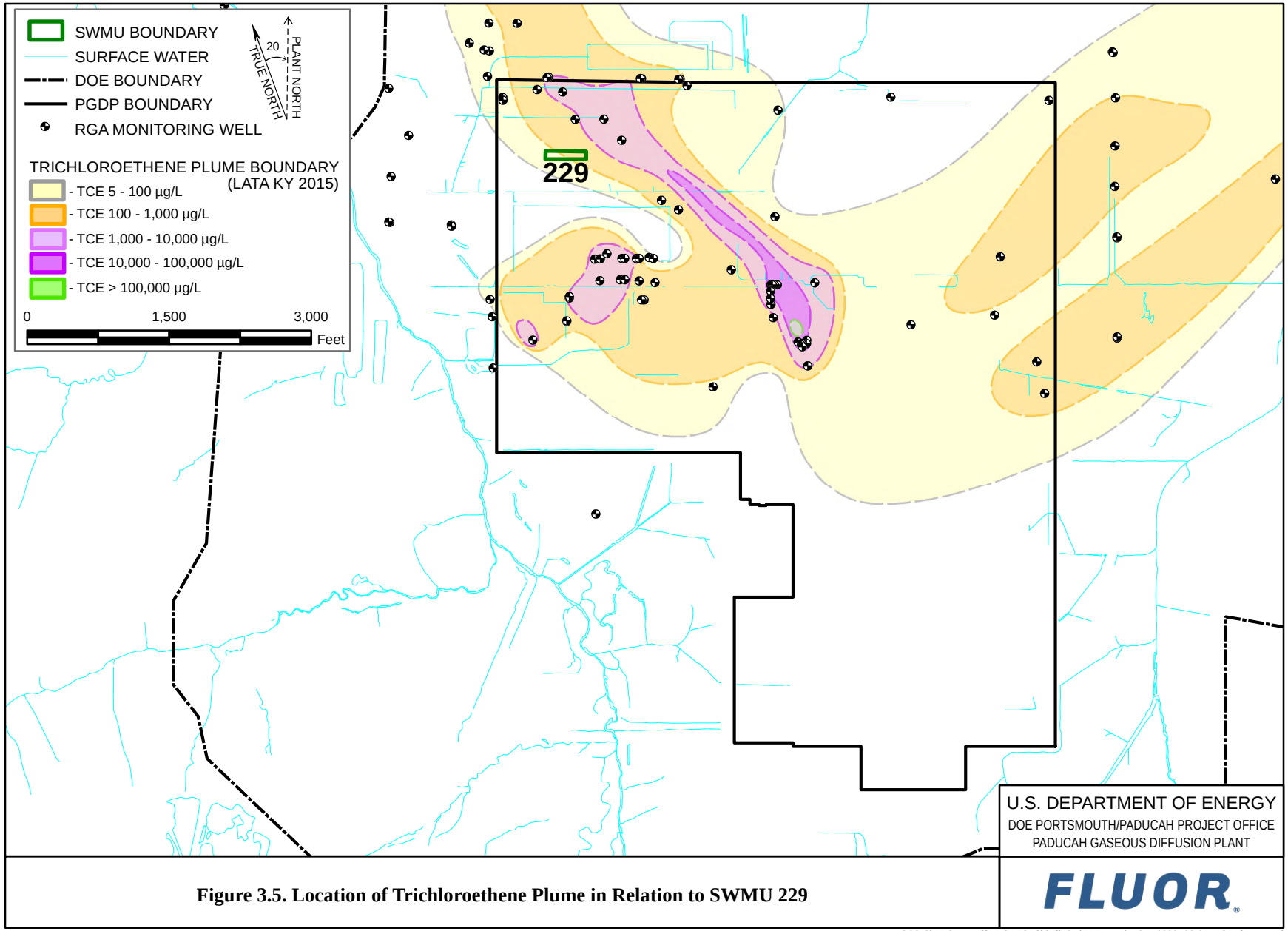

Figure 3.5. Location of Trichloroethene Plume in Relation to SWMU 229

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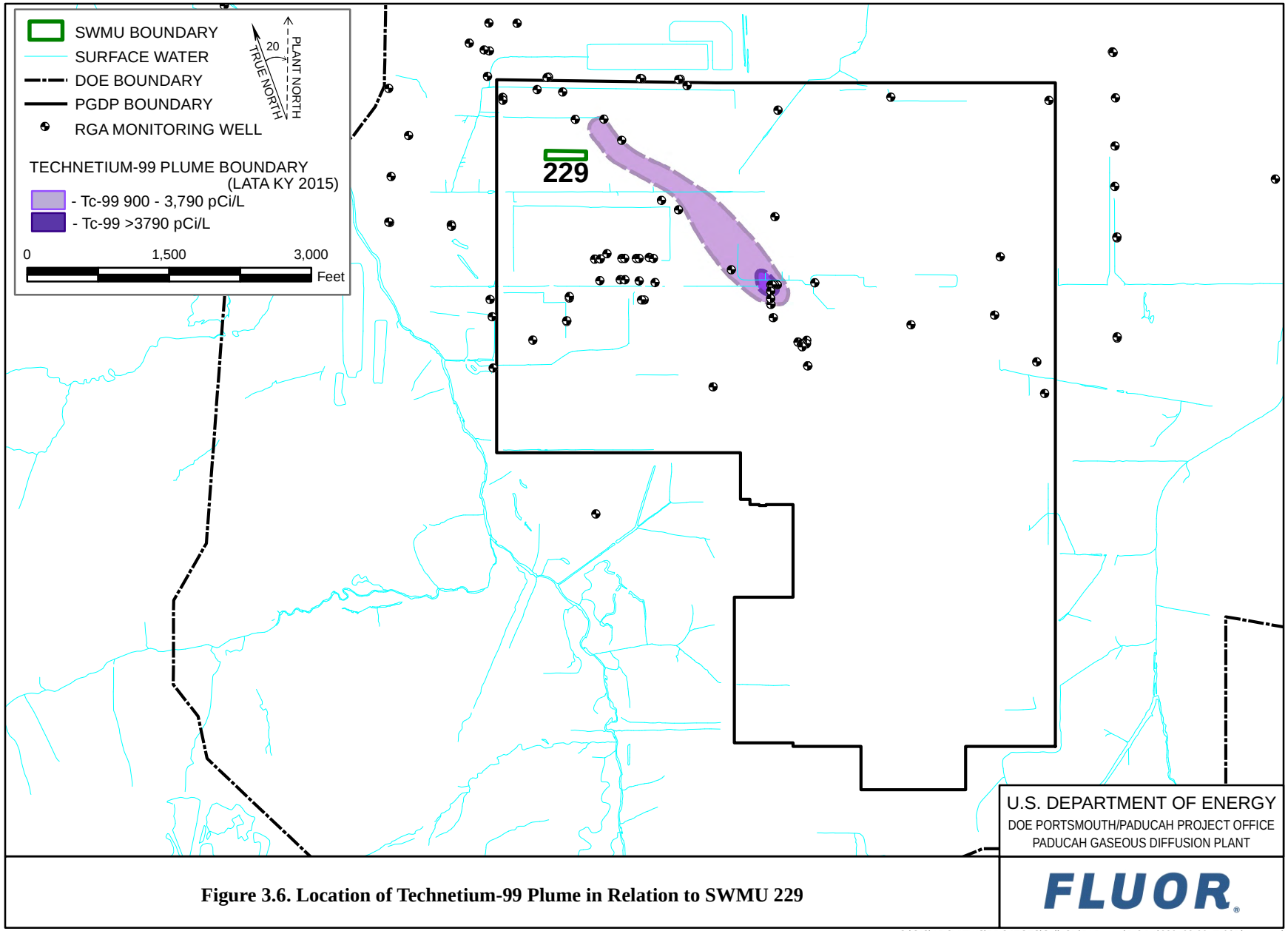

Figure 3.6. Location of Technetium-99 Plume in Relation to SWMU 229

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RGA and McNairy Flow System changes from a downward vertical gradient to an upward vertical gradient, parallels the Ohio River near the northern DOE property boundary (LMES 1996).]

The contact between the Lower Continental Deposits and the McNairy Formation is a marked hydraulic properties boundary. Representative lateral and vertical hydraulic conductivities of the upper McNairy Formation in the area of PGDP are approximately 0.02 ft/day and 0.0005 ft/day, respectively. Vertical infiltration of groundwater into the McNairy Formation beneath PGDP is on the order of 0.1 inch per year. (Lateral flow in the McNairy Formation beneath PGDP is on the order of 0.03 inch per year.) As a result, little interchange occurs between the RGA and McNairy Flow System.

Hydrogeologic Units

Five hydrogeologic units (HUs) commonly are used to discuss the shallow groundwater flow system beneath the DOE site and the contiguous lands to the north (Figure 3.7). HUs 1 through 5 underlie SWMU 229. In descending order, the HUs are described as follows:

- Upper Continental Deposits
  - HU 1 (UCRS): Loess that covers the entire site.
  - HU 2 (UCRS): Discontinuous sand and gravel lenses in a clayey silt matrix. In some areas of the plant, the HU2 interval consists of an upper sand and gravel member (HU2A) and a lower sand and gravel member (HU2B) separated by a thin silt unit.
  - HU 3 (UCRS): Relatively impermeable unit that acts as the upper semiconfining-to-confining layer for the RGA. The lithologic composition of HU3 varies from clay to fine sand, but is predominantly silt and clay.
  - HU 4 (RGA): Near-continuous sand unit with a clayey silt matrix that forms the top of the RGA.
- Lower Continental Deposits
  - HU 5 (RGA): Gravel, sand, and silt.

3.7 DEMOGRAPHY AND LAND USE

The WKWMA and some sparsely populated agricultural lands surround PGDP. Historically, the economy of western Kentucky had been based on agriculture, although there has been increased industrial development in recent years. The population of McCracken County, Kentucky is approximately 66,000 (DOC 2013). The major city in McCracken County is Paducah, Kentucky, whose population is approximately 25,000 (DOC 2013). Three small communities are located within 3 miles of the DOE property boundary at PGDP: Heath and Grahamville to the east and Kevil to the southwest.

The population within a 50-mile radius of PGDP is about 534,000 according to the 2010 census. Within a 10-mile radius of PGDP, the population is about 89,000 (ESRI 2012).

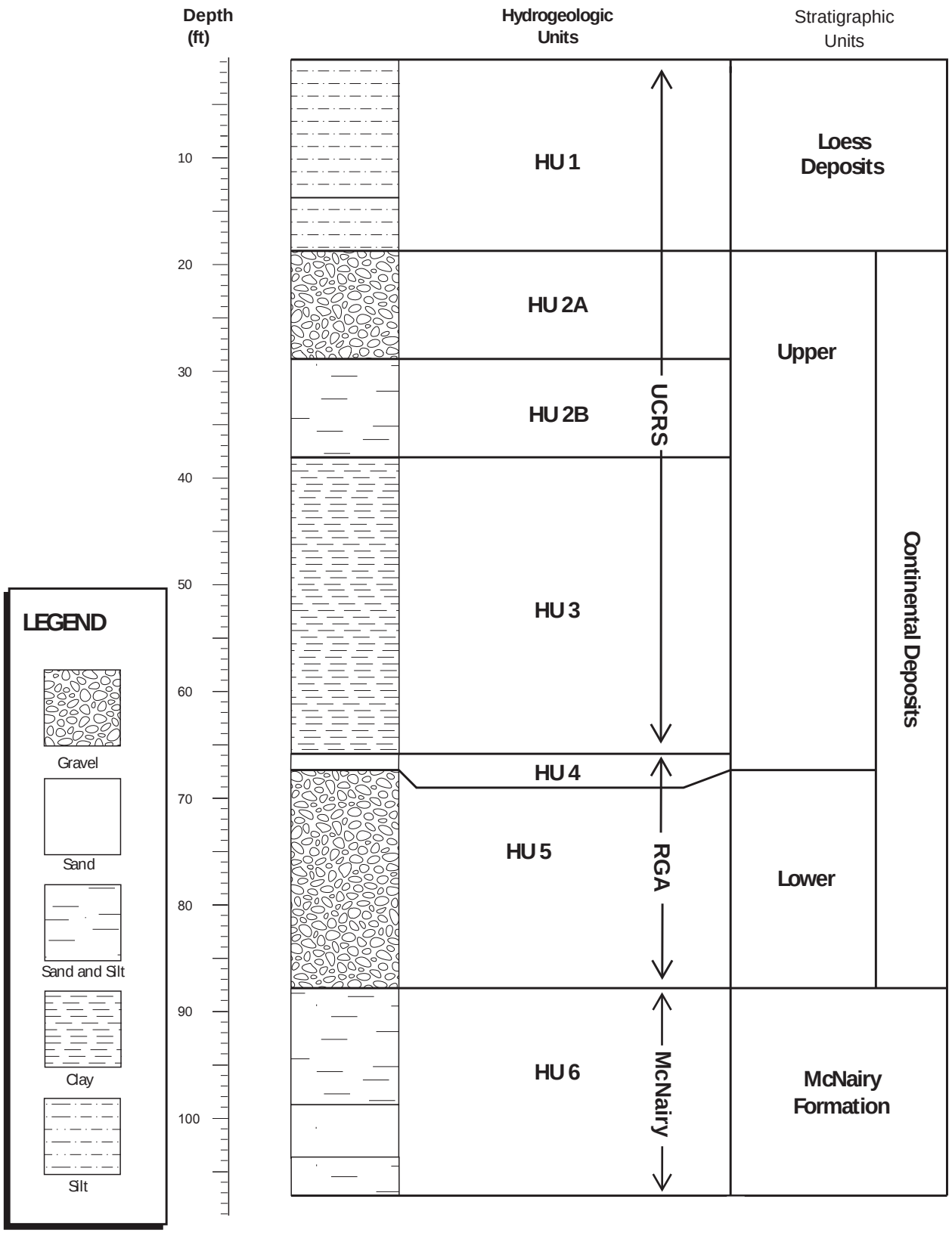

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Figure 3.7. Example Stratigraphic and Hydrogeologic Units

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In addition to the residential population surrounding the plant, WKWMA draws thousands of visitors each year for recreational purposes. Visitors use the area primarily for hunting and fishing, but other activities include horseback riding, hiking, and bird watching. An estimated 7,500 fishermen visit the area each year (DOE 2015b).

For the PGDP area, current and reasonably anticipated future land use is depicted in the SMP, as shown in Figures 3.8 and 3.9 (DOE 2015b).

3.8 ECOLOGY

The following sections give a brief overview of the terrestrial and aquatic systems at PGDP. A more detailed description, including identification and discussion of sensitive habitats and threatened/endangered species, is contained in the *Investigation of Sensitive Ecological Resources Inside the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (CDM Federal 1994) and *Environmental Investigations at the Paducah Gaseous Diffusion Plant and Surrounding Area, McCracken County, Kentucky, Volume V: Floodplain Investigation, Part A: Results of Field Survey* (COE 1994).

3.8.1 Terrestrial Systems

The terrestrial component of the PGDP ecosystem includes the plants and animals that use the upland habitats for food, reproduction, and protection. Upland vegetative communities in the vicinity of PGDP consist primarily of grassland, forest, and thicket habitats with agricultural areas. The main crops grown in the PGDP area include soybeans, corn, tobacco, and sorghum.

Most of the area in the vicinity of PGDP has been cleared of vegetation at some time. PGDP mows much of the grassland habitat adjacent to the plant. The Kentucky Department of Fish and Wildlife Resources manages a large percentage of the adjacent WKWMA to promote native prairie vegetation by burning, mowing, and various other techniques.

Dominant overstory species of the forested areas include oaks, hickories, maples, elms, and sweetgum. Understory species include snowberry, poison ivy, trumpet creeper, Virginia creeper, and Solomon's seal. Thicket areas consist predominantly of maples, black locust, sumac, persimmon, and forest species in the sapling stage with herbaceous ground cover similar to that of the forest understory.

Wildlife commonly found in the PGDP area consists of species indigenous to open grassland, thicket, and forest habitats. Small mammal surveys conducted on WKWMA documented the presence of southern short-tailed shrew, prairie vole, house mouse, rice rat, and deer mouse (KSNPC 1991). Large mammals commonly present in the area include coyote, eastern cottontail, opossum, groundhog, whitetail deer, raccoon, and gray squirrel. Mist netting activities in the area have captured red bat, little brown bat, Indiana bat, northern long-eared bat, evening bat, and eastern pipistrelle (KSNPC 1991).

The typical birds of the area are European starling, cardinal, red-winged blackbird, mourning dove, bobwhite quail, turkey, killdeer, American robin, eastern meadowlark, eastern bluebird, blue jay, red-tail hawk, and great horned owl.

Amphibians and reptiles present in the PGDP area include cricket frog, Fowler's toad, common snapping turtle, green tree frog, chorus frog, southern leopard frog, eastern fence lizard, and red-eared slider (KSNPC 1991). Additionally, snakes, skinks, and salamanders have been observed in the PGDP area according to the Kentucky Department of Fish and Wildlife Resources (KDFWR 2015).

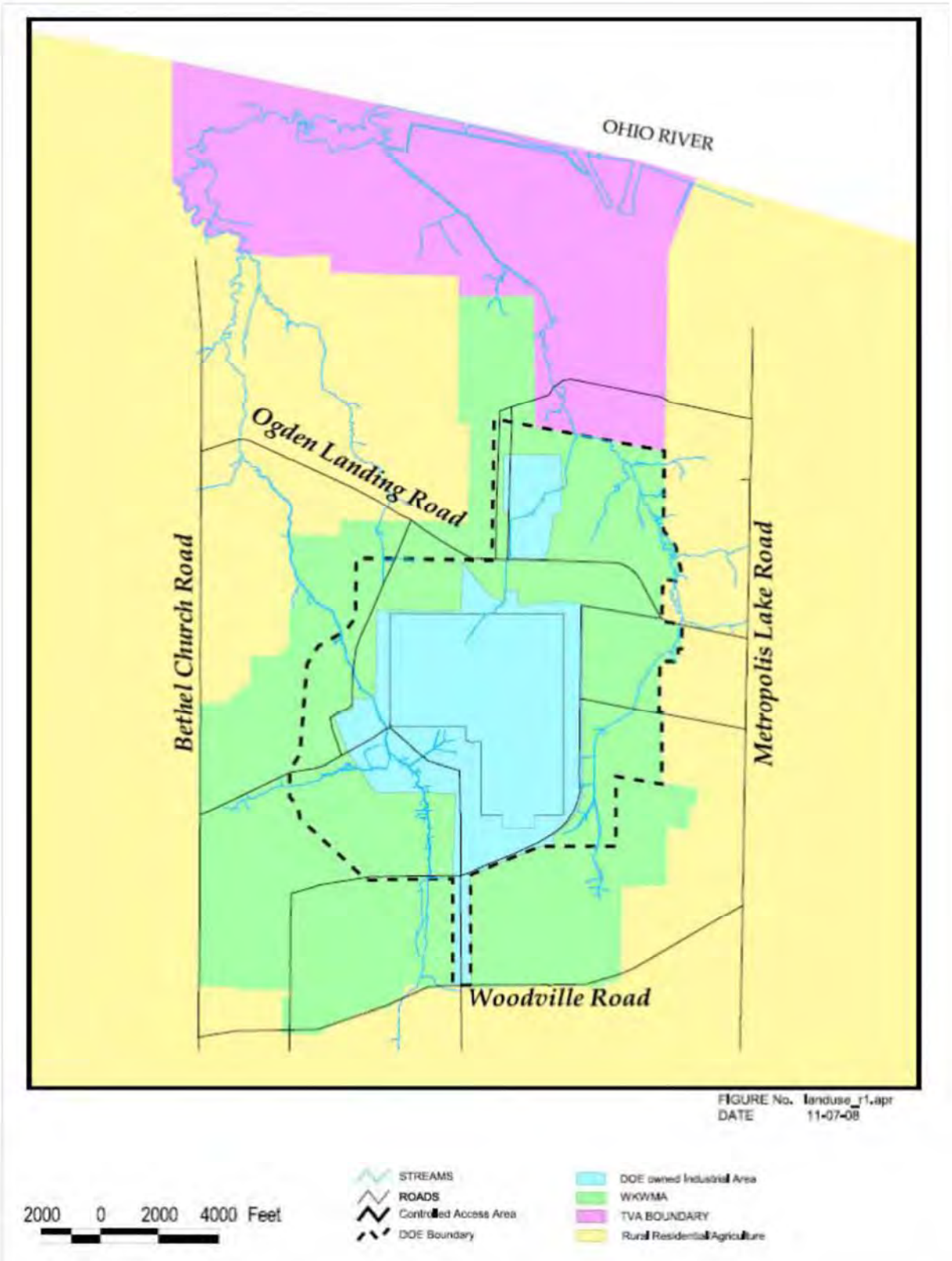

Figure taken from DOE 2015a.

Figure 3.8. Current Land Use at PGDP

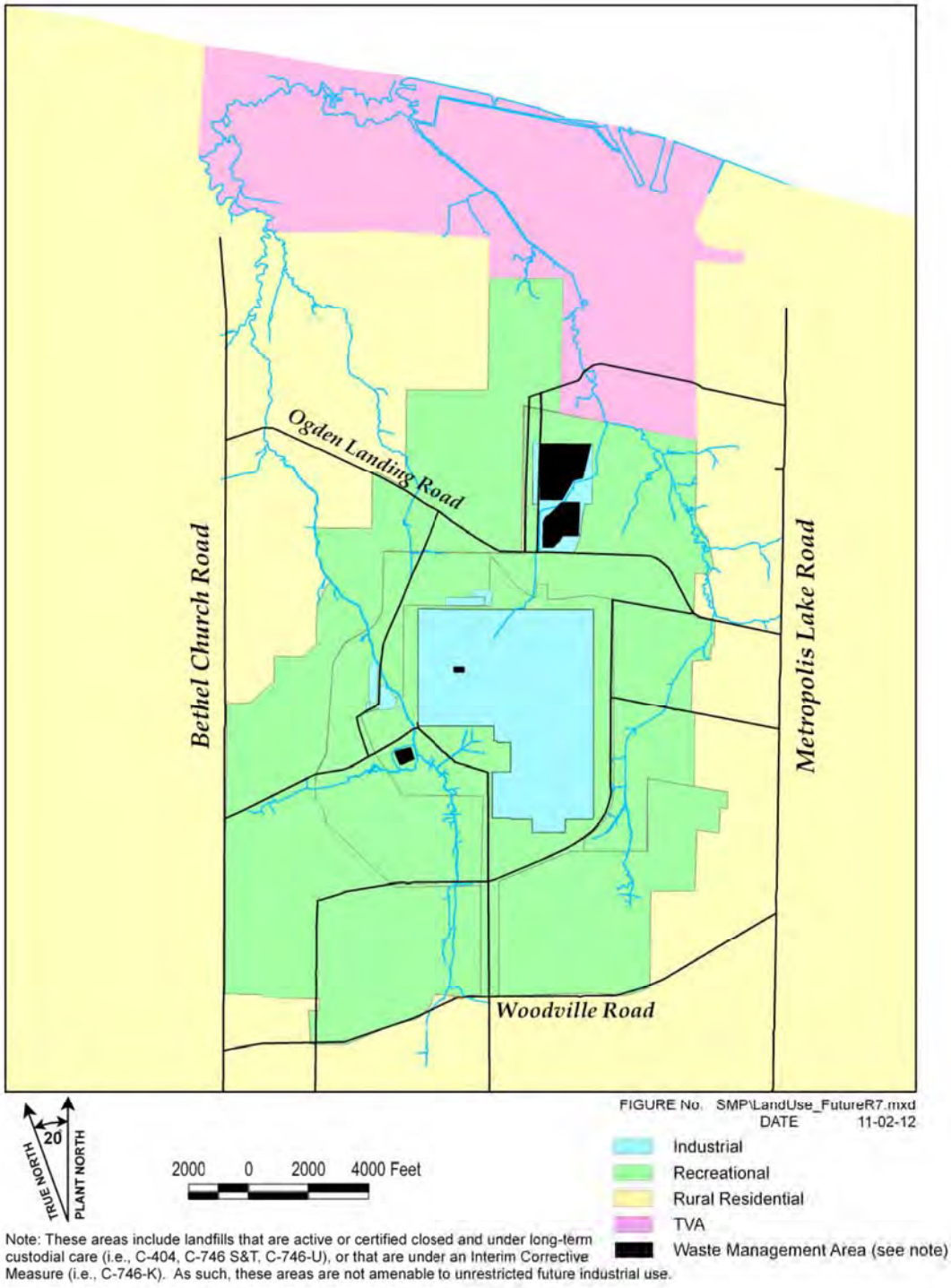

Figure taken from DOE 2015a.

Figure 3.9. Reasonably Anticipated Future Land Use at PGDP

3.8.2 Aquatic Systems

The aquatic communities, which includes vertebrates and invertebrates, in and around the PGDP area that could be impacted by PGDP discharges are found in two perennial streams (Bayou Creek and Little Bayou Creek), the North-South Diversion Ditch (a former ditch for the discharge of plant effluents to Little Bayou Creek), a marsh located at the confluence of Bayou Creek and Little Bayou Creek, and other drainage areas. The dominant fish species found are several species of sunfish, especially bluegill and green sunfish, bass, and catfish. Shallow streams, characteristic of the two main area creeks, are commonly dominated by bluegill, green and longear sunfish, and stonerollers.

3.8.3 Wetlands and Floodplains

The wetlands of the PGDP vicinity include a swamp covering 165 acres immediately south of the confluence of Bayou and Little Bayou Creeks. A 1994 study of the PGDP area by the U.S. Corps of Engineers (COE) (1994) groups the area wetlands into 16 vegetative cover types encompassing forested, scrub/shrub, and emergent wetlands. Wetland vegetation consists of species such as sedges, rushes, spikerushes, and various other grasses and forbs in the emergent portions; red maple, sweet gum, oaks, and hickories in the forested portions; and black willow and various other saplings of forested species in the thicket portions. Wetlands inside the plant security fence are confined to portions of drainage ditches traversing the site (CDM Federal 1994).

At PGDP, three bodies of water cause most area flooding: the Ohio River, Bayou Creek, and Little Bayou Creek. The floodplain analysis performed by the COE found that much of the built-up portions of the plant lie outside the 100- and 500-year floodplains of these streams (COE 1994). In addition, this analysis determined that ditches within the plant area can contain the expected 100- and 500-year discharges. It should be noted that precipitation frequency estimates for the 100- and 500-year events were updated in 2004 in the NOAA Atlas 14 (NOAA 2004). In the updated report, the mean precipitation estimate for the 100-year, 24-hour event in Atlas 14 for the Paducah area is 10.1% to 15% greater than the mean estimate in previous publications. As stated in Atlas 14, in many cases, the mean precipitation estimate used previously still is within the confidence limits provided in Atlas 14; therefore, it is likely the plant ditches still will contain the 100- and 500-year discharges.

4. EVALUATION APPROACH

This project was scoped prior to GDP shutdown (see Chapter 1). As discussed in the SMP, prior to GDP shutdown, the Soils OU will focus on accessible plant surface soils (ground surface to 10 ft bgs and 16 ft bgs in the vicinity of pipelines) not associated with PGDP operations (DOE 2015b). This Soils OU Report addendum has been prepared to present findings from the investigation conducted to assess adequately the nature and extent of the release or threat of release of hazardous substances, pollutants, or contaminants or hazardous wastes and hazardous constituents and to gather necessary data to support the corresponding BRA and FS at, and it is consistent with 40 *CFR* § 300.5 (EPA 1998), as planned by the Work Plan (DOE 2010) and addendum (DOE 2014a). This report is a foundation to determine what actions, if any, are needed to address impacts in soils associated with the Soils OU SWMU 229.

This report does the following:

- Provides a summary of the samples collected and analytical results by COPC, including a summary of the sampling methodology;
- Screens the results against background and risk-based levels taken from the Risk Methods Document (DOE 2015c) and developed in the BHHRA (Appendix D) to identify COPCs and COCs that are present at the SWMU;
- Presents the results of a BHHRA, including selection of COCs and priority COCs, based upon consideration of uncertainties in risk characterization and observations on the risk evaluation;
- Presents the results of a SERA;
- Develops remedial goal options (RGOs) for scenarios evaluated in the BHHRA; and
- Compares the analytical results to the RGOs and presents a summary of those comparisons.

The information/data and analyses that form the basis of the decision process for SWMU 229 are documented in Chapter 5 of this RI addendum. This chapter highlights the information to be presented generally for the SWMU 229 evaluation to address the goals of the RI.

4.1 DATA SETS

The data set for SWMU 229 consists of historical data collected at depths up to 10 ft bgs and data collected during the 2010 investigation (Soils OU RI) and 2015 investigation (Soils OU RI 2). Use of historical and RI data is addressed in Appendix B. The historical data set includes the Soils OU analytical suite as defined in the work plan addendum (DOE 2014a); it was evaluated as described in the Work Plan (DOE 2010). Any exceptions to the rules identified in the Work Plan have been noted in Appendix B (DOE 2010).

Collectively, quality historical data and RI data are considered the representative data set and are sufficient for decision making associated with SWMU 229 evaluated in this report. In order to more comprehensively evaluate the data for SWMU 229, plutonium-239 data were assessed as plutonium-239/240 and uranium-235/236 were assessed as uranium-235. Data summaries use Total PCBs and Total PAHs; individual contributors are not included in the summaries (DOE 2015c).

XRF data is discussed in the Soils OU RI 2 Report (DOE 2015a). See Appendix B for additional information.

Uncertainty Analysis. To be consistent with the Soils OU RI (DOE 2013) and Soils OU RI 2 (DOE 2015a), the conducted evaluations used the entire data set, default assumptions, and standard evaluations (e.g., screening using maximum values) that did not incorporate potentially relevant differences within SWMU 229. This is appropriate for the RI; however, the use of this approach introduces an uncertainty because such an evaluation may overestimate the impacts associated with the SWMU. In developing alternatives in the FS, additional evaluation of data collected and compiled for this addendum may be performed to address these uncertainties. Additional evaluation may include these steps or processes; some of these are discussed further in the Data Quality Analysis (Appendix B) and the BHHRA (Appendix D).

1. Incorporate future changes to site conditions.

2. Evaluate the data from SWMU 229 against the full range of background (rather than the initial screening against site-specific background already conducted). This additional evaluation would seek to identify whether the presence of certain metals and radionuclides in SWMU 229 is at levels consistent with or above background.

3. Reconsider the default assumptions used in the data treatment for SWMU 229 to ensure that the FS considers the data and determines them to be representative of the SWMU conditions.

4. Evaluate individual constituent results to ensure that they should properly be considered as representative of the data set. These evaluations may include these steps or processes.

    - Review data associated with common laboratory contaminants [e.g., methylene chloride (EPA 1996)]. The concentrations in the Soils OU data set may be associated with laboratory contamination; therefore, before an action is taken to address the methylene chloride at a given SWMU, its presence in the SWMU may be reevaluated to determine whether these data are representative of the actual site conditions.

    - Reevaluate data to develop a set more representative of actual conditions. As noted, the RI typically conducted an initial screening using the maximum value. The FS may perform additional data evaluation to subdivide the SWMU to allow the remedial approach to treat sub-areas differently, should this evaluation warrant. For example, the FS could contemplate removal of hot spots that would then allow a reestimation of the data set to be representative of the residual conditions.

5. Adjust the default parameters to more accurately reflect the specific SWMU conditions. For example, the soil/water distribution coefficient (i.e., K_d) for Tc-99 is a very sensitive parameter used in groundwater modeling (DOE 2015c). The K_d (0.2 L/kg) for Tc-99 that was used in the modeling assumes the Tc-99 is in a form that will readily dissolve in water; however, the form of this constituent at a particular SWMU may not conform to this assumption. Should additional evaluation identify that the K_d for a given constituent for a SWMU is not appropriate, the value may be adjusted and the modeling reperformed, with agreement among the FFA parties during scoping that additional modeling is warranted to support the FS remedy evaluation.

4.2 GAMMA WALKOVER SURVEY

Gamma Walkover Surveys (GWSs) were completed as part of this addendum to indicate levels of high activity to support the collection of judgmental radiological samples for fixed-base laboratory analysis to be used to better understand the nature of contamination (DOE 2010). Results of GWS were found not to match up well with results from samples sent for fixed-base laboratory analyses. There are two primary contributing factors for this lack of correlation between the results of GWS and analyses of samples sent to the fixed-base laboratory:

- *A priori* calculations of detector response and scanning minimum detectable concentration (MDC) were performed in accordance with Multi-Agency Radiological Survey and Site Investigation Manual (MARSSIM), as approved by Nuclear Regulatory Commission, DOE, and EPA. Guidance and examples contained within MARSSIM and supporting documents (such as NUREG 1507) provide the equations and parameters for determining scanning MDC and derivation of a net count per minute (cpm) value correlating to a specific soil concentration in pCi/g. These calculations are performed using default parameters that describe an area 56 cm in diameter uniformly contaminated down to 15 cm bgs. If the contaminated area is larger or smaller than the area used in the calculations or the contamination is not uniform, then different results in net cpm correlate to varying activity concentrations. For example, using the default parameters, a 10,800 net cpm is equivalent to an activity concentration of uranium-238 and short-lived decay products of 171 pCi/g of soil. If the contaminated area is really 100 cm in diameter, then the same reading of 10,800 cpm is equivalent to an activity concentration of uranium-238 and short-lived decay products of 25 pCi/g of soil.

- The GWS net cpm result and the fixed-base laboratory sampling result represent contamination present in different parts of the soil column. The GWS net cpm result is representative of contamination found on or near the soil surface. The sample collected for fixed-based laboratory analysis, however, is representative of contamination that extends from the soil surface to a depth of 6 inches after the vegetative layer is removed, if necessary.

Some other contributing factors that may lead to a lack of correlation between the results of GWS and analyses of samples sent to the fixed-base laboratory include inaccurate positional data, heterogeneous distribution of radionuclides in soil, and geometric variation in source/detector distance due to probe movement.

4.3 NATURE AND EXTENT

The Soils OU evaluations focus first on summarizing the representative analytical results for surface and subsurface soils. The process for highlighting chemicals of greatest potential interest was done consistent with the Work Plan (DOE 2010) considering the following:

- Background concentrations;

- Action levels (ALs) and NALs (future industrial worker[4] for inside the Limited Area); and

- Groundwater protection site-specific soil screening levels (SSLs) for the UCRS and RGA [dilution attenuation factors (DAFs) of 1 and 58 for the UCRS and RGA, respectively, based on maximum contaminant levels (MCLs), where available] (see Appendix C).

[4] The "future industrial worker" reflects default assumptions (i.e., 250 days/year for 25 years) (DOE 2015c).

The values used for highlighting the contaminants of greatest potential interest (denoted as COPCs in Nature and Extent sections) are consistent with the Risk Methods Document (DOE 2015c) and are included in Appendix D for the chemicals evaluated for this RI. The SSLs protective of groundwater for the RGA screening are discussed further in Section 4.4 and Appendix C.

4.4 FATE AND TRANSPORT

Potential migration of surface and subsurface contamination via leaching to groundwater and subsequent transport or runoff of surface contamination to adjacent drainageways is unlikely since SWMU 229 has no direct connection to any drainageways. Internal plant ditches are grass-lined and the outfall ditches are grass-lined or otherwise stabilized; therefore, the contaminants are not likely to be transported attached to suspended soil particles within the ditches and outfalls in the event transport or runoff to a drainageway did occur (DOE 2008b).

A primary migration pathway of concern for contaminants in soil is the potential for these to pose an ongoing source of contamination to RGA groundwater and subsequent migration to off-site areas. In Chapter 5 of this RI, the nature and extent evaluation highlights detected contaminants exceeding the SSL for one or more of the samples. The SSL for the RGA screening is derived using the project-specific DAF of 58 and the SSL for the UCRS screening was derived using the project-specific DAF of 1, as presented in Appendix C, Attachment C2 of the Soils OU RI Report (DOE 2013).

This process conservatively identifies chemicals that should be considered further for potential impacts to the RGA and downgradient receptors. The screening process is supplemented with a review of related information to ensure that concentrations that may be below background levels of constituents that do not pose a threat to the RGA at PGDP and/or are infrequently detected/exceeded are not evaluated further. A process to refine this list and identify chemicals for more detailed modeling was established in Appendix C, Attachment C1 of the Soils OU RI Report (DOE 2013), and is presented with updated information in Appendix C, Attachment C1 of this document.

4.4.1 Process for Developing Target Soil Constituents for Modeling

The overall modeling process as detailed in Appendix C includes the following:

- Screen historical and RI analytical results against the SSLs protective of groundwater to identify soil constituents that might impact groundwater;
- Review of the site-related soil constituents that are not screened from further modeling to identify which SWMU soil constituent combinations to subject to more detailed modeling;
- Identify certain process-related soil constituents for detailed modeling even though they were not detected above SSLs for groundwater protection to ensure appropriate DAF was used;
- Identify hotspots by evaluating the distribution of soil contaminants across the SWMU using three-dimensional modeling software;
- Evaluate transport to the RGA using Seasonal Soil Compartment Model (SESOIL) for soil constituents selected for detail modeling; and
- Estimate the concentrations of soil constituents in RGA groundwater at the SWMU boundary using Analytical Transient 1-,2-,3-Dimensional (AT123D).

It was clear when reviewing these screening results, that many of these chemicals present no potential threats to groundwater based on the data patterns, background, and results of groundwater monitoring. Many of the SSLs are at concentrations consistent with background for many naturally occurring chemicals, a factor that was considered further in the modeling process. Because of these issues, the list of chemicals was refined to include only those with potential concern for impacts to the RGA.

This RI developed information to support the FS evaluation of a range of remedial alternatives that addresses potentially complete exposure pathways and manages the risks/uncertainties identified in this RI.

Initial screening of the maximum detected value of constituents included determining how many of the results from the SWMU had a detected value greater than the SSL or the greater of the surface and subsurface background value.

Additional evaluation was conducted to identify which groundwater SWMU soil constituent combinations actually were subjected to groundwater modeling. The additional evaluation included a comparison of the overall average value of the constituent (calculated using both detected values and nondetected values at one-half the detection limit) with the screening values described above. If the overall average value of the constituent for the SWMU was below the background value or the SSL, then the constituent was not considered further for modeling for fate and transport. If the average value was above both the background value and the SSL, then the constituent was reviewed further to identify whether modeling would be performed.

Further, to determine if hot spots existed within the SWMU, the detected results of those constituents exceeding either the SSL or background value were visually examined and evaluated, [e.g., consideration of GWOU FS (DOE 2001) and AT123D software (see Appendix C)].

Based on the screening discussed in Appendix C, modeling was completed for the soil constituent as listed in Table 4.1.

Table 4.1. Soil Constituent Subjected to Modeling

SWMU	Soil Constituent
229	Tc-99

At SWMU 229, uranium-234 was detected at an activity concentration greater than both the background value and SSL and exhibited clustering when the results were viewed in 3-D; however, the mass concentration of uranium assumed to be present based upon the assumption that the uranium isotopes were present at natural abundance would be 883 mg/kg. At 883 mg/kg, the average concentration is less than the average uranium concentration at SWMU 81 (2,502 mg/kg) in which modeling in the Soils OU RI Report (DOE 2013) found not to migrate to the RGA within 1,000 years. Based on this, uranium was not modeled at SWMU 229.

4.4.2 Data Interpretation and Results for Target Groundwater Modeling Soil Constituents

Tc-99 was subject to detailed modeling for SESOIL and AT123D modeling evaluation to refine further the estimates of RGA groundwater concentrations at the SWMU boundary (Appendix C).

4.5 RISK ASSESSMENT

Grid sampling for the Soils OU was set up primarily on 45-ft centers with compositing of five grab samples within each grid for two horizons: surface and subsurface. Coordinates for these samples were recorded as the center of the grid, as the composite sampling was designed to be representative of the grid. The grid sampling yielded approximately 10 samples per horizon per half acre, on average. [One-half acre is significant because it typically is used as the size of an exposure unit (EU) for risk assessment purposes (DOE 2015c).]

Acceptable historical data, as determined by the data quality analysis, were assigned to an appropriate grid before beginning the data analysis described here. Historical data located outside the SWMU boundary were not considered representative of the SWMU.

For each grid, a detect or nondetect flag was assigned for each analyte using field laboratory data, fixed-base laboratory data, and/or historical data. For purposes of assigning flags, historical data should be included with fixed-base laboratory results or field laboratory results, whichever is applicable. A nondetect flag was set only if both field laboratory results and fixed-base results are nondetect or not available. Flags were assigned according to the following rules as specified in the work plan (DOE 2010):

(1) If field laboratory result is a nondetect and a fixed-base laboratory sample was not collected and an acceptable historical result is not available for the grid, then the grid is assigned a nondetect flag.

(2) If the field laboratory result is a nondetect and a fixed-base laboratory sample was collected or an acceptable historical result is available, then the fixed-base laboratory or historical result is used in assigning flag.

   (a) If the fixed-base laboratory result is a nondetect, then the grid is assigned a nondetect flag.

   (b) If the fixed-base laboratory result is a detect, then the grid is assigned a detect flag.

(3) If the field laboratory result is a detect and a fixed-base laboratory sample was not collected and no acceptable historical result is available for the grid, then the grid is assigned a detect flag.

(4) If the field laboratory result is a detect and a fixed-base laboratory sample was collected or an acceptable historical result is available, then

   (a) If the fixed-base laboratory result is a nondetect, then the grid is assigned a detect flag.

   (b) If the fixed-base laboratory result is a detect, then the grid is assigned a detect flag.

For each grid, a concentration for each analyte was assigned.

(1) If the analyte has a nondetect flag for the grid, then the concentration was set as the lower of field laboratory and fixed-base laboratory detection limit.

(2) If the analyte has a detect flag, then the concentration was set as the maximum detected value across field laboratory and fixed-base laboratory results.

These rules are in the flowchart depicted in Figure 4.1.

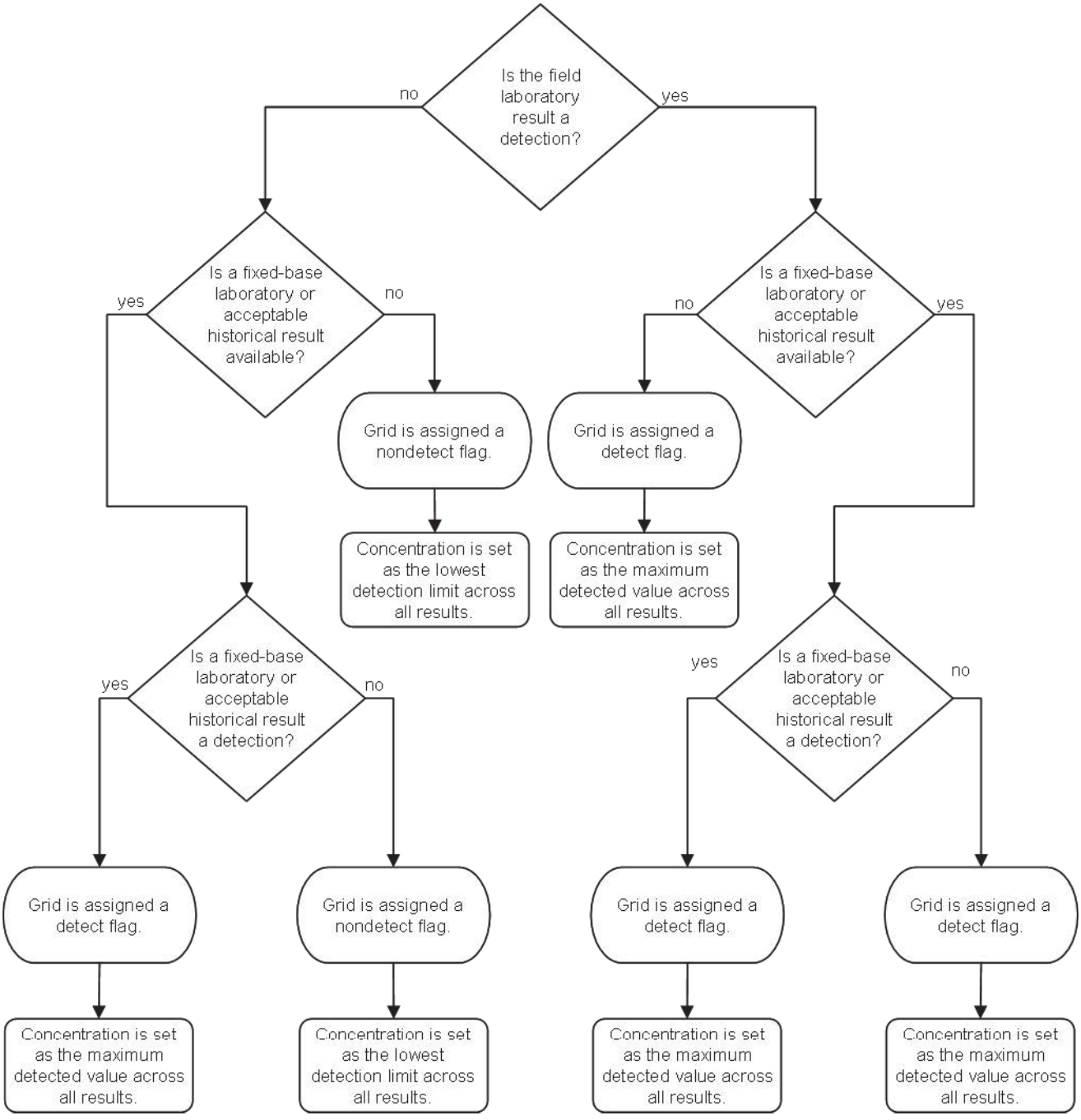

Figure taken from DOE 2010.

Figure 4.1. Flowchart Depicting Application of Detect and Nondetect Flags

Background values (see Appendix D) were compared on an EU basis by examining the results across all the grids within the EU. Nondetect results were not considered present above background even if the detection limit for the chemical was greater than the background value; a discussion of the uncertainty associated with this approach is presented in Appendix D, Attachment D4. The magnitude of this uncertainty was determined to be small. If an analyte was detected in one or more grids within the EU, then the maximum detected value across all grids within the EU was used for background comparison. (If the maximum detected value was greater than background, then the analyte is considered to be present above background. If the maximum detected value was less than background, then the analyte is not considered to be present above background.) The maximum radiological value across all the grids within the EU was used for background comparison.

COPCs were selected for each EU for those analytes that were detected above background and where the maximum detected value is greater than the NAL [as defined in the Risk Methods Document (DOE 2015c) for the hypothetical child residential scenario,[5] see Appendix D]. As described in the Work Plan (DOE 2010), for those analytes that were never detected within an EU, even if the detection limit is greater than the NAL, the analyte was not considered a COPC (DOE 2010). With the large number of samples required for the gridded sampling approach, the majority of the samples were analyzed using field analytical instruments. Though the quantitation limits are higher for these instruments, the increased coverage of each unit decreases the uncertainty of the analytical precision. Trace analytes may not be determined throughout the unit, but major constituents are thus, less likely to be missed. Fixed-base laboratory detection limits that are higher than NALs were addressed as an uncertainty in the baseline human health risk assessment.

Exposure point calculations were performed for each EU for those analytes that were retained as COPCs. For each COPC, data were summarized within each sampling location (i.e., within each grid) before calculating the exposure point concentration (EPC) for the EU. This was necessary to ensure that each location was equally represented in the EU EPC calculation. The scenarios shown in Figure 4.2 illustrate each possible case that may have resulted from implementation of the field sampling strategy for this RI and its response.

Further, in Case 1, shown in Figure 4.2, the COPC consists of all detected results, so the EPC was calculated using, as the grid result, the maximum detected value within the grid.

In Case 2, only detect and nondetect field results are available for grids. In this case, the EPC for the EU is calculated using the maximum detected field result for grids with detected results and the field detection limit for grids without a detected result.

In Case 3, data are a combination of historical and field results. In this case, maximum field detect result is used for the grid value if all historical results are nondetects; the maximum historical detect result is used for the grid value if all field results are nondetects; the largest detected value is used as the grid result if all field and historical results are detects, and, the smallest detection limit is used for the grid result if all field and historical results are nondetects. [It should be noted, discarding nondetect results that are greater than the maximum detected result in this manner, if they do not significantly influence the outcome, is consistent with EPA Risk Assessment Guidance for Superfund (RAGS) (EPA 1989).]

[5] In the Risk Methods Document, the child resident scenario NAL is the lesser of the hazard-based value for a child age 1 to 6 and the lifetime excess cancer risk-based value for the resident. The hazard target used in the calculation is 0.1, and the excess cancer risk target used in the calculation is 1×10^{-6}. Consistent with the Work Plan (DOE 2010), the project action limits in the Quality Assurance Project Plan were set to the child resident scenario NAL for the Risk Methods Document (DOE 2001).

	RESULTS	TO REPRESENT GRID ANALYTE CONCENTRATION
Case 1: *Field laboratory results, Fixed-base laboratory results, No historical results*	Field laboratory: detect Fixed-base laboratory: nondetect	Use the field laboratory result
	Field laboratory: nondetect Fixed-base laboratory: detect	Use the fixed-base laboratory result
	Field laboratory: detect Fixed-base laboratory: detect	Use the maximum detected result
	Field laboratory: nondetect Fixed-base laboratory: nondetect	Use the smaller detection limit
Case 2: *Field laboratory results, No fixed-base laboratory results, No historical results*	Field laboratory: detect	Use the field laboratory result
	Field laboratory: nondetect	Use the field laboratory detection limit
Case 3: *Field laboratory results, No fixed-base laboratory results, Historical results*	Field laboratory: detect Historical: nondetect	Use the field laboratory result
	Field laboratory: nondetect Historical: detect	Use the historical result
	Field laboratory: detect Historical: detect	Use the maximum detected result
	Field laboratory: nondetect Historical: nondetect	Use the smaller detection limit
Case 4: *Field laboratory results, Fixed-base laboratory results, Historical results*	Field laboratory: detect Fixed-base laboratory: nondetect Historical: nondetect	Use the field laboratory result
	Field laboratory: nondetect Fixed-base laboratory: detect Historical: nondetect	Use the fixed-base laboratory result
	Field laboratory: nondetect Fixed-base laboratory: nondetect Historical: detect	Use the historical result and consider any uncertainties regarding historical data during project nature and extent scoping
	Field laboratory: detect Fixed-base laboratory: detect Historical: nondetect	Use the maximum detected result
	Field laboratory: detect Fixed-base laboratory: nondetect Historical: detect	Use the maximum detected result
	Field laboratory: nondetect Fixed-base laboratory: detect Historical: detect	Use the maximum detected result
	Field laboratory: detect Fixed-base laboratory: detect Historical: detect	Use the maximum detected result
	Field laboratory: nondetect Fixed-base laboratory: nondetect Historical: nondetect	Use the smallest detection limit

Figure taken from DOE 2010.

Figure 4.2. Exposure Point Concentration Calculation Scenarios

In Case 4, data are a combination of historical, fixed-base laboratory, and field results. In this case, maximum field detect result is used for the grid value if all historical results and fixed-base results are nondetects; the maximum fixed-base detect result is used for the grid value if all field results and historical results are nondetects; the maximum historical detect result is used for the grid value if all field results and fixed-base results are nondetects; the largest detected value is used as the grid result if a combination of field, fixed-base, and historical results are detects; and the smallest detection limit is used for the grid result if all field, fixed-base, and historical results are nondetects. [This methodology is consistent with RAGS (EPA 1989).] A calculation was completed to determine the importance of the anomalous situation where the nondetect result exceeds the maximum detected value within a data set being analyzed. If the nondetect value that exceeds the maximum detected result would cause the EPC to exceed the maximum detected result, then it would be discarded from the data set.

Analytical results from radiological judgmental sampling and historical sampling were included with other fixed-base laboratory results when assigning grid values with the grid sampling previously described.

After the data set was built for each analyte within the EU, because there were fewer than ten grids in each EU in SWMU 229, the EU EPC was the maximum detected concentration across all grids within the EU.

The BHHRA characterized cancer risks and noncancer hazards by EU for all COPCs for the following scenarios:

- Current Industrial Worker[6]
- Future Industrial Worker (see footnote 6)
- Outdoor Worker
- Excavation Worker
- Recreational User
- Future Hypothetical Rural Resident

Likely scenarios for SWMU 229 are discussed in Chapter 5 and include that of the future industrial worker since SWMU 229 is located inside the Limited Area. Additionally, a hypothetical residential scenario, and an excavation worker scenario were assessed.

4.5.1 Human Health

A detailed approach to the risk assessment and the supporting information and tables is provided in Appendix D. For the SWMU 229 summary, tables are provided with the risk estimates for the various receptors, the COCs, and the primary routes of exposure that are driving these results.

The receptors evaluated and the exposure parameters used to develop risk estimates are in Table 4.2. The following highlighted components of the risk assessment are included in the SWMU 229 summary, as appropriate.

[6] The "future industrial worker" reflects default assumptions (i.e., 250 days/year for 25 years). A "current industrial worker" scenario has been added to the default scenario to be more reflective of current site conditions and practices with a lower exposure frequency (i.e., 14 days/years for 25 years) (DOE 2015c).

Table 4.2. Exposure Factors Used for Intake Calculations in BHHRA[a]

Pathway Variable	Units	Current Industrial Worker[b]	Future Industrial Worker	Outdoor Worker	Excavation Worker	Adult Resident	Child Resident	Adult Recreational User	Teen Recreational User	Child Recreational User
Exposure frequency	days/year	14	250	185	185	350	350	104	140	140
Exposure duration	years	25	25	25	5	20	6	10	10	6
Body weight	kg	80	80	80	80	80	15	80	44[c]	15
Averaging time—cancer	days	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365
Averaging time—noncancer	days	365 × 25	365 × 25	365 × 25	365 × 5	365 × 20	365 × 6	365 × 10	365 × 10	365 × 6
Incidental Ingestion of Soil/Sediment										
Incidental ingestion rate	mg/day	50	50	480	480	100	200	100	100	200
Fraction ingested		1	1	1	1	1	1	1	1	1
Dermal Contact with Soil/Sediment										
Body surface area exposed	m^2/day	0.3527[d]	0.3527[d]	0.3527[d]	0.3527[d]	0.6032	0.2373[d]	0.6032	0.75	0.2373[d]
Soil-to-skin adherence factor	mg/cm^2–day	1	1	1	1	1	1	1	1	1
Inhalation of Vapors and Particulates Emitted from Soil/Sediment										
Total inhalation rate	m^3/hour	2.5	2.5	2.5	2.5	0.833	0.833	2.5	2.5	2.5
Exposure time	hours/day	8	8	8	8	24	24	5	5	5
Particulate emission factor	m^3/kg	6.20E+08	6.20E+08	6.20E+08	6.20E+08	9.30E+08	9.30E+08	9.30E+08	9.30E+08	9.30E+08
External Exposure to Ionizing Radiation from Soil/Sediment										
Exposure frequency	day/day	14/365	250/365	185/365	185/365	350/365	350/365	104/365	140/365	140/365
Gamma shielding factor	unitless	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
Gamma exposure time factor	hr/hr	8/24	8/24	8/24	8/24	18/24	18/24	5/24	5/24	5/24
Ingestion of Groundwater										
Drinking water ingestion rate	L/day	N/A	N/A	N/A	N/A	2.5	0.78	N/A	N/A	N/A
Dermal Contact with RGA Groundwater (Showering)										
Body surface area exposed	m^2	N/A	N/A	N/A	N/A	2.09	0.6378	N/A	N/A	N/A
Event time	hour/event	N/A	N/A	N/A	N/A	0.71	0.71	N/A	N/A	N/A
Event frequency	events/day	N/A	N/A	N/A	N/A	1	1	N/A	N/A	N/A

Table 4.2. Exposure Factors Used for Intake Calculations in BHHRA[a] (Continued)

Pathway Variable	Units	Current Industrial Worker	Future Industrial Worker	Outdoor Worker	Excavation Worker	Adult Resident	Child Resident	Adult Recreational User	Teen Recreational User	Child Recreational User
Inhalation RGA Groundwater										
Indoor inhalation rate	m^3/hour	N/A	N/A	N/A	N/A	0.833	0.833	N/A	N/A	N/A
Exposure time in the shower	hours/day	N/A	N/A	N/A	N/A	0.71	0.54[d]	N/A	N/A	N/A
Time of shower	hour	N/A	N/A	N/A	N/A	0.1	0.1	N/A	N/A	N/A
Time after shower	hour	N/A	N/A	N/A	N/A	0.1	0.1	N/A	N/A	N/A
Fraction volatilized while showering	unitless	N/A	N/A	N/A	N/A	0.75	0.75	N/A	N/A	N/A
Water flow rate	L/h	N/A	N/A	N/A	N/A	890	890	N/A	N/A	N/A
Bathroom volume	m^3	N/A	N/A	N/A	N/A	11	11	N/A	N/A	N/A
Averaging time—cancer	hours	N/A	N/A	N/A	N/A	24 × 70 × 365	24 × 70 × 365	N/A	N/A	N/A
Averaging time—noncancer	hours	N/A	N/A	N/A	N/A	24 × 365 × 20	24 × 365 × 6	N/A	N/A	N/A
Exposure time household use	hours/day	N/A	N/A	N/A	N/A	24	24	N/A	N/A	N/A
Exchange rate	changes/day	N/A	N/A	N/A	N/A	10	10	N/A	N/A	N/A
Mixing coefficient	unitless	N/A	N/A	N/A	N/A	0.5	0.5	N/A	N/A	N/A
Fraction volatilized household use	unitless	N/A	N/A	N/A	N/A	0.5	0.5	N/A	N/A	N/A
Water flow rate	L/day	N/A	N/A	N/A	N/A	890	890	N/A	N/A	N/A
House volume	m^3	N/A	N/A	N/A	N/A	450	450	N/A	N/A	N/A

Notes:
[a] Information compiled September 2014, See DOE 2015c, *Methods for Conducting Risk Assessment and Risk Evaluation at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky, Volume 1. Human Health,* DOE/LX/07-0107&D2/R6/V1, July.
[b] Best professional judgment; similar to value used for DOE 2008b.
[c] Updated, based on Paducah Risk Assessment Working Group follow-up e-mail, October 20, 2015.
[d] Updated, based on Paducah Risk Assessment Working Group meeting minutes, September 16, 2016.
N/A = not available or not applicable.

Direct Contact Exposures. This includes incidental ingestion, inhalation, dermal absorption, and external exposure to ionizing radiation routes of exposure. This may include contact with contamination currently at the surface or to contaminants in the entire soil column in the future during earthwork.

- **Surface soil (0–1 ft) impacts are evaluated with a range of exposure scenarios.** Because of the sizes of the EUs and limited activities in these areas, current worker exposures are estimated based on a more representative frequency (14 days/year); however, the future worker scenario includes default assumptions (250 days/year). A future hypothetical resident, a recreational user, and outdoor worker scenarios also were evaluated.

- **Surface/subsurface soils.** Bounding the potential contact issues with contaminants that may be present in soils from 0–10 ft requires scenarios either for temporary exposures during excavation or longer term exposures if the soil column were mixed during future activities and, subsequently, a receptor may be in contact with this average concentration for a longer duration. The surface/subsurface soils were evaluated using the outdoor worker assumptions [185 days/year for 25 years as per the Risk Methods Document (DOE 2015c)]. The intake parameters for the excavation worker are the same as the outdoor worker with the exception of exposure duration. Exposure duration was shortened to 5 years for the excavation worker.

Surface Water. Although SWMU 229 is located near drainageways, significant surface water contamination is not expected as a result of the SWMU (UK 2007). Internal plant ditches are grass-lined and the outfalls are grass-lined or otherwise stabilized; therefore, the contaminants are not likely to be transported attached to suspended soil particles within the ditches and outfalls in the event transport or runoff to a drainageway did occur (DOE 2008b). Further, due to the physical cover at the SWMU limiting the potential for particulate transport through sheet flow and based upon the modeling performed as part of the SI report for the outfalls and the associated internal ditches, no contaminants are migrating in surface water (dissolved or through sediment) from ditches to surrounding creeks at concentrations that may adversely impact human health (DOE 2008a). The uncertainty in surface water transport of contaminants will be managed in the FS**.** As a result, human health risks associated with exposure to surface water will not be assessed in the BHHRA (Appendix D).

Groundwater. Ingestion of groundwater is evaluated only for hypothetical future residential scenarios at SWMU 229 identified in the fate and transport section and modeled to show transport potentially reaching the RGA. The modeled RGA groundwater concentration at the SWMU boundary was used for risk estimates. No UCRS groundwater samples were collected as part of this addendum to the RI 2 report, and evaluation refers to modeling results only. The UCRS groundwater is not evaluated specifically; however, the tables shown in the nature and extent section highlight those constituents that exceeded SSL values for the UCRS. Though not quantified in this evaluation, UCRS groundwater could pose as a medium of concern under certain exposure scenarios; however, these risks were not quantified due to the high improbability of the UCRS being used as a drinking water aquifer [see Section 3.3.4.3 of the Risk Methods Document (DOE 2015c)].

Dose Assessment. This RI does not integrate potential dose across multiple routes of exposure, particularly since radionuclides were not identified during the evaluation of impacts to groundwater and dose from ingestion of game was not evaluated for the current on-site areas. Dose assessments are conducted to provide information for risk managers and are separate from the risk assessment conducted for decision making. The Risk Methods Document (Table A.8) provides dose-based SSLs. These were used to derive an estimate of the total dose (mrem/yr) for each of the primary scenarios evaluated (DOE 2015c). In presenting these results, the following comparisons are considered:

- Per the Risk Methods Document (DOE 2015c), a dose less than 1 mrem/yr is *de minimis*, and the benchmark for dose-based action is 25 mrem/year [DOE Order 458.1 states that if the estimated total effective dose (TED) for members of the public exceeds 25 mrem in a year, then additional evaluation is conducted] (DOE 2015c).

- DOE Order 458.1, *Radiation Protection of the Public and Environment*, requires that all exposure pathways not result in radiation exposures to members of the general public greater than a TED of 100 mrem/year (not applicable for current on-site areas, but consideration for future use).

- These do not reflect exposures to the public, which would be estimated at the site boundary. Significant releases to air are not expected from SWMU 229.

Pathways Not Quantitatively Evaluated. The following discusses pathways not quantitatively evaluated.

- SWMU 229 is not connected to a drainageway and that is noted as such in Section 4.4, under Fate and Transport. Surface water pathways were not quantitatively evaluated in this OU because the potential for surface water migration of contaminants was addressed during the SWOU (On-Site) SI. The Engineering Evaluation/Cost Analysis for that project stated the following: "Based upon the modeling performed as part of the SI report for the outfalls and the associated internal ditches, no contaminants are migrating in surface water (dissolved or through sediment) from ditches to surrounding creeks at concentrations that may adversely impact human health" (DOE 2008a).

  A removal action for the contaminated sediment associated with SWOU (On-Site) (DOE 2011) was conducted for Outfalls 001, 008, 010, 011, and 015 and associated internal ditches. A final response action for internal ditches, outfalls, and creeks will be addressed by the SWOU, as described in the SMP (DOE 2015b).

- A rural resident with a garden or raising beef was not evaluated. Residential use on-site is not reasonably anticipated. Criteria more protective than the typical residential scenarios may be derived during the FS. (SWMU 229 exceeds 1E-06 risk cumulative risk for the hypothetical resident without including the garden/beef scenarios.)

- Ingestion of game. Recreational use of the area has been evaluated; however, ingestion of game was not included in the SWMU 229 evaluation. Considering the range of the game, the range of the hunter, and the small size of the SWMU, the analysis of this has great uncertainty for any SWMU-specific risk management decision.

Lead. Lead is evaluated separately from the cancer risks and noncancer hazards assessment methodology, as proposed by EPA. Exposures to lead were evaluated based on the approach recommended in the *Memorandum: Revised Interim Soil Lead Guidance for CERCLA Sites and RCRA Corrective Action Facilities* (EPA 1994). The site media lead levels are compared directly against the health protective lead concentrations for the risk-based site management decisions. Lead was not identified as a COPC because the maximum concentration is less than 400 mg/kg (residential screening value) consistent with the Risk Methods Document (DOE 2015c).

Contaminants of Concern. For SWMU 229, the total ELCR and total HI for all pathways within a use scenario of concern are compared to the benchmarks of ELCR > 1E-06 or an HI > 0.1, respectively. COPCs within a use scenario of concern exceeding either of these benchmarks are deemed COCs for the use scenario of concern. The COCs are identified in the tables in Chapter 5. Priority COCs are identified

as those COCs with either ELCR > 1E-04 or HI > 1 or both to highlight to risk managers the COCs driving total ELCR or total HI at SWMU 229 (DOE 2015c).

Uncertainty Analysis. The uncertainty discussion for the BHHRA (Appendix D) documents a range of issues that may be considered by risk managers in making decisions for these sites.

4.5.2 Ecological Risk Screening

The surface soil concentrations were screened against the ecological screening values (ESVs) for soil as included in Appendix E. This approach does not include consideration of background or other factors; however, given the industrial nature of SWMU 229, the background screening values are included. Consistent with the Soils OU RI Report, for the SWMU 229 summary, the primary chemicals that exceeded the respective screening values are shown [hazard quotient (HQ) ≥ 10] as well as the overall HI for the constituents detected, allowing comparison of the HIs, SWMU size, and other factors like proximity to a drainageway (DOE 2013). These primary chemicals exceeding screening values with an HQ ≥ 10 are termed priority chemicals of potential ecological concern (COPECs) within this report.

4.6 REMEDIAL GOAL OPTIONS

RGOs were developed individually for each SWMU 229 EU for scenarios analyzed in the BHHRA. RGOs were calculated for each COC as determined in the conclusions of the BHHRA. COCs and RGOs are presented to evaluate direct contact exposure for the future industrial worker, excavation worker, and future hypothetical resident for SWMU 229 located inside the Limited Area in Chapter 5.

4.7 SWMU AREA DETERMINATIONS

The human health and ecological risk assessments used acreage for the SWMU based on global positioning system (GPS) coordinates and mapping tools. This acreage is reflected in the figures within this document. Of note, the acreage presented in the background sections of this document may be inconsistent with acreage used in risk assessments due to its being based on historical SWMU assessment report administrative boundaries, which typically were estimated using a map/figure.

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5. SWMU 229, C-764-F, DMSA OS-18

5.1 BACKGROUND

SWMU 229, the location of the former DOE Material Storage Area (DMSA) OS-18, is located north of C-764-F in the Northwest portion of the plant site. The SWMU 229 boundary encompasses approximately .806 acres. There is no direct connection between the SWMU and surface water.

This area was established soon after plant construction to store excess railroad supplies, parts, components, etc. Later it became an area for storing various excess materials. Material found to have been stored within the SWMU included the following:

scrap metal
concrete
fireproof safes
portable work platform
empty trash cans
empty 55-gal drums
miscellaneous equipment and parts
railroad ties
fans
chain link fencing
two small buildings
light bulbs
oils
parts from railroad cars
road signs
manhole covers
scaffolding
circuit boards
fuses
batteries

In 2001, DOE began characterization and remediation of the materials in the DMSAs. RCRA-regulated items have been removed from the SWMU and placed in proper storage. This DMSA now qualifies as a Phase 3 DMSA because it has been fully characterized and contains no fissionable material (DOE 2003a).

5.2 FIELDWORK SUMMARY

During the first RI for the Soils OU, 36 grid samples were planned and collected for the unit. Contingency samples were not required. The unit also underwent a GWS using a FIDLER; the 14,546 measurements ranged from 4,002 to 535,073 cpm. A judgmental grab sample was collected for radiological constituents. The ground cover is a mixture of gravel, soil, and grass.

During RI 2, the unit underwent a second GWS (Figure 5.1) using a FIDLER; the 25,177 measurements ranged from 1,763 to 133,807 cpm. A judgmental grab sample was collected for radiological constituents. The second GWS was delayed post RI 2 sampling due to water standing on unit. Based on Soils OU Work Plan, GWS would not be performed on units with standing water. GWS was performed on October 2, 2015 for the RI 2.

5.3 NATURE AND EXTENT OF CONTAMINATION—SURFACE SOILS

The representative data set presented in Table 5.1 provides the nature of the contamination in SWMU 229 surface soils, and Figures 5.2–5.4 illustrate the horizontal extent. A complete list of sampling results is provided in Appendix F. Grid numbers shown below are truncated from the figures. Figures contain the SWMU#–grid#, with zeros filling the appropriate spaces to make three digits.

The lateral extent of SWMU 229 surface soil contamination is considered defined adequately for supporting the BRA and FS. SWMU 229 consists of 2 EUs.

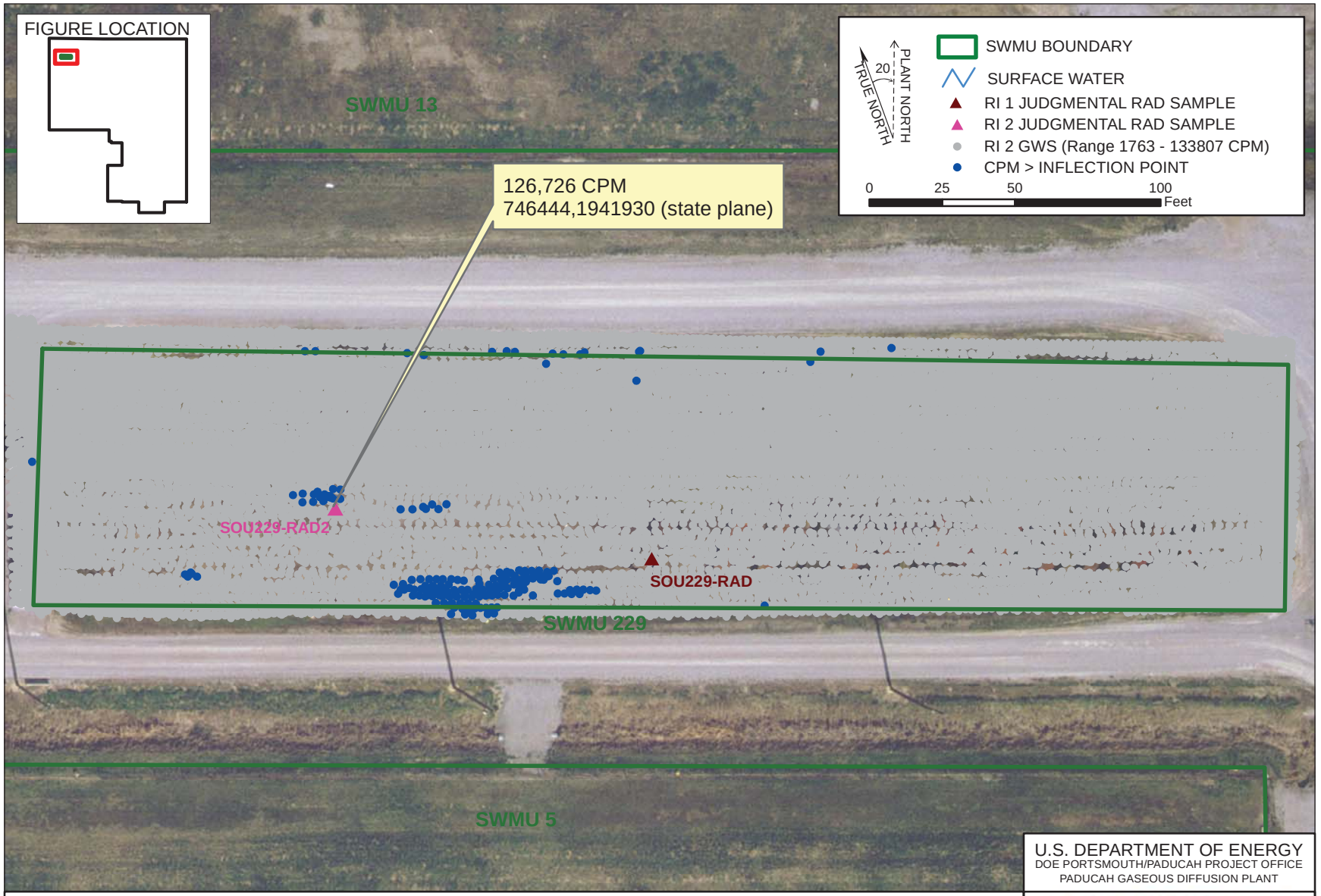

Figure 5.1. SWMU 229 Gamma Walkover Survey Completed for RI 2 Report

G:\GIS\ARCVIEWS\PROJECTS\SoilsOU\RI Report\RI2 D1\SWMU229 1 GWS.mxd
11/16/2015

Table 5.1. Surface Soil Data Summary: SWMU 229

Type	Analysis	Unit	Detected Results			J-qualified		Provisional Background		Industrial Worker		Industrial Worker		GW Protection Screen		
			Min	Max	Avg	FOD	FOD	FOE	Bkgd	FOE	NAL	FOE	AL	RGA	UCRS	DL Range
METAL	Aluminum	mg/kg	3.60E+03	6.21E+03	4.91E+03	0/2	2/2	0/2	1.30E+04	0/2	1.00E+05	0/2	1.00E+05	0/2	2/2	5.3 - 11
METAL	Antimony	mg/kg	5.23E+01	1.50E+02	9.85E+01	0/19	17/19	17/19	2.10E-01	10/19	9.34E+01	0/19	2.80E+03	17/19	17/19	0.53 - 30
METAL	Arsenic	mg/kg	5.60E+00	2.12E+01	1.02E+01	0/19	11/19	1/19	1.20E+01	11/19	1.41E+00	0/19	1.41E+02	1/19	11/19	1.1 - 11
METAL	Barium	mg/kg	3.16E+02	6.16E+02	4.48E+02	0/19	19/19	19/19	1.70E+02	0/19	4.04E+04	0/19	1.00E+05	0/19	19/19	2.1 - 100
METAL	Beryllium	mg/kg	2.40E-01	7.90E-01	5.15E-01	0/2	2/2	1/2	6.70E-01	0/2	4.50E+02	0/2	1.35E+04	0/2	0/2	0.22 - 0.53
METAL	Cadmium	mg/kg	3.10E-01	2.12E+01	1.38E+01	0/19	6/19	6/19	2.10E-01	0/19	6.12E+01	0/19	1.84E+03	0/19	5/19	0.053 - 12
METAL	Calcium	mg/kg	1.93E+05	2.38E+05	2.16E+05	0/2	2/2	1/2	2.00E+05	0/2	N/A	0/2	N/A	N/A	N/A	265 - 549
METAL	Chromium	mg/kg	8.20E+00	2.91E+01	1.57E+01	0/19	3/19	2/19	1.60E+01	2/19	1.23E+01	0/19	1.23E+03	0/19	0/19	1.1 - 85
METAL	Cobalt	mg/kg	4.30E+00	7.70E+00	6.00E+00	0/2	2/2	0/2	1.40E+01	0/2	6.87E+01	0/2	2.06E+03	2/2	2/2	0.21 - 0.44
METAL	Copper	mg/kg	6.00E+00	5.19E+01	1.71E+01	0/19	3/19	1/19	1.90E+01	0/19	9.34E+03	0/19	1.00E+05	0/19	1/19	1.1 - 35
METAL	Iron	mg/kg	7.44E+03	2.74E+04	1.31E+04	0/19	19/19	0/19	2.80E+04	0/19	1.00E+05	0/19	1.00E+05	19/19	19/19	5.3 - 100
METAL	Lead	mg/kg	1.03E+01	2.72E+01	1.59E+01	0/19	18/19	0/19	3.60E+01	0/19	8.00E+02	0/19	8.00E+02	0/19	12/19	0.32 - 13
METAL	Magnesium	mg/kg	6.99E+03	7.27E+03	7.13E+03	0/2	2/2	0/2	7.70E+03	0/2	N/A	0/2	N/A	N/A	N/A	53 - 110
METAL	Manganese	mg/kg	2.15E+02	6.81E+02	3.52E+02	0/19	19/19	0/19	1.50E+03	0/19	4.72E+03	0/19	1.00E+05	19/19	19/19	0.21 - 85
METAL	Mercury	mg/kg	9.06E-02	1.72E-01	1.31E-01	0/19	2/19	0/19	2.00E-01	0/19	7.01E+01	0/19	2.10E+03	0/19	2/19	0.0354 - 10
METAL	Molybdenum	mg/kg	2.50E-01	1.00E+00	6.25E-01	0/19	2/19	0/19	N/A	0/19	1.17E+03	0/19	3.51E+04	0/19	2/19	0.53 - 15
METAL	Nickel	mg/kg	1.05E+01	9.93E+01	5.73E+01	0/19	9/19	7/19	2.10E+01	0/19	4.30E+03	0/19	1.00E+05	0/19	9/19	0.53 - 65
METAL	Selenium	mg/kg	9.10E-01	1.10E+00	1.01E+00	0/19	2/19	2/19	8.00E-01	0/19	1.17E+03	0/19	3.51E+04	0/19	2/19	0.53 - 20
METAL	Silver	mg/kg	2.50E-02	3.60E-02	3.05E-02	0/19	2/19	0/19	2.30E+00	0/19	1.17E+03	0/19	3.51E+04	0/19	0/19	0.21 - 10
METAL	Sodium	mg/kg	1.13E+02	1.32E+02	1.23E+02	0/2	2/2	0/2	3.20E+02	0/2	N/A	0/2	N/A	N/A	N/A	21.2 - 44
METAL	Thallium	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	2.10E-01	0/2	2.34E+00	0/2	7.02E+01	0/2	0/2	0.21 - 0.44
METAL	Uranium	mg/kg	8.57E+00	1.56E+02	3.59E+01	0/21	14/21	14/21	4.90E+00	0/21	6.81E+02	0/21	2.04E+04	0/21	10/21	0.03 - 20
METAL	Vanadium	mg/kg	1.22E+01	3.13E+01	2.18E+01	0/19	2/19	0/19	3.80E+01	0/19	1.15E+03	0/19	3.45E+04	0/19	2/19	1.1 - 70
METAL	Zinc	mg/kg	3.82E+01	8.33E+02	1.60E+02	0/19	19/19	16/19	6.50E+01	0/19	7.01E+04	0/19	1.00E+05	0/19	19/19	2.1 - 25
PPCB	PCB, Total	mg/kg	N/A	N/A	N/A	0/19	0/19	0/19	N/A	0/19	3.05E-01	0/19	3.05E+01	0/19	0/19	0.32 - 5
SVOA	1,2,4-Trichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	1,2-Dichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	1,3-Dichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	1,4-Dichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2,4,5-Trichlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2,4,6-Trichlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2,4-Dichlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2,4-Dimethylphenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2,4-Dinitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	2,4-Dinitrotoluene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2,6-Dinitrotoluene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2-Chloronaphthalene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2-Chlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2-Methyl-4,6-dinitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	2-Methylnaphthalene	mg/kg	2.10E-01	2.10E-01	2.10E-01	1/2	1/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2-Methylphenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	2-Nitrobenzenamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	2.91E+02	0/2	8.73E+03	0/2	0/2	1.7 - 1.8
SVOA	2-Nitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	3,3'-Dichlorobenzidine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	3-Nitrobenzenamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	4-Bromophenyl phenyl ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	4-Chloro-3-methylphenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	4-Chlorobenzenamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	4-Chlorophenyl phenyl ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	4-Nitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	Acenaphthene	mg/kg	2.40E-01	2.40E-01	2.40E-01	1/2	1/2	0/2	N/A	0/2	1.40E+03	0/2	4.20E+04	0/2	0/2	0.35 - 0.36
SVOA	Acenaphthylene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	4.20E+04	N/A	N/A	0.35 - 0.36
SVOA	Anthracene	mg/kg	3.70E-01	3.70E-01	3.70E-01	0/2	1/2	0/2	N/A	0/2	6.99E+03	0/2	1.00E+05	0/2	0/2	0.35 - 0.36

FOD = frequency of detection
FOE = frequency of exceedance
N/A = not applicable

Table 5.1. Surface Soil Data Summary: SWMU 229 (Continued)

Type	Analysis	Unit	Detected Results			J-qualified	FOD	Provisional Background		Industrial Worker		Industrial Worker		GW Protection Screen		DL Range
			Min	Max	Avg	FOD		FOE	Bkgd	FOE	NAL	FOE	AL	RGA	UCRS	
SVOA	Benzenemethanol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Benzo(ghi)perylene	mg/kg	8.80E-02	7.90E-01	4.39E-01	1/2	2/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Benzoic acid	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	Bis(2-chloroethoxy)methane	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Bis(2-chloroethyl) ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.007 - 0.0073
SVOA	Bis(2-chloroisopropyl) ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Bis(2-ethylhexyl)phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	5.88E+01	0/2	5.88E+03	0/2	0/2	0.35 - 0.36
SVOA	Butyl benzyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Dibenzofuran	mg/kg	3.00E-01	3.00E-01	3.00E-01	1/2	1/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Diethyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Dimethyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Di-n-butyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Di-n-octylphthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Fluoranthene	mg/kg	2.90E-01	5.10E+00	2.70E+00	1/2	2/2	0/2	N/A	0/2	9.32E+02	0/2	2.80E+04	0/2	0/2	0.35 - 0.36
SVOA	Fluorene	mg/kg	2.70E-01	2.70E-01	2.70E-01	1/2	1/2	0/2	N/A	0/2	9.32E+02	0/2	2.80E+04	0/2	0/2	0.35 - 0.36
SVOA	Hexachlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	5.15E-01	0/2	5.15E+01	0/2	0/2	0.35 - 0.36
SVOA	Hexachlorobutadiene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Hexachlorocyclopentadiene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	Hexachloroethane	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	Isophorone	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	m,p-Cresol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.7 - 0.73
SVOA	Naphthalene	mg/kg	9.00E-02	9.00E-02	9.00E-02	1/2	1/2	0/2	N/A	0/2	1.67E+01	0/2	1.61E+03	1/2	1/2	0.35 - 0.36
SVOA	Nitrobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	N-Nitroso-di-n-propylamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	1.18E-01	0/2	1.18E+01	0/2	0/2	0.007 - 0.0073
SVOA	N-Nitrosodiphenylamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	PAH, Total	mg/kg	1.57E-01	1.69E+00	9.26E-01	0/2	2/2	0/2	N/A	2/2	8.94E-02	0/2	8.94E+00	0/2	1/2	-
SVOA	Pentachlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	8.91E-01	0/2	8.91E+01	N/A	N/A	1.7 - 1.8
SVOA	Phenanthrene	mg/kg	4.10E-02	4.80E+00	2.42E+00	1/2	2/2	0/2	N/A	0/2	1.40E+03	0/2	4.20E+04	1/2	2/2	0.35 - 0.36
SVOA	Phenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.35 - 0.36
SVOA	p-Nitroaniline	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.7 - 1.8
SVOA	Pyrene	mg/kg	2.50E-01	4.00E+00	2.13E+00	1/2	2/2	0/2	N/A	0/2	6.99E+02	0/2	2.10E+04	0/2	1/2	0.35 - 0.36
SVOA	Pyridine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.7 - 0.73
RADS	Americium-241	pCi/g	4.50E-02	7.40E-02	5.95E-02	0/6	2/6	0/6	N/A	0/6	5.99E+00	0/6	5.99E+02	0/6	0/6	0.018 - 0.0513
RADS	Cesium-137	pCi/g	4.80E-02	3.21E-01	1.92E-01	0/6	5/6	0/6	4.90E-01	4/6	1.02E-01	0/6	1.02E+01	0/6	0/6	0.0393 - 0.087
RADS	Neptunium-237	pCi/g	2.17E-01	1.69E+00	9.04E-01	0/5	4/5	4/5	1.00E-01	3/5	2.29E-01	0/5	2.29E+01	0/5	4/5	0.048 - 0.174
RADS	Plutonium-238	pCi/g	2.40E-02	2.40E-02	2.40E-02	0/6	1/6	0/6	7.30E-02	0/6	2.87E+01	0/6	2.87E+03	0/6	0/6	0.019 - 0.386
RADS	Plutonium-239/240	pCi/g	2.80E-02	2.69E-01	1.97E-01	0/6	4/6	4/6	2.50E-02	0/6	2.47E+01	0/6	2.47E+03	0/6	3/6	0.012 - 0.281
RADS	Technetium-99	pCi/g	5.81E+00	4.34E+01	2.70E+01	0/6	6/6	6/6	2.50E+00	0/6	1.20E+03	0/6	1.00E+05	6/6	6/6	0.4 - 1.35
RADS	Thorium-228	pCi/g	3.04E-01	6.25E-01	4.96E-01	0/6	6/6	0/6	1.60E+00	0/6	N/A	0/6	N/A	N/A	N/A	0.005 - 0.109
RADS	Thorium-230	pCi/g	6.68E-01	2.42E+00	1.53E+00	0/6	6/6	3/6	1.50E+00	0/6	3.39E+01	0/6	3.39E+03	0/6	2/6	0.013 - 0.122
RADS	Thorium-232	pCi/g	2.48E-01	6.47E-01	4.58E-01	0/6	6/6	0/6	1.50E+00	0/6	N/A	0/6	N/A	N/A	N/A	0.012 - 0.0412
RADS	Uranium-234	pCi/g	2.09E+00	1.61E+03	4.02E+02	0/6	6/6	6/6	1.20E+00	2/6	5.53E+01	0/6	5.53E+03	4/6	6/6	0.04 - 1.8
RADS	Uranium-235	pCi/g	1.02E-01	1.03E+02	2.55E+01	0/6	6/6	6/6	6.00E-02	4/6	3.40E-01	2/6	3.40E+01	2/6	6/6	0.027 - 1.67
RADS	Uranium-238	pCi/g	2.47E+00	1.71E+03	4.34E+02	0/6	6/6	6/6	1.20E+00	6/6	1.60E+00	2/6	1.60E+02	6/6	6/6	0.008 - 1.56

One or more samples exceed AL value
One or more samples exceed NAL value
One or more samples exceed background value
One or more samples exceed SSLs of RGA and UCRS groundwater protection

Counts of analyses are based on the maximum detected result from a sample (i.e., if a sample has analytical results from two different labs, only the maximum value is counted).
Field replicates, or separate samples are counted independently.

The uranium (metal)/uranium (isotopic) may not be from the same sample thus a correlation between uranium (metal)/uranium (isotopic) data may not be possible.

FOD = frequency of detection
FOE = frequency of exceedance
N/A = not applicable

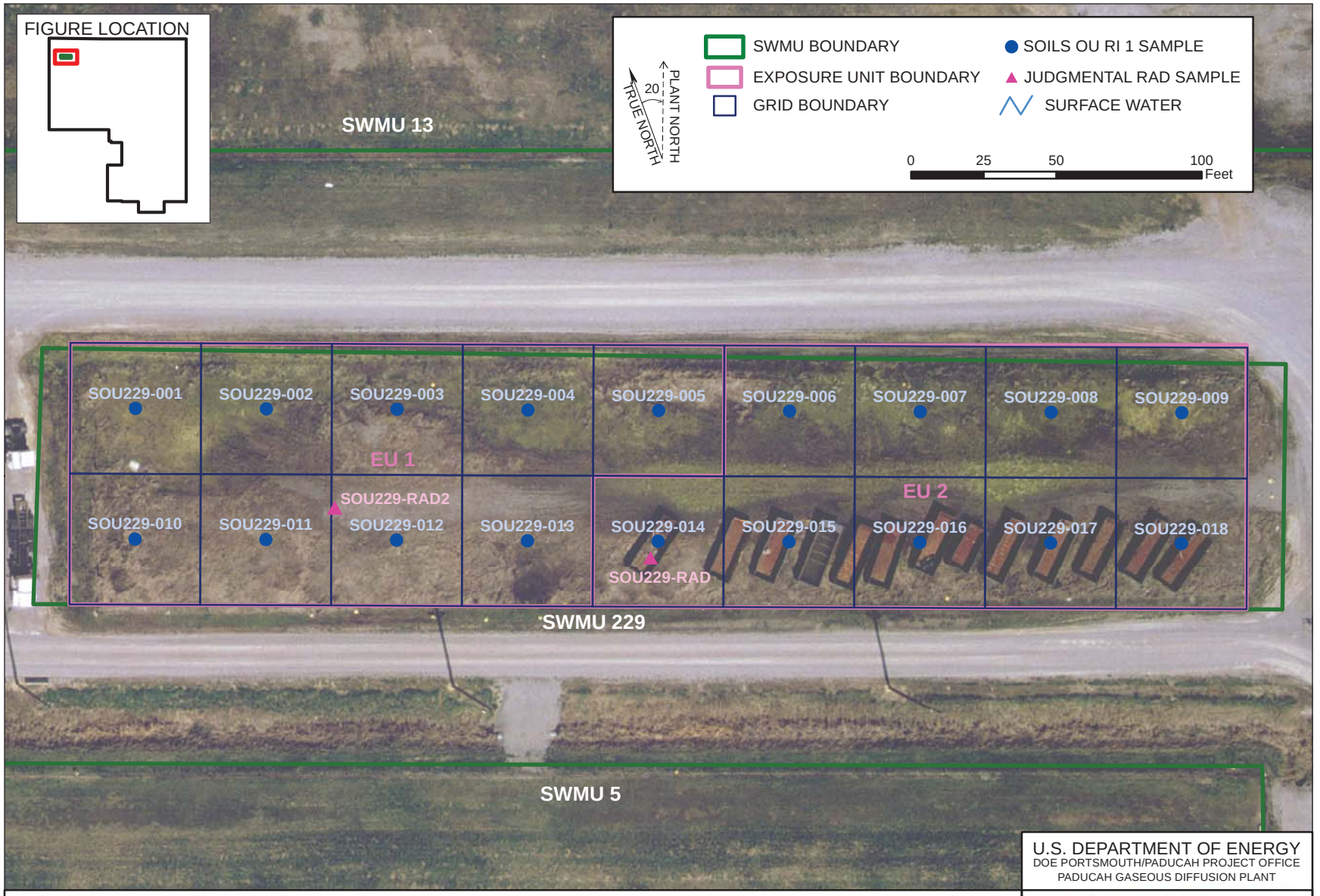

Figure 5.2. SWMU 229 Sample Locations—Surface Soil

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12/28/2015

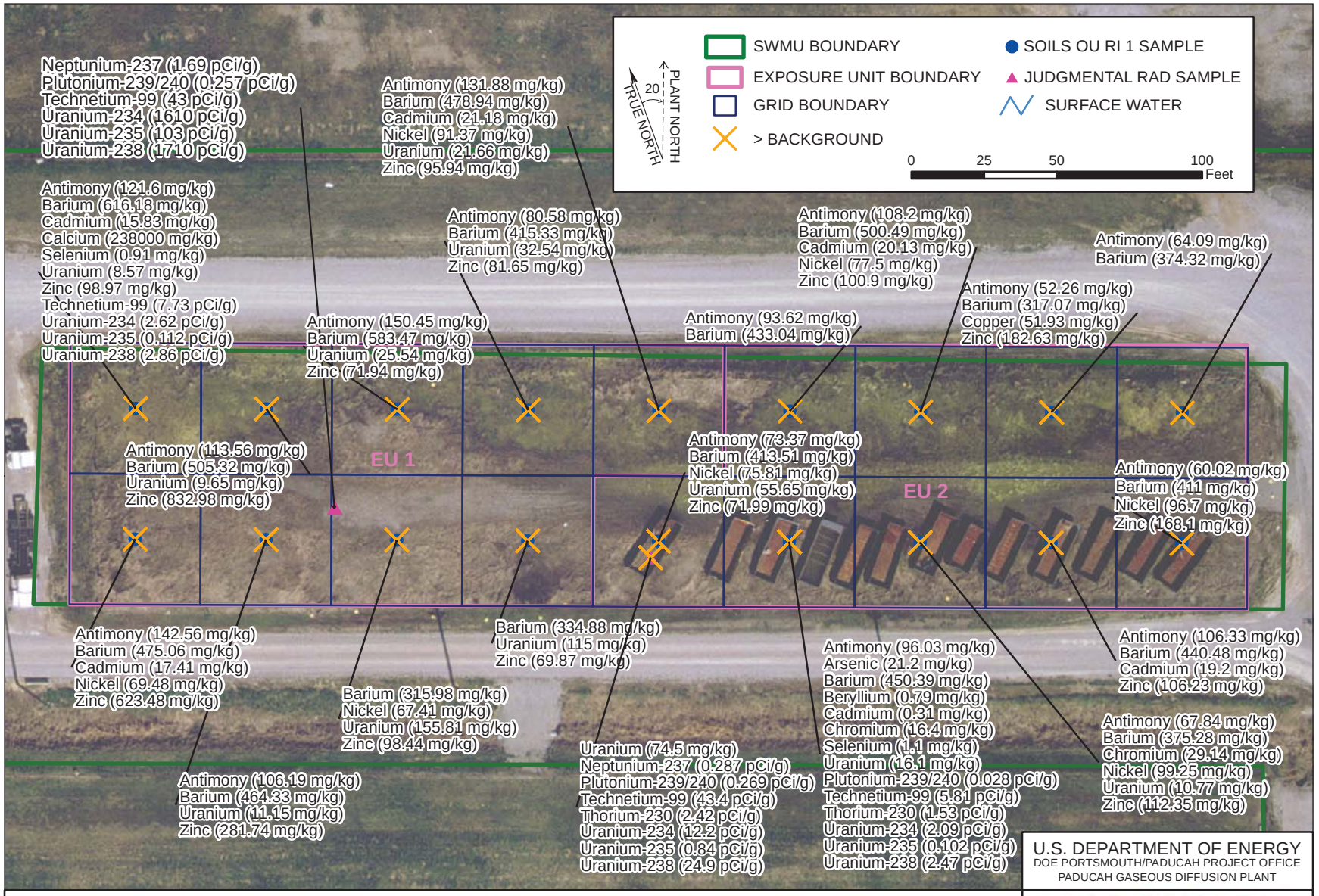

Figure 5.3. SWMU 229 Background Exceedances—Surface Soil

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12/28/2015

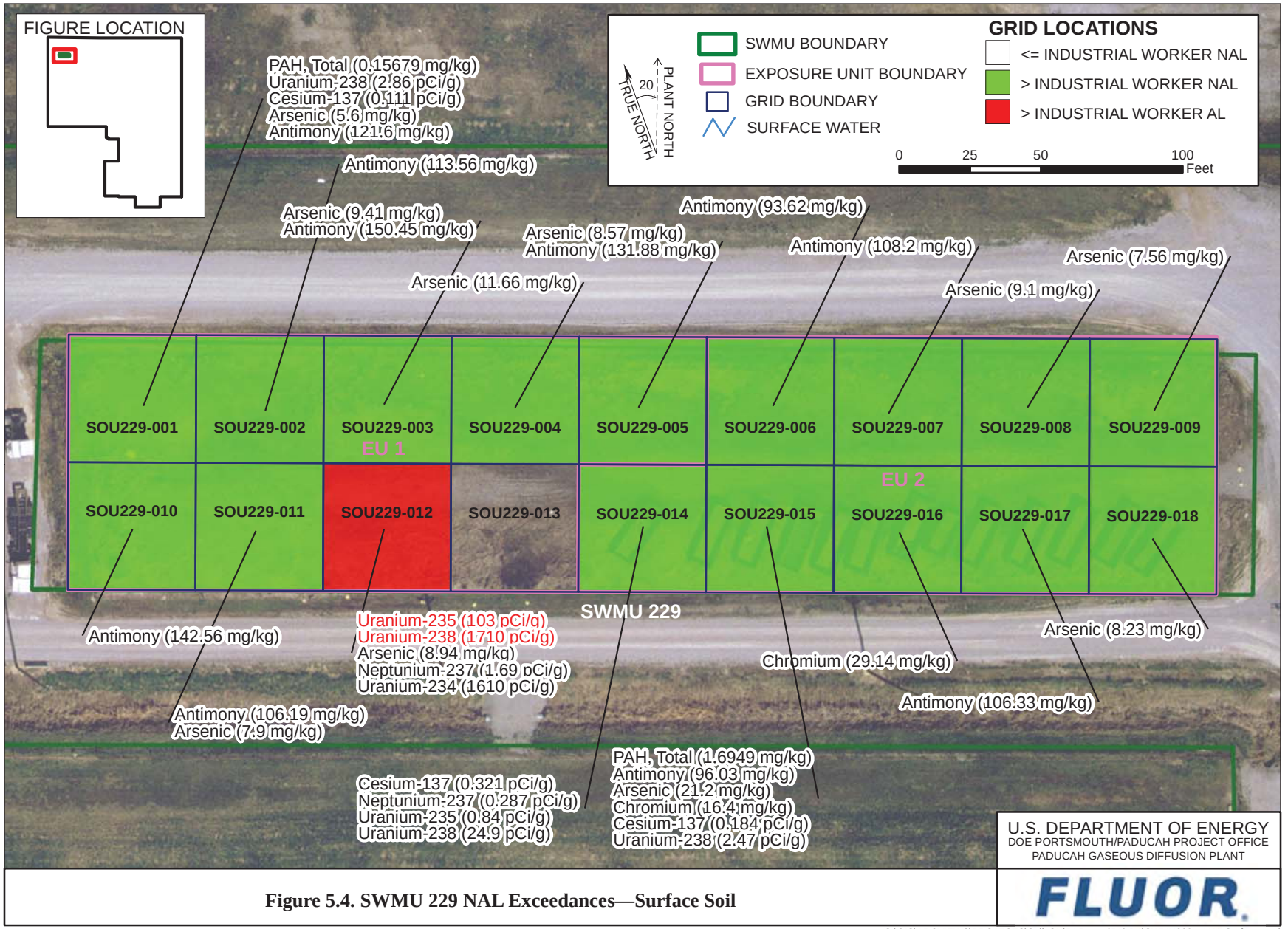

Figure 5.4. SWMU 229 NAL Exceedances—Surface Soil

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11/16/2015

Metals

Antimony (EU1, EU2), arsenic (EU2) and chromium (EU2) were detected in the surface soil above both the background screening level and the industrial worker NAL. No metals were detected above both the background screening level and the industrial worker ALs.

The following metals were detected in the SWMU 229 surface soil above both the SSLs for the protection of UCRS groundwater and the background screening levels (if available): antimony (EU1, EU2), arsenic (EU2), barium (EU1, EU2), cadmium (EU1, EU2), copper (EU2), molybdenum (EU1, EU2), nickel (EU1, EU2), selenium (EU1, EU2), uranium (EU1, EU2) and zinc (EU1, EU2). Additionally, antimony (EU1, EU2) and arsenic (EU2) were detected above the SSL for the protection of RGA groundwater and the background screening level.

PCBs

No PCBs were detected for this unit.

SVOCs

Total PAHs (EU1, EU2) was detected above industrial worker NALs in the surface soil in SWMU 229.

Four SVOCs were detected in the SWMU 229 surface soil above the SSLs for the protection of UCRS groundwater and the background screening levels (if available): naphthalene (EU2), PAH, Total (EU2), phenanthrane (EU1, EU2) and pyrene (EU2).

Two SVOCs were detected above the SSLs for the protection of RGA groundwater and the background screening level: naphthalene (EU2) and phenanthrene (EU2).

VOCs

No volatile organic compounds (VOCs) were sampled for this unit.

RADs

Neptunium-237 (EU1, EU2), uranium-234 (EU1), uranium-235 (EU1, EU2) and uranium-238 (EU1, EU2) were detected in the surface soil exceeding both the background screening level and industrial worker NAL values. Additionally, uranium-235 (EU1) and uranium-238 (EU1) exceeded the industrial worker AL value in the surface soil at SWMU 229.

Neptunium-237 (EU1, EU2), plutonium-239/240 (EU1, EU2), Tc-99 (EU1, EU2), thorium-230 (EU2), uranium-234 (EU1, EU2), uranium-235 (EU1, EU2) and uranium-238 (EU1, EU2) were detected in the SWMU 229 surface soil above the SSLs for the protection of UCRS groundwater and the background screening levels. Additionally, the following were detected above the SSLs for the protection of RGA groundwater and the background screening level: Tc-99 (EU1, EU2), uranium-234 (EU1, EU2), uranium-235 (EU1), uranium-238 (EU1, EU2).

5.4 NATURE AND EXTENT OF CONTAMINATION—SUBSURFACE SOILS

The representative data set presented in Table 5.2 provides the nature of the contamination in SWMU 229 subsurface soils, and Figures 5.5–5.7 illustrate the horizontal extent. A complete list of sampling results is

Table 5.2. Subsurface Soil Data Summary: SWMU 229

Type	Analysis	Unit	Detected Results			J-qualified		Provisional Background		Industrial Worker		Industrial Worker		GW Protection Screen		
			Min	Max	Avg	FOD	FOD	FOE	Bkgd	FOE	NAL	FOE	AL	RGA	UCRS	DL Range
METAL	Aluminum	mg/kg	5.55E+03	6.51E+03	6.03E+03	0/2	2/2	0/2	1.20E+04	0/2	1.00E+05	0/2	1.00E+05	0/2	2/2	5.8 - 6.2
METAL	Antimony	mg/kg	4.07E+01	1.18E+02	7.10E+01	0/19	18/19	18/19	2.10E-01	16/19	9.34E+01	0/19	2.80E+03	18/19	18/19	0.58 - 30
METAL	Arsenic	mg/kg	7.47E+00	1.16E+01	8.33E+00	0/19	5/19	2/19	7.90E+00	5/19	1.41E+00	0/19	1.41E+02	0/19	5/19	1.2 - 11
METAL	Barium	mg/kg	2.73E+02	5.54E+02	4.13E+02	0/19	19/19	19/19	1.70E+02	0/19	4.04E+04	0/19	1.00E+05	0/19	19/19	2.3 - 100
METAL	Beryllium	mg/kg	3.10E-01	4.30E-01	3.70E-01	0/2	2/2	0/2	6.90E-01	0/2	4.50E+02	0/2	1.35E+04	0/2	0/2	0.58 - 0.62
METAL	Cadmium	mg/kg	1.80E-02	1.77E+01	8.94E+00	0/19	3/19	2/19	2.10E-01	0/19	6.12E+01	0/19	1.84E+03	0/19	2/19	0.058 - 12
METAL	Calcium	mg/kg	1.30E+03	1.65E+05	8.32E+04	0/2	2/2	1/2	6.10E+03	0/2	N/A	0/2	N/A	N/A	N/A	62 - 289
METAL	Chromium	mg/kg	9.10E+00	4.80E+01	2.58E+01	0/19	6/19	2/19	4.30E+01	4/19	1.23E+01	0/19	1.23E+03	0/19	0/19	1.2 - 85
METAL	Cobalt	mg/kg	4.20E+00	4.50E+00	4.35E+00	0/2	2/2	0/2	1.30E+01	0/2	6.87E+01	0/2	2.06E+03	2/2	2/2	0.23 - 0.25
METAL	Copper	mg/kg	4.50E+00	1.93E+01	8.34E+00	0/19	3/19	0/19	2.50E+01	0/19	9.34E+03	0/19	1.00E+05	0/19	0/19	1.2 - 35
METAL	Iron	mg/kg	6.22E+03	1.85E+04	9.64E+03	0/19	19/19	0/19	2.80E+04	0/19	1.00E+05	0/19	1.00E+05	19/19	19/19	5.8 - 100
METAL	Lead	mg/kg	7.32E+00	1.44E+01	1.18E+01	0/19	19/19	0/19	2.30E+01	0/19	8.00E+02	0/19	8.00E+02	0/19	3/19	0.35 - 13
METAL	Magnesium	mg/kg	6.11E+02	7.61E+03	4.11E+03	0/2	2/2	1/2	2.10E+03	0/2	N/A	0/2	N/A	N/A	N/A	57.8 - 62
METAL	Manganese	mg/kg	1.02E+02	4.35E+02	2.69E+02	0/19	19/19	0/19	8.20E+02	0/19	4.72E+03	0/19	1.00E+05	18/19	19/19	0.23 - 85
METAL	Mercury	mg/kg	7.50E-03	9.27E+00	4.15E+00	0/19	3/19	2/19	1.30E-01	0/19	7.01E+01	0/19	2.10E+03	2/19	2/19	0.0385 - 10
METAL	Molybdenum	mg/kg	3.90E-01	5.40E-01	4.65E-01	0/19	2/19	0/19	N/A	0/19	1.17E+03	0/19	3.51E+04	0/19	2/19	0.58 - 15
METAL	Nickel	mg/kg	6.20E+00	7.65E+01	2.75E+01	0/19	4/19	2/19	2.20E+01	0/19	4.30E+03	0/19	1.00E+05	0/19	4/19	0.58 - 65
METAL	Selenium	mg/kg	9.20E-01	1.20E+00	1.06E+00	0/19	2/19	2/19	7.00E-01	0/19	1.17E+03	0/19	3.51E+04	0/19	2/19	0.58 - 20
METAL	Silver	mg/kg	4.10E-02	4.20E-02	4.15E-02	0/19	2/19	0/19	2.70E+00	0/19	1.17E+03	0/19	3.51E+04	0/19	0/19	0.23 - 10
METAL	Sodium	mg/kg	5.19E+01	1.31E+02	9.15E+01	0/2	2/2	0/2	3.40E+02	0/2	N/A	0/2	N/A	N/A	N/A	23.1 - 24.8
METAL	Thallium	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	3.40E-01	0/2	2.34E+00	0/2	7.02E+01	0/2	0/2	0.23 - 0.25
METAL	Uranium	mg/kg	2.64E+00	1.97E+01	9.07E+00	0/19	4/19	3/19	4.60E+00	0/19	6.81E+02	0/19	2.04E+04	0/19	2/19	0.02 - 20
METAL	Vanadium	mg/kg	1.35E+01	2.09E+01	1.72E+01	0/19	2/19	0/19	3.70E+01	0/19	1.15E+03	0/19	3.45E+04	0/19	2/19	1.2 - 70
METAL	Zinc	mg/kg	1.05E+01	2.88E+01	2.02E+01	0/19	19/19	0/19	6.00E+01	0/19	7.01E+04	0/19	1.00E+05	0/19	0/19	2.3 - 25
PPCB	PCB, Total	mg/kg	N/A	N/A	N/A	0/19	0/19	0/19	N/A	0/19	3.05E-01	0/19	3.05E+01	0/19	0/19	0.35 - 5
SVOA	1,2,4-Trichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	1,2-Dichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	1,3-Dichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	1,4-Dichlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2,4,5-Trichlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2,4,6-Trichlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2,4-Dichlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2,4-Dimethylphenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2,4-Dinitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	2,4-Dinitrotoluene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2,6-Dinitrotoluene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2-Chloronaphthalene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2-Chlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2-Methyl-4,6-dinitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	2-Methylnaphthalene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2-Methylphenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	2-Nitrobenzenamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	2.91E+02	0/2	8.73E+03	0/2	0/2	1.8 - 2
SVOA	2-Nitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	3,3'-Dichlorobenzidine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	3-Nitrobenzenamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	4-Bromophenyl phenyl ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	4-Chloro-3-methylphenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	4-Chlorobenzenamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	4-Chlorophenyl phenyl ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	4-Nitrophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	Acenaphthene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	1.40E+03	0/2	4.20E+04	0/2	0/2	0.38 - 0.41
SVOA	Acenaphthylene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	4.20E+04	N/A	N/A	0.38 - 0.41
SVOA	Anthracene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	6.99E+03	0/2	1.00E+05	0/2	0/2	0.38 - 0.41

FOD = frequency of detection
FOE = frequency of exceedance
N/A = not applicable

Table 5.2. Subsurface Soil Data Summary: SWMU 229 (Continued)

Type	Analysis	Unit	Detected Results			J-qualified		Provisional Background		Industrial Worker		Industrial Worker		GW Protection Screen		
			Min	Max	Avg	FOD	FOD	FOE	Bkgd	FOE	NAL	FOE	AL	RGA	UCRS	DL Range
SVOA	Benzenemethanol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Benzo(ghi)perylene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Benzoic acid	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	Bis(2-chloroethoxy)methane	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Bis(2-chloroethyl) ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.0076 - 0.0082
SVOA	Bis(2-chloroisopropyl) ether	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Bis(2-ethylhexyl)phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	5.88E+01	0/2	5.88E+03	0/2	0/2	0.38 - 0.41
SVOA	Butyl benzyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Dibenzofuran	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Diethyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Dimethyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Di-n-butyl phthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Di-n-octylphthalate	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Fluoranthene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	9.32E+02	0/2	2.80E+04	0/2	0/2	0.38 - 0.41
SVOA	Fluorene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	9.32E+02	0/2	2.80E+04	0/2	0/2	0.38 - 0.41
SVOA	Hexachlorobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	5.15E-01	0/2	5.15E+01	0/2	0/2	0.38 - 0.41
SVOA	Hexachlorobutadiene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Hexachlorocyclopentadiene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	Hexachloroethane	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	Isophorone	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	m,p-Cresol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.76 - 0.82
SVOA	Naphthalene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	1.67E+01	0/2	1.61E+03	0/2	0/2	0.38 - 0.41
SVOA	Nitrobenzene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	N-Nitroso-di-n-propylamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	1.18E-01	0/2	1.18E+01	0/2	0/2	0.0076 - 0.0082
SVOA	N-Nitrosodiphenylamine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	PAH, Total	mg/kg	7.80E-03	7.80E-03	7.80E-03	0/2	1/2	0/2	N/A	0/2	8.94E-02	0/2	8.94E+00	0/2	0/2	-
SVOA	Pentachlorophenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	8.91E-01	0/2	8.91E+01	N/A	N/A	1.8 - 2
SVOA	Phenanthrene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	1.40E+03	0/2	4.20E+04	0/2	0/2	0.38 - 0.41
SVOA	Phenol	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.38 - 0.41
SVOA	p-Nitroaniline	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	1.8 - 2
SVOA	Pyrene	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	6.99E+02	0/2	2.10E+04	0/2	0/2	0.38 - 0.41
SVOA	Pyridine	mg/kg	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	N/A	0/2	N/A	N/A	N/A	0.76 - 0.82
RADS	Americium-241	pCi/g	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	5.99E+00	0/2	5.99E+02	0/2	0/2	0.022 - 0.022
RADS	Cesium-137	pCi/g	N/A	N/A	N/A	0/2	0/2	0/2	2.80E-01	0/2	1.02E-01	0/2	1.02E+01	0/2	0/2	0.082 - 0.087
RADS	Plutonium-238	pCi/g	N/A	N/A	N/A	0/2	0/2	0/2	N/A	0/2	2.87E+01	0/2	2.87E+03	0/2	0/2	0.016 - 0.038
RADS	Plutonium-239/240	pCi/g	7.60E-03	7.60E-03	7.60E-03	0/2	1/2	0/2	N/A	0/2	2.47E+01	0/2	2.47E+03	0/2	0/2	0.0069 - 0.036
RADS	Technetium-99	pCi/g	4.64E+00	4.64E+00	4.64E+00	0/2	1/2	1/2	2.80E+00	0/2	1.20E+03	0/2	1.00E+05	1/2	1/2	0.37 - 0.44
RADS	Thorium-228	pCi/g	8.60E-01	9.30E-01	8.95E-01	0/2	2/2	0/2	1.60E+00	0/2	N/A	0/2	N/A	N/A	N/A	0.03 - 0.2
RADS	Thorium-230	pCi/g	1.25E+00	1.38E+00	1.32E+00	0/2	2/2	0/2	1.40E+00	0/2	3.39E+01	0/2	3.39E+03	0/2	0/2	0.02 - 0.19
RADS	Thorium-232	pCi/g	5.50E-01	8.40E-01	6.95E-01	0/2	2/2	0/2	1.50E+00	0/2	N/A	0/2	N/A	N/A	N/A	0.02 - 0.07
RADS	Uranium-234	pCi/g	8.60E-01	1.63E+00	1.25E+00	0/2	2/2	1/2	1.20E+00	0/2	5.53E+01	0/2	5.53E+03	0/2	2/2	0.02 - 0.02
RADS	Uranium-235	pCi/g	2.90E-02	9.70E-02	6.30E-02	0/2	2/2	1/2	6.00E-02	0/2	3.40E-01	0/2	3.40E+01	0/2	1/2	0.018 - 0.024
RADS	Uranium-238	pCi/g	8.80E-01	1.68E+00	1.28E+00	0/2	2/2	1/2	1.20E+00	1/2	1.60E+00	0/2	1.60E+02	0/2	2/2	0.007 - 0.02

One or more samples exceed AL value
One or more samples exceed NAL value
One or more samples exceed background value
One or more samples exceed SSLs of RGA and UCRS groundwater protection

Counts of analyses are based on the maximum detected result from a sample (i.e., if a sample has analytical results from two different labs, only the maximum value is counted). Field replicates, or separate samples are counted independently.

The uranium (metal)/uranium (isotopic) may not be from the same sample thus a correlation between uranium (metal)/uranium (isotopic) data may not be possible.

FOD = frequency of detection
FOE = frequency of exceedance
N/A = not applicable

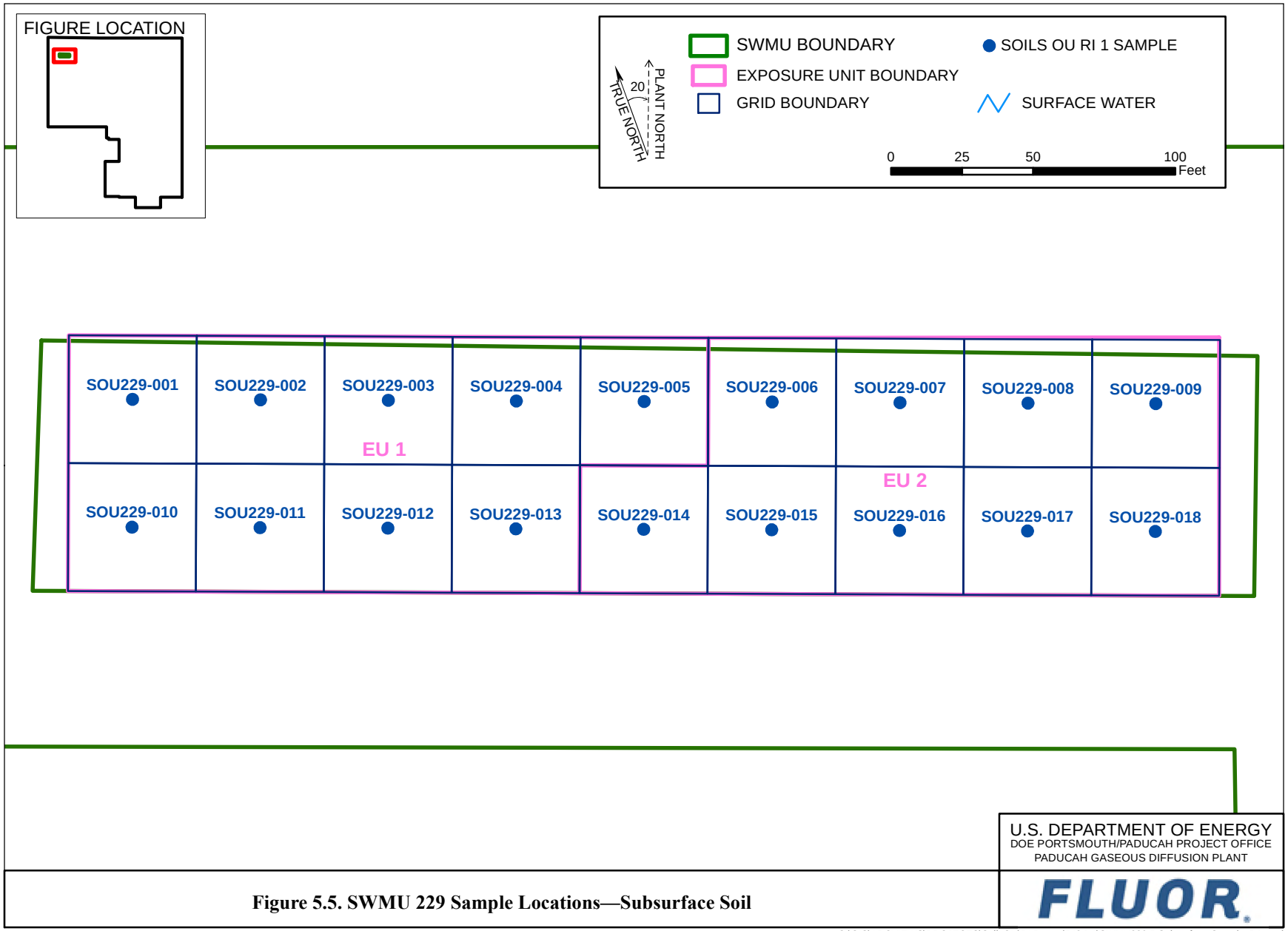

Figure 5.5. SWMU 229 Sample Locations—Subsurface Soil

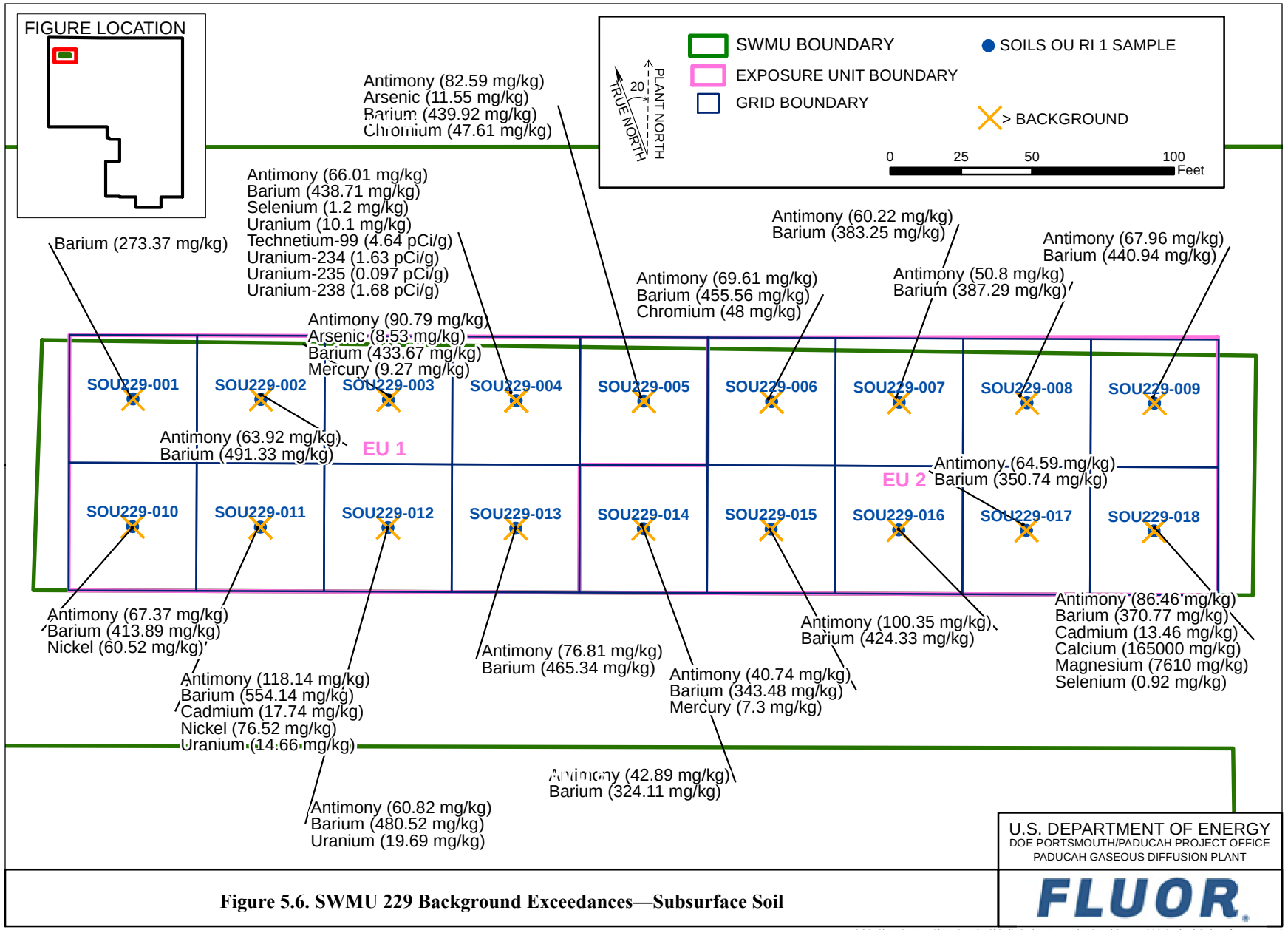

Figure 5.6. SWMU 229 Background Exceedances—Subsurface Soil

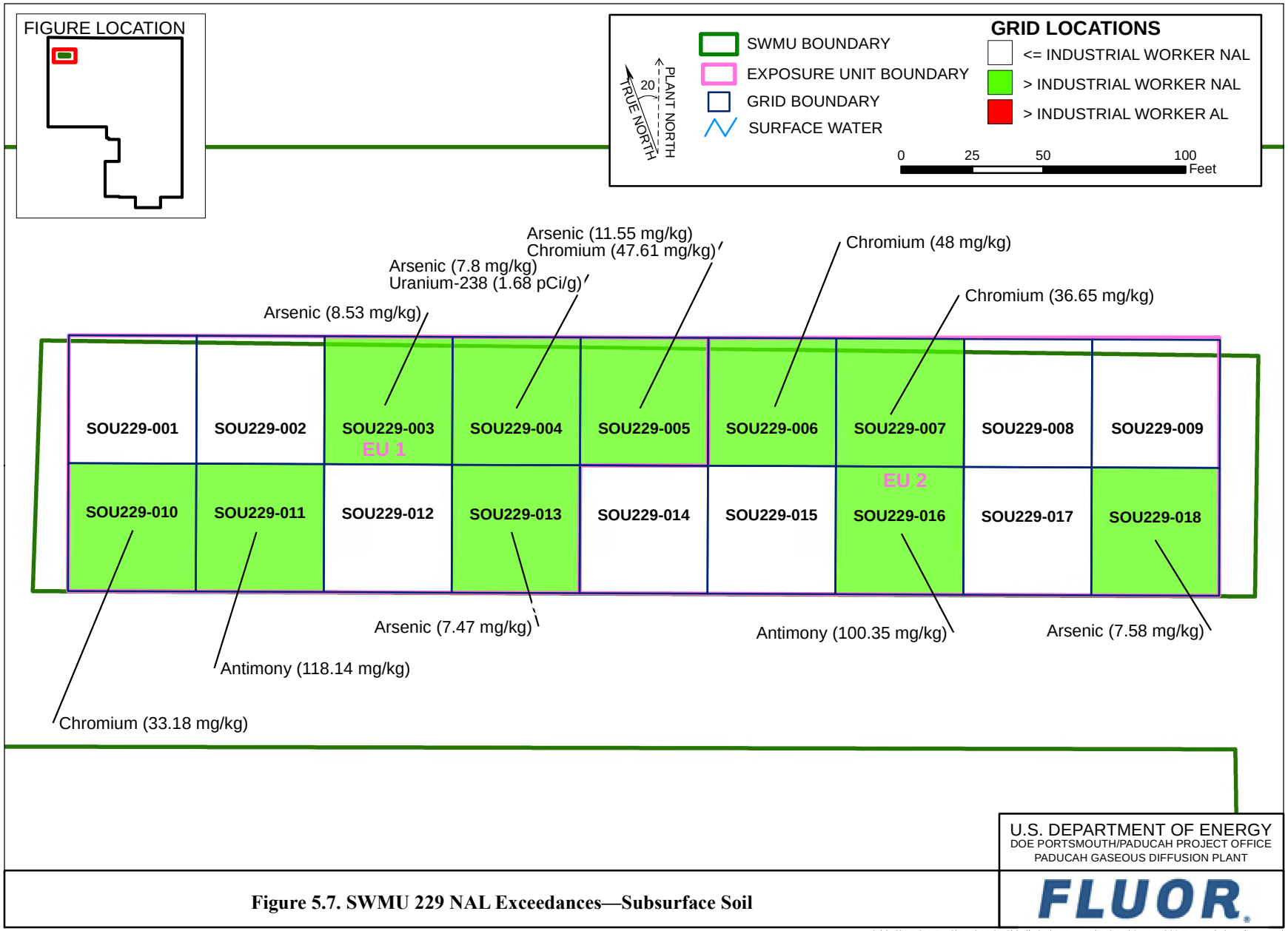

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Figure 5.7. SWMU 229 NAL Exceedances—Subsurface Soil

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provided in Appendix F. Grid numbers shown below are truncated from the figures. Figures contain the SWMU#–grid#, with zeros filling the appropriate spaces to make three digits.

The lateral extent of SWMU 229 subsurface soil contamination is considered defined adequately for supporting the BRA and FS. SWMU 229 consists of 2 EUs.

Metals

Antimony (EU1, EU2), arsenic (EU1), and chromium (EU1, EU2) were detected in the subsurface soil above both the background screening level and the industrial worker NAL. No metals were detected above both the background screening level and the industrial worker ALs in the subsurface soils.

The following metals were detected in the SWMU 229 subsurface soil above both the SSLs for the protection of UCRS groundwater and the background screening levels (if available): antimony (EU1, EU2), arsenic (EU1), barium (EU1, EU2), cadmium (EU1, EU2), mercury (EU1, EU2), molybdenum (EU1, EU2), nickel (EU1), selenium (EU1, EU2) and uranium (EU1). Additionally, antimony (EU1, EU2) and mercury (EU1, EU2) were detected above the SSL for the protection of RGA groundwater and the background screening level.

PCBs

No PCBs were detected for this unit.

SVOCs

No SVOCs were detected above NALs in the subsurface soils at SWMU 229.

VOCs

No VOCs were sampled for this unit.

RADs

Uranium-238 (EU1) was detected in the subsurface soil exceeding both the background screening level and industrial worker NAL values. No RADs exceeded the industrial worker AL value in the subsurface soil at SWMU 229.

Tc-99 (EU1), uranium-234 (EU1), uranium-235 (EU1) and uranium-238 (EU1) were detected in the SWMU 229 surface soil above the SSLs for the protection of UCRS groundwater and the background screening levels. Additionally, Tc-99 (EU1) was detected above the SSLs for the protection of RGA groundwater and the background screening level.

5.5 FATE AND TRANSPORT

Tc-99 and uranium-234 at SWMU 229 were identified for further evaluation under fate and transport (Chapter 4). SESOIL and AT123D simulation modeling results are summarized in Appendix C.

Tc-99 was selected for modeling because the average concentration at the SWMU exceeded both the RG SSL and background concentrations (see Appendix C). Modeling predicts Tc-99 to be 340 pCi/L at the

SWMU boundary when it reaches the RGA, which is less than 900 pCi/L screening criterion (DOE 2013).

Uranium-234 was detected at an activity concentration greater than both the background value and SSL and exhibited clustering when the results were viewed in 3-dimensions; however, the mass concentration of uranium assumed to be present based upon the assumption that the uranium isotopes were present at natural abundance would be 883 mg/kg. At 883 mg/kg, the average concentration is less than the average uranium concentration at SWMU 81 (2,502 mg/kg) that modeling in the Soils OU RI Report (DOE 2013) found not to migrate to the RGA within 1,000-years. Based on this, uranium-234 was not modeled at SWMU 229.

5.6 BASELINE RISK ASSESSMENT

Human Health. Potential risks and hazards for current/future human health for SWMU 229 were evaluated for each of the two EUs (~ 0.5 acres each) for direct contact. These results are summarized in Appendix D and in the subsections that follow, including the COCs and relative contributions to the overall ELCR and HI.

The cumulative ELCR and the cumulative HI for both EUs at SWMU 229 exceed the benchmarks of cumulative ELCR of 1E-06 and cumulative HI greater than 1, respectively for one or more scenarios; therefore, as stated in the Work Plan, Decision Rule D1a, (DOE 2010), this SWMU will be evaluated in the FS. As described in the BHHRA (Appendix D), COCs were identified after considering the results of the risk characterization and the uncertainties affecting the results.

COCs were identified as those COPCs considered contributing at least 1E-06 ELCR or 0.1 HI to a scenario of concern. The basis for COC identification is presented in Appendix D.

The identified COCs considered to contribute to the ELCR/HI, the EPC, and the RGOs calculated for a range of ELCR/HI benchmarks are presented in Chapter 6 for the future industrial worker, excavation worker, and the hypothetical resident. Chapter 6 also compares the EPC to the RGO for each COC under each exposure scenario. Chapter 6 summarizes the ELCR/HI posed by the COCs for this SWMU under each exposure scenario by depicting the maximum ELCR/HI contribution per COC.

Ecological Screening. COPECs for SWMU 229 include metals. Potential hazards for ecological receptors and the associated priority COPECs (maximum HQ ≥ 10) are discussed further in Chapter 6.

5.7 SWMU 229 SUMMARY

Goal 1. Characterize Nature and Extent of Source Zone

Plant processes that could have contributed to contamination at SWMU 229 are spill and/or discharges from the waste and equipment stored there.

COPCs for surface and subsurface soils from SWMU 229 are shown on Tables 5.1 and 5.2 as those analytes with green boxes under the “Industrial Worker/Frequency of Exposure (FOE)” columns for surface and shallow subsurface soil, and those with blue boxes under the “GW Protection Screen, RGA, and UCRS” columns for groundwater. For metals and radioisotopes, an orange box under the “Provisional Background” also must accompany the green and blue boxes. Contaminants were detected

greater than background and greater than industrial worker NALs to a maximum depth of 10 ft bgs. The COPCs identified for each EU in SWMU 229 are as follows:

- EU 1
  - Surface—metals, PAHs, SVOCs, radionuclides
  - Subsurface—metals, radionuclides
- EU 2
  - Surface—metals, PAHs, SVOCs, radionuclides
  - Subsurface—metals

Goal 2. Determine Surface and Subsurface Transport Mechanisms and Pathways

The contaminants at SWMU 229 are readily adsorbed to soil particles, so they do not migrate without a direct connection to surface water. The conceptual site model can be found in Appendix D.

Goal 3. Complete a Baseline Risk Assessment for the Soils OU

Cumulative ELCRs or HIs exceeded benchmarks of 1E-06 and 1, respectively, for the future industrial worker, excavation worker, and hypothetical residential scenarios. COCs for these scenarios for SWMU 229 are as follows:

- Future Industrial Worker
  - Arsenic
  - Total PAHs
  - Neptunium-237
  - Uranium-234
  - Uranium-235
  - Uranium-238
- Excavation Worker
  - Arsenic
  - Total PAHs
  - Neptunium-237
  - Uranium-234
  - Uranium-235
  - Uranium-238
- Hypothetical Resident (hazards evaluated against the child resident)
  - Arsenic
  - Technetium-99
  - Total PAHs
  - Neptunium-237
  - Uranium-234

— Uranium-235
— Uranium-238

COCs for additional scenarios are discussed in Appendix D.

Figure 5.8 shows the COCs exceeding RGOs for the future industrial worker.

Priority COCs (i.e., HQ > 1 or chemical-specific ELCR > 1E-04) for SWMU 229 are located in both EUs. The priority COCs are uranium-235 and uranium-238 for the industrial worker; antimony, uranium-234, and uranium-238 for the excavation worker; and antimony, arsenic, uranium-234, uranium-235, and uranium-238 for the hypothetical resident. Priority COCs for other scenarios are described in Appendix D.

Tc-99 was found as a COC at SWMU 229 as having a potential to affect the RGA groundwater. Although modeled-predicted concentrations in the RGA groundwater are lower than the screening criterion of 900 pCi/L, they are at concentrations that exceed 1E-06 risk. There were no priority COCs having a potential to affect the RGA groundwater.

For SWMU 229, COPECs exceed ESVs. Priority COPECs (i.e., maximum HQ ≥ 10) are the following:

- Aluminum
- Antimony
- Cadmium
- High Molecular Weight PAHs
- Iron
- Mercury
- Selenium
- Uranium
- Zinc

Goal 4. Support Evaluation of Remedial Alternatives

The representative data set used for SWMU 229 is sufficient to support decision making and indicates that an FS is appropriate. An uncertainty concerning depth of contamination should be considered in the FS. Possible remedial technologies applicable for this unit, as discussed in the Work Plan (DOE 2010), are posting, fencing (or other means of limiting access), excavation, and/or other remedial technologies that will be described in the FS.

5.8 SWMU 229 CONCLUSION

This RI Addendum defines adequately the nature and extent of contamination in soils at SWMU 229; an FS is appropriate for the SWMU due to cancer risks and/or noncancer hazards exceeding the decision rule benchmarks for scenarios including the future industrial worker, excavation worker, and hypothetical resident (DOE 2010). The reasonably anticipated future land use of this SWMU is industrial, as shown in the SMP (DOE 2015b).

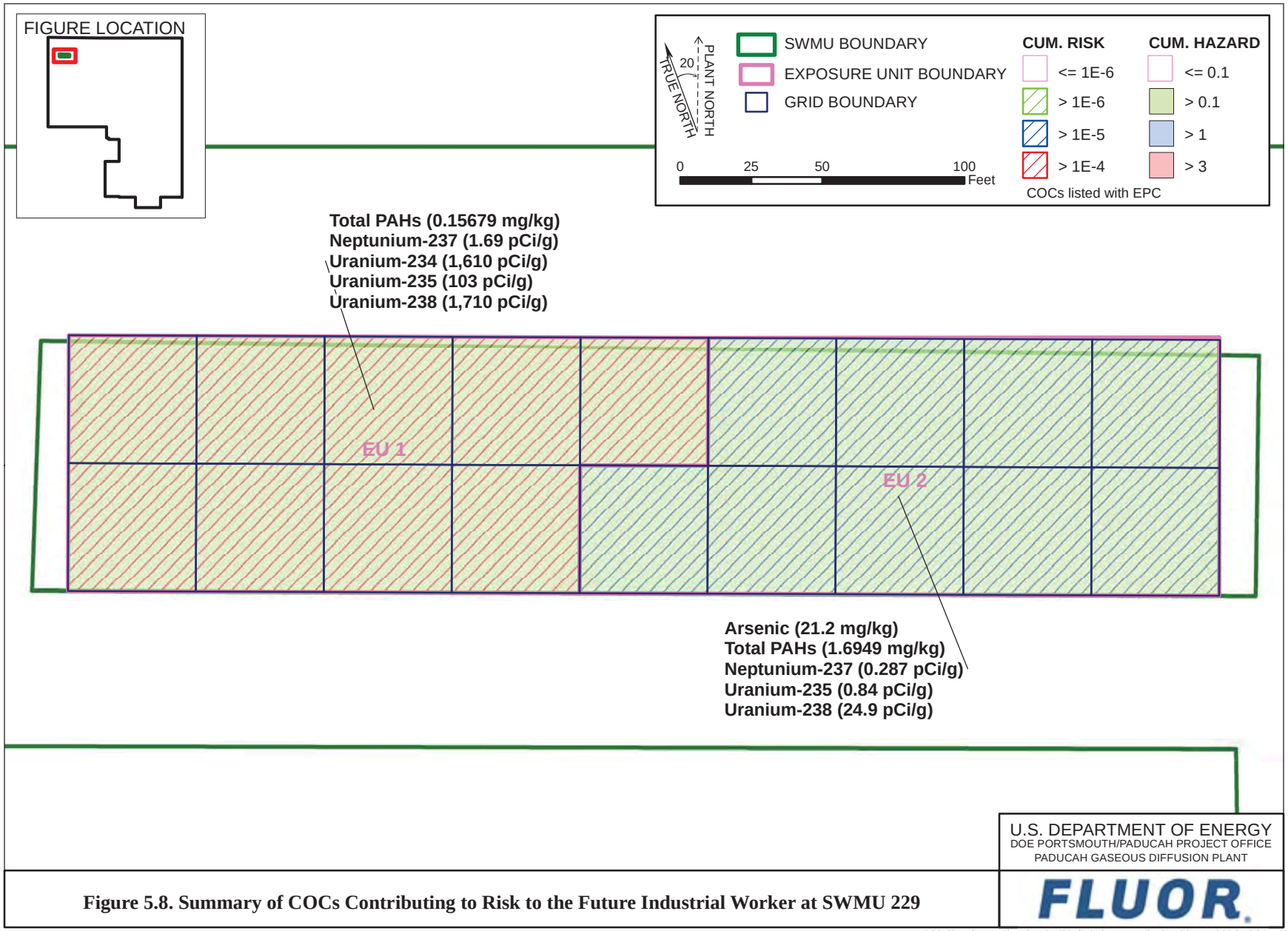

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Figure 5.8. Summary of COCs Contributing to Risk to the Future Industrial Worker at SWMU 229

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6. CONCLUSIONS FOR THE SOILS OU REMEDIAL INVESTIGATION

This RI was designed to investigate nature and extent of contamination and contaminant fate and transport and to characterize potential risks/hazards from potential current and future exposures[7] as a basis for evaluating remedial alternatives in an FS for SWMU 229 using historical data along with data collected during the Soils OU RI and Soils OU RI 2 to supplement the existing data. The final representative data set includes samples analyzed by laboratory and field methods to join with the historical data. Among the objectives for the sampling and analysis strategy were to provide sufficient delineation of COCs and to provide grid-based sampling that allows better estimates of average concentrations to be used for risk estimates.

The goals of this RI, consistent with Work Plan (DOE 2010), are as follows:

(1) Goal 1: Characterize Nature and Extent of Source Zone(s);
(2) Goal 2: Determine Surface and Subsurface Transport Mechanisms and Pathways;
(3) Goal 3: Complete a Baseline Risk Assessment for the Soils OU; and
(4) Goal 4: Support Evaluation of Remedial Alternatives.

6.1 GOAL 1: CHARACTERIZE NATURE AND EXTENT OF SOURCE ZONE(S)

The nature and extent of contamination at SWMU 229 is considered defined adequately.

To determine nature of contamination in surface soils, results of analyses in SWMU 229 were compared to surface background values, where available. Consistent with the Work Plan (DOE 2010), which identifies industrial or recreational use as the current and reasonably anticipated future land uses, results of analyses were compared further to future industrial worker NALs for SWMU 229 since it is located inside the Limited Area. Table 6.1 indicates the constituent that exceeded this screening in at least one location (shown with a green, italic *X*). Constituents that also exceed ALs are shown in bold, red font.

6.2 GOAL 2: DETERMINE SURFACE AND SUBSURFACE TRANSPORT MECHANISMS AND PATHWAYS

6.2.1 Migration to Groundwater

Screening evaluation, as described in Chapter 4 and Appendix C, identified SWMU 229 as having potentially problematic soil contamination by leaching to groundwater and impacting the RGA above drinking water standards. Tc-99 was the only soil constituent at SWMU 229 subjected to modeling. Further examination indicated that uranium-234 did not require modeling. Transport properties for the modeled constituent are listed in Table 6.2.

[7] The BHHRA in this report considers residential land use consistent with EPA Region 4 Human Health Risk Assessment Supplemental Guidance. As discussed in the Paducah SMP (DOE 2015b), the Paducah Human Health Risk Methods Document (DOE 2015c), and the Soils OU RI 2 Report (DOE 2015a), industrial, and not residential use, is the reasonably anticipated land use for SWMU 229. The risk characterization for the residential scenario will be used in subsequent documents to identify unlimited use/unlimited exposure for no further action determinations and any LUCs appropriate for reasonably anticipated land uses.

Table 6.1. Exceedances of NAL Screening

	Surface Soils	Subsurface Soils
	Future Industrial Worker*	Future Industrial Worker*
Metals		
Antimony	*X*	*X*
Arsenic	*X*	*X*
Chromium	*X*	*X*
SVOCs		
Total PAHs	*X*	
Radionuclides		
Cesium-137	*X*	
Neptunium-237	*X*	
Uranium-234	*X*	
Uranium-235	**X**	
Uranium-238	**X**	*X*

* Future Industrial Worker reflects default assumptions (i.e., 250 days/year for 25 years).
X constituent that exceeds the NAL in at least one location (DOE 2015c).
X constituent that also exceeds the AL (DOE 2015c).

Table 6.2. SWMU 229 Constituents for the Groundwater Pathway and Properties

Soil Constituents	Mol. Wt. (MW) (g/gmol)	Solubility in water (mg/L)	Diffusion in air (cm^2/s)	Diffusion in water (m^2/hr)	Henry's Constant ($atm.m^3/mol$)	K_{oc} (L/kg)	K_d[a] (L/kg)	Degradation Half Life (years)
Tc-99	99	7.18E+03[b]	N/A	3.60E-07	N/A	N/A	0.2	2.13E+05

[a] K_d values are taken from the EPA Web site http://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search, consistent with the Risk Methods Document, except for Tc-99 and uranium. The Tc-99 and uranium Kd values are set at levels consistent with the Burial Grounds Operable Unit to reflect the PGDP Site. The model input parameters are found in Table B.2 and Table B.3 of the *Remedial Investigation for the Burial Grounds Operable Unit at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0030&D2/R1, February 2010.

[b] Tc-99 solubility is derived from the geochemical database "thermo.com.V8.R6.230," which was prepared by Lawrence Livermore National Laboratory. The exact database used here is 'llnl.dat 4023 2010-02-09 21:02:42Z,' which was converted to PHREEQC format by Greg Anderson and David Parkhurst of USGS.

Based on the modeling results presented in Table 6.3, the incremental contributions of Tc-99 currently present in soil at SWMU 229 do not have the potential to impact the RGA groundwater at the SWMU boundary at a concentration (340 pCi/L) that exceeds the screening criterion of 900 pCi/L (DOE 2013). Consistent with the Soils OU RI Report (DOE 2013), 900 pCi/L was the criterion used in screening to determine if the SWMU was modeled for Tc-99 transport. Although the model predicts that the Tc-99 associated with the vadose zone at SWMU 229 will leach to the RGA, the mass flux of Tc-99 from the vadose zone to the RGA is insufficient to cause RGA groundwater concentrations to exceed the 900 pCi/L screening criterion. Model predictions indicate that for SWMU 229, dissolved Tc-99 reaches the underlying saturated zone at 32.06 years and the SWMU boundary at 32.6 years. The peak predicted Tc-99 concentration occurs at 37.5 years.

At SWMU 229, uranium-234 was detected at an activity concentration greater than both the background value and SSL and exhibited clustering when the results were viewed in 3-dimensions; however, the mass concentration of uranium assumed to be present based upon the assumption that the uranium isotopes were present at natural abundance would be 883 mg/kg. At 883 mg/kg, the average concentration for SWMU 229 is less than the average concentration at SWMU 81 (2,502 mg/kg), that modeling in the Soils OU RI Report (DOE 2013) found not to migrate to the RGA within 1,000 years. Based on this, uranium-234 was not modeled at SWMU 229.

Table 6.3. RGA Groundwater Modeling Results at the SWMU Boundary and Points of Exposure

SWMU	Soil Constituents	Maximum RGA Groundwater Concentration at SWMU Boundary (Time to Reach Boundary)
229	Tc-99	340 pCi/L (32.6 years)

6.2.2 Runoff

Section 5 and Table 6.7, included in the summary of the potential ecological risks, identifies the ground cover and whether the SWMU is located near a drainageway or outfall. Impacts in these receiving areas have been evaluated separately in the SWOU and are not quantified in this assessment (DOE 2008b). A removal action for the contaminated sediment associated with SWOU (On-Site) (DOE 2011) was conducted for Outfalls 001, 008, 010, 011, 015, and associated internal ditches. A final response action for internal ditches, outfalls, and creeks will be addressed by the SWOU, as described in the SMP (DOE 2015b). SWMU 229 has no direct connection to any drainageways.

6.3 GOAL 3: COMPLETE A BASELINE RISK ASSESSMENT FOR THE SOILS OU

PGDP is an industrial facility surrounded by a state-maintained wildlife refuge and residential property. The current and reasonably anticipated future use of locations within the Limited Area is industrial, and the reasonably anticipated future use of locations outside the Limited Area is recreational. The risk characterization for these current and reasonably anticipated future uses will be used when making risk management decisions in subsequent documents.

Consistent with the Paducah Human Health Risk Methods Document (DOE 2015c), which incorporates both EPA and Kentucky risk assessment guidance, the BHHRA for SWMU 229 characterized risk for a range of reasonably anticipated and hypothetical current and future use scenarios. In developing these scenarios, the concept of reasonable maximum exposure (RME) was used. Additionally, consistent with the results available, the exposure assessment primarily considered exposure to soil (surface and/or subsurface).

This section summarizes the following:

(1) Priority Contaminants. Identification of the contaminants that most frequently are present and contribute most substantially to the ELCR/HI estimates at SWMU 229.

(2) Relative Risks (ELCRs) and Hazards (HIs). Relative risks (ELCRs) and hazards (HIs) at SWMU 229 based on contact with contaminants in soil and interpretation of these as priorities for management action.

(3) Ecological risk/hazard considerations of potential ecological receptors.

(4) Other COPECs/Uncertainties.

6.3.1 Priority Contaminants

For SWMU 229, there were six COCs that exceeded either ELCR >1E-6 or HQ > 1 for the future industrial worker scenario based on analytical results. The six COCs were arsenic, Total PAHs, neptunium-237, uranium-234, uranium-235, and uranium-238. Two priority COCs [priority COCs are

identified as those COCs with a chemical-specific ELCR > 1E-04 or a chemical-specific HQ > 1, to highlight to risk managers the COCs driving Total ELCR or Total HQ at SWMU 229], uranium-235 and uranium-238, are associated with the highest Total ELCRs at SWMU 229 exceeding ELCR > 1E-04. Potential cancer risk and noncancer hazard for SWMU 229 are illustrated in Chapter 5, as appropriate. Table 6.4 lists the Priority COCs.

Table 6.4. SWMU 229 Future Industrial Worker Priority COCs

EU with Priority COCs	COC	Exposure Point Concentration	HQ	ELCR
1	Uranium-235	103 pCi/g	N/A	2.7E-04
1	Uranium-238	1,710 pCi/g	N/A	9.6E-04

6.3.2 Dose Assessment

The dose assessment performed for the surface soil estimated dose for SWMU 229 inside the Limited Area as high as 59.5 mrem/yr for the future industrial worker, which is higher than the 25 mrem/yr benchmark (DOE 2015c). Although the risk assessment estimates ELCR for radionuclides included in the total risk, a dose assessment for these constituents allows comparison of the detected levels (pCi/g), with an estimate of mrem/yr to consider DOE guidelines for radiation exposure. The results of this analysis indicate in a parallel analysis that radionuclides are significant contributors to the risk.

6.3.3 Relative Risks (ELCRs) and Hazards (HIs)

The BHHRA process allows a range of scenarios to be considered to help understand the contaminants that pose the greatest hazards. For SWMU 229, the scenarios consistent with reasonably anticipated future use include default assumptions used for future industrial worker since the SWMU is inside the Limited Area (DOE 2015c). Similarly, evaluation of ELCRs and HIs provides an upper bounding estimate, if the site were to become residential. Incidental ingestion of contaminated soil, dermal contact with contaminated soil, inhalation of particulate emitted from contaminated soil, and external exposure to ionizing radiation emitted from contaminated soil were the exposure routes evaluated in the BHHRA. Each of these exposure routes presented a pathway of concern (i.e., HI ≥ 0.1 and/or ELCR ≥ 1E-06) at SWMU 229.

Scenarios that assume some future contact with contaminants in the subsurface soil (e.g., the excavation worker) are used to consider contact with the entire soil column (0–10 ft bgs) either during construction or over the longer term as the site soils are mixed and disturbed for alternate uses.

Table 6.5 shows a summary of direct contact risks for SWMU 229, along with the highlighted scenario. The scenarios highlighted are those for the reasonably anticipated future use of the area of SWMU 229, as presented in the discussions in Chapter 5. Additionally, for SWMU 229, since it has more than one EU, the highest Total HI, Total ELCR, and Total Dose across both EUs are presented.

Table 6.5. Summary of Maximum Direct Contact Total HI, Total ELCR, and Total Doses for SWMU 229

EU	Scenario	Direct Contact*		
		Total HI	Total ELCR	Total Dose (mrem/yr)
Former Facilities				
1	Future Industrial Worker	< 1	***1.3E-03***	59.5
2	Future Industrial Worker	< 1	**5.2E-05**	0.8

Bold indicates total HI > 1 or total ELCR > 1E-06; ***bold italics*** indicates total HI > 3 or total ELCR > 1E-04.
*For direct contact, future industrial worker for SWMU 229 inside the Limited Area. Total HI and Total ELCR represent the cumulative value across all exposure routes assessed within this BHHRA (i.e., incidental ingestion, dermal contact, inhalation, and external exposure to ionizing radiation).

Following are the uncertainties affecting the estimation of ELCR and HI in the human health risk assessment for SWMU 229.

- The range of background was not considered beyond the initial screening against site-specific background.

- Concentration of total cancerous PAHs was used to estimate risk, and the minimum detection limit of the PAHs with toxicity equivalence factors was used when PAHs were not detected.

- Some detection limits for XRF data are above background concentrations and NALs; the COPCs identified using these data are expected to overstate the presence of these metals.

- For those constituents that never were detected within an EU, even if the detection limit is greater than the NAL, the constituent was not considered a COPC.

- Conservative (i.e., health protective) exposure factors are used when information available is limited in the form of using RME assumptions, per the Risk Methods Document (DOE 2015c). This may result in an overestimation of potential ELCRs and HIs.

- The risk assessment does not consider that concentrations of some COCs may be lower or higher in the future because of processes such as degradation and attenuation.

- Additivity of multiple chemicals is assumed. Whether assuming additivity can lead to an underestimation or overestimation of risk is unknown.

- Most of the assumptions about exposure and toxicity used in the BHHRA are representative of the maximums for each parameter. The result of combining several such upper-bound assumptions is that the final estimate of potential exposure or potential risk is conservative.

6.3.4 Ecological Risk Considerations

Consistent with the Paducah Ecological Risk Methods Document (DOE 2015d), which incorporates both EPA and Kentucky risk assessment guidance, the SERA was limited to a comparison of maximum concentrations in surface soils at the SWMU against ecological screening levels in order to identify COPECs. The SERA does not consider the limited habitat, SWMU size, or other factors that also need to be considered to characterize ecological risk. The following observations were made for the SERA as summarized on Tables 6.6 and 6.7.

Table 6.6. Summary of Suite of COPECs Retained in Surface Soil

SWMU	Media	Number of Metals	Number of Rads	Number of PCBs	Number of SVOCs	Number of VOCs
229	Soil	20	1	---	2	---

---: no COPECs

Table 6.7. SWMU 229 Ecological Risk Summary

Description	Area Acres	Ground Cover	Near a Surface Water Body?	Total HI[a]	Priority COPECs	Background (mg/kg)[b]	Maximum Detection or ½ Maximum Detection Limit (mg/kg)	Soil ESV (mg/kg)	EPC (mg/kg)	HQ[a]
DMSA OS-18	0.849	Soil/gravel mix	No	742	Aluminum	13000	6210	50	6210	124.2
					Antimony	0.21	150.45	0.27	104.8	388.1
					Cadmium	0.21	21.18	0.36	15.67	43.5
					Iron	28,000	27,400	200	14,399	72.0
					Mercury	0.2	5	0.1	5	50.0
					Selenium	0.8	10	0.52	10	19.2
					Uranium	4.9	155.81	5	71.61	14.3

[a] HI and HQ calculated from the EPC (Section E.3).
[b] Background values are for surface soil taken from DOE 2015c; ESVs are taken from DOE 2015d and Appendix E of this document.

The primary risk drivers when comparing maximum detection to ecological risk are metals. Metals, especially antimony and iron contribute the majority of the total estimated HQ for ecological risk.

6.3.5 Other COPECs/Uncertainties

As indicated in Appendix B, there may be uncertainties when using XRF data to estimate risks. Seven metals (aluminum, antimony, cadmium, iron, mercury, selenium, and uranium) show significant exceedances of the ESVs.

6.4 GOAL 4: SUPPORT EVALUATION OF REMEDIAL ALTERNATIVES

The representative data set used for SWMU 229 is sufficient to support decision making and indicates that an FS is appropriate. Other information was gathered in support of the evaluation of remedial alternatives to include infrastructure issues, extent of contamination, and verification of site descriptions. Possible remedial technologies applicable for this unit is, as discussed in the Work Plan (DOE 2010), posting, fencing (or other means of limiting access), excavation, and/or other remedial technologies that will be described in the FS. Chapter 5 contains SWMU 229 specific details.

6.4.1 Remedial Goal Options

SWMU 229 requires further review in the FS to evaluate the appropriate options to address current or potential future risks/hazards. The BHHRA in this RI characterized the cancer risks and noncancer hazards (i.e., Total ELCRs and Total HIs, respectively) potentially resulting from exposure to contaminants in soil.

RGOs were calculated for each COC as determined by the conclusions of the BHHRA. These RGOs should not be interpreted as being cleanup goals, but as risk-based values that may be used by risk managers to revise preliminary remediation goals to be consistent with the RAOs in the FS and to develop cleanup goals from these revised preliminary remediation goals in the ROD. The COCs and RGOs consistent with the current and reasonably anticipated future use scenarios (i.e., industrial use, including both the industrial and excavation worker) are shown in Table 6.8.

Table 6.8. RGOs for SWMU 229

EU	COC	EPC	Units	ELCR	RGO at ELCR=1E-6	RGO at ELCR=1E-5	RGO at ELCR=1E-4	HI	RGO at HI=0.1	RGO at HI=1	RGO at HI=3
Industrial Worker Soil Exposure											
1	PAH, Total	1.57E-01	mg/kg	1.8E-06	8.81E-02	8.81E-01	8.81E+00	N/A	N/A	N/A	N/A
1	Neptunium-237	1.69E+00	pCi/g	6.6E-06	2.55E-01	2.55E+00	2.55E+01	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	3.1E-05	5.16E+01	5.16E+02	5.16E+03	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	2.7E-04	3.78E-01	3.78E+00	3.78E+01	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	9.6E-04	1.78E+00	1.78E+01	1.78E+02	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	1.9E-05	8.81E-02	8.81E-01	8.81E+00	N/A	N/A	N/A	N/A
2	Arsenic	2.12E+01	mg/kg	1.5E-05	1.40E+00	1.40E+01	1.40E+02	< 0.1	N/A	N/A	N/A
2	Neptunium-237	2.87E-01	pCi/g	1.1E-06	2.55E-01	2.55E+00	2.55E+01	N/A	N/A	N/A	N/A
2	Uranium-235	8.40E-01	pCi/g	2.2E-06	3.78E-01	3.78E+00	3.78E+01	N/A	N/A	N/A	N/A
2	Uranium-238	2.49E+01	pCi/g	1.4E-05	1.78E+00	1.78E+01	1.78E+02	N/A	N/A	N/A	N/A
Excavation Worker Surface and Subsurface Soil Exposure											
1	Antimony	1.50E+02	mg/kg	N/A	N/A	N/A	N/A	1.1	1.32E+01	1.32E+02	3.95E+02
1	Arsenic	1.17E+01	mg/kg	4.6E-06	2.51E+00	2.51E+01	2.51E+02	0.1	8.07E+00	8.07E+01	2.42E+02
1	Uranium	1.56E+02	mg/kg	N/A	N/A	N/A	N/A	0.2	9.80E+01	9.80E+02	2.94E+03
1	Neptunium-237	1.69E+00	pCi/g	1.0E-06	1.67E+00	1.67E+01	1.67E+02	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	3.7E-05	4.31E+01	4.31E+02	4.31E+03	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	4.2E-05	2.43E+00	2.43E+01	2.43E+02	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	1.8E-04	9.46E+00	9.46E+01	9.46E+02	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	5.3E-06	3.23E-01	3.23E+00	3.23E+01	N/A	N/A	N/A	N/A
2	Antimony	1.08E+02	mg/kg	N/A	N/A	N/A	N/A	0.8	1.32E+01	1.32E+02	3.95E+02
2	Arsenic	2.12E+01	mg/kg	8.4E-06	2.51E+00	2.51E+01	2.51E+02	0.3	8.07E+00	8.07E+01	2.42E+02
2	Uranium-238	2.49E+01	pCi/g	2.6E-06	9.46E+00	9.46E+01	9.46E+02	N/A	N/A	N/A	N/A

Table 6.8. RGOs for SWMU 229 (Continued)

EU	COC	EPC	Units	ELCR	RGO at ELCR=1E-6	RGO at ELCR=1E-5	RGO at ELCR=1E-4	HI	RGO at HI=0.1	RGO at HI=1	RGO at HI=3
Hypothetical Child Residential User Soil Exposure											
1	PAH, Total	1.57E-01	mg/kg	6.9E-06	2.27E-02	2.27E-01	2.27E+00	N/A	N/A	N/A	N/A
1	Antimony	1.50E+02	mg/kg	N/A	N/A	N/A	N/A	4.8	3.13E+00	3.13E+01	9.39E+01
1	Cadmium	2.12E+01	mg/kg	N/A	N/A	N/A	N/A	0.4	5.28E+00	5.28E+01	1.58E+02
1	Uranium	1.56E+02	mg/kg	N/A	N/A	N/A	N/A	0.7	2.34E+01	2.34E+02	7.01E+02
1	Neptunium-237	1.69E+00	pCi/g	2.2E-05	7.72E-02	7.72E-01	7.72E+00	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	2.8E-04	5.73E+00	5.73E+01	5.73E+02	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	9.1E-04	1.14E-01	1.14E+00	1.14E+01	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	3.4E-03	4.99E-01	4.99E+00	4.99E+01	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	7.5E-05	2.27E-02	2.27E-01	2.27E+00	N/A	N/A	N/A	N/A
2	Antimony	1.08E+02	mg/kg	N/A	N/A	N/A	N/A	3.5	3.13E+00	3.13E+01	9.39E+01
2	Arsenic	2.12E+01	mg/kg	8.0E-05	2.67E-01	2.67E+00	2.67E+01	1.2	1.73E+00	1.73E+01	5.19E+01
2	Cadmium	2.01E+01	mg/kg	N/A	N/A	N/A	N/A	0.4	5.28E+00	5.28E+01	1.58E+02
2	Uranium	7.45E+01	mg/kg	N/A	N/A	N/A	N/A	0.3	2.34E+01	2.34E+02	7.01E+02
2	Neptunium-237	2.87E-01	pCi/g	3.7E-06	7.72E-02	7.72E-01	7.72E+00	N/A	N/A	N/A	N/A
2	Uranium-234	1.22E+01	pCi/g	2.1E-06	5.73E+00	5.73E+01	5.73E+02	N/A	N/A	N/A	N/A
2	Uranium-235	8.40E-01	pCi/g	7.4E-06	1.14E-01	1.14E+00	1.14E+01	N/A	N/A	N/A	N/A
2	Uranium-238	2.49E+01	pCi/g	5.0E-05	4.99E-01	4.99E+00	4.99E+01	N/A	N/A	N/A	N/A

Grayed cells indicate EPC value is lower than RGO value or an RGO value is not applicable.
N/A = Not applicable because the COC was not applicable (i.e., the COC was of concern for HI, but not ELCR, or it was of concern for ELCR, but not HI).

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APPENDIX A

TECHNICAL MEMORANDUM FOR FIELD ACTIVITIES

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ACRONYMS

AOC	area of concern
bgs	below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	*Code of Federal Regulations*
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ES&H	environment, safety, and health
FS	feasibility study
KPDES	Kentucky Pollutant Discharge Elimination System
OU	operable unit
PGDP	Paducah Gaseous Diffusion Plant
PPE	personal protective equipment
QC	quality control
RCRA	Resource Conservation and Recovery Act
RCT	radiological control technician
RI	remedial investigation
SWMU	solid waste management unit

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A.1. INTRODUCTION

The purpose of this memorandum is to provide certain technical details regarding field activities pertaining to the Soils Operable Unit (OU) Remedial Investigation (RI) for Solid Waste Management Unit (SWMU) 229. A brief summary of project objectives is provided below; a more thorough discussion is contained in the main text of the report.

The Soils OU is one of the OUs located within the Paducah Gaseous Diffusion Plant (PGDP). This OU consists of contamination associated with PGDP's soils.

The primary focus of this RI was to collect field and fixed-base analytical data necessary to determine the nature and extent of any soil contamination. The data will be used to support the completion of a baseline human health risk assessment and a screening-level ecological risk assessment. The data also will be used in conjunction with other data that may be necessary to evaluate appropriate remedial alternatives, as necessary, at Solid Waste Management Unit (SWMU) 229.

Table A.1 presents procedures and work instructions that were used to complete the fieldwork conducted as part of the RI.

Table A.1. Examples of Procedures Used in the RI

Work Instructions or Procedures Required for Fieldwork and Sampling Activities
Archival of Environmental Data Within the Environmental Restoration Program
Chain-of-Custody
Cleaning and Decontaminating Sample Containers and Sampling Equipment
Data Entry
Data Management Coordination
Data Validation
Environmental Radiological Screening
Equipment Decontamination
Field Quality Control
Identification and Management of Waste not from a Radioactive Material Management Area
Labeling, Packaging, and Shipping of Environmental Field Samples
On-Site Handling and Disposal of Waste Materials
Opening Containerized Waste
Paducah Contractor Records Management Program
Quality Assured Data
Sampling of Soil
Composite Sampling
Use of Field Logbooks

The original scope of the soils OU consisted of 86 solid waste management units (SWMUs)/areas of concern (AOCs). During the Soils OU RI conducted in 2010, grid-based sampling was performed at SWMU 229. Sixteen SWMUs/AOCs, including SWMU 229, were determined to require additional characterization subsequent to the Soils OU RI to delineate the nature and extent of contamination. A work plan addendum was developed and approved to describe how additional sampling would be performed (DOE 2014). This work plan addendum supplemented the approved Soils OU RI/Feasibility Study (FS) Work Plan (Work Plan) (DOE 2010), which was completed in June 2010. The work performed in this phase of the project was referred to as the Soils OU RI 2. During the course of the Soils OU RI 2 fieldwork, SWMU 229 consistently contained standing water. As stated in the survey plan of the work plan addendum (DOE 2014), gamma radiological surveys would not be performed in areas of

standing water; therefore, the planned activities (i.e., radiological walkover survey and a judgmental grab sample) for this unit could not be completed. After discussion among the Federal Facility Agreement parties on December 2, 2014, it was concluded that the activities for SWMU 229 would need to be conducted at a later time when the unit was free of standing water and reported in an addendum to the Soils OU RI 2 report once field activities were completed. A gamma radiological walkover survey was performed and a judgmental sample was collected in October 2015.

A.2. SOIL SAMPLING STRATEGY

The field sampling strategy used for the RI consisted of intrusive media sampling (surface and subsurface soil). The investigation activities used standard industry practices that were consistent with U.S. Environmental Protection Agency (EPA) procedures and protocols. Sampling activities for the Soils OU focused on the soils from 0–10 ft below ground surface (bgs).

Soil samples generally were taken by hand using a hand-auger for the 0–1 ft bgs; the 1–4 ft bgs were collected with a track-mounted rig capable of direct push technology drilling. This track-mounted drill rig utilized push rods to advance a soil sample tube with an acetate liner to collect undisturbed soil samples. If refusal was met using the push rods, the sample was offset 10 ft and attempted again up to 2 times. Samples consisted of a 5-point composite in each 45 ft by 45 ft grid and for each depth interval, as described in the Work Plan (DOE 2010).

The field crew sampled the soil borings in accordance with U.S. Department of Energy (DOE) Prime Contractor-approved procedures, consistent with *Environmental Investigation Standard Operating Procedures and Quality Assurance Manual* (EPA 2001). As soon as the drill crew recovered the acetate liner containing the soil sample, the soil core was placed in the sample preparation area. A health and safety specialist and radiological control technician (RCT) scanned the acetate sleeve and the ends of the soil core for volatile organic compounds and radiation before releasing the core to the sample crew. Once the soil core in acetate sleeve was cleared, the sample crew opened the acetate sleeve with a utility knife and, once again, a health and safety officer and radiation control officer scanned the sample for contamination. When contamination was found, the health and safety officer and radiation control officer directed the field crew in any additional personal protective equipment (PPE) requirements and appropriate handling precautions.

Immediately upon approval from the health and safety specialist and RCT, the field crew collected the samples by placing the soil in a clean bowl and mixed thoroughly. Samplers placed the resulting soil mixture in the appropriate sample jars for analysis.

A.3. SURVEYING

As the field crew performed the Soils OU sampling, they marked the boring locations using flagging and/or paint. Global Positioning System units with submeter accuracy documented the sample locations. The RI included surveying of sampling center grid locations prior to sampling activities. This survey work was performed by or under responsible charge of a Professional Land Surveyor registered in the Commonwealth of Kentucky, locating each sample point with its horizontal and vertical position using the PGDP coordinate system for horizontal control. Additionally, the survey identified the State Plane Coordinates for each sample location using the U.S. Coast and Geodetic Survey North American Datum of 1983. The datum for vertical

control was the U.S. Coast and Geodetic Survey North American Vertical Datum of 1988. Accuracy for this work was that of a Class 1 First Order survey.

Project personnel entered the coordinates into the Paducah Project Environmental Measurements System and the coordinate locations were transferred with the station's ready-to-load file to the Paducah Oak Ridge Environmental Information System.

The RI also performed nonintrusive data collection (gamma radiological walkover survey) for SWMU 229. Biased, 0–6-inch samples were taken from a location selected by inflection point analysis in SWMU 229 and submitted to the fixed-base laboratory for radionuclide analysis.

A.4. SAMPLING PROCEDURES

During the sampling event, two types of samples—soil and field quality control (QC)—were collected and submitted for analysis. Prior to initiation of field sampling, all sample team members completed all required training.

The sampling team collected, stored, and shipped the samples according to preestablished QC protocols and approved project procedures, which were consistent with EPA Region 4 sampling methodologies. Sample container, preservation, and holding time requirements were in accordance with the EPA Engineering Support Branch Standard Operating Procedures.

Samples collected for this project were assigned unique sample identifiers that were recorded on the sample labels and chain-of-custody forms.

An example of the sample numbering scheme used for SWMU 229, as discussed in the Work Plan (DOE 2010), is provided below.

SOUsssseeeMA000

Where:

SOU	Identifies the project (i.e., Soils OU)
sss	Identifies the SWMU being investigated
eee	Identifies the grid
M	Identifies the media type (W identifies the sample as water, S identifies the sample as soil)
A	Identifies the sequential sample (usually "A" for a primary sample and "B" for a secondary sample) If additional rounds of sampling are required, the sequential letter designations will continue.
000	Identifies the planned depth of the sample in ft bgs

Sample team crew members directly affixed labels to the sample containers that included the following information:

- Station name
- Sample identification number
- Sample matrix
- Sample type
- Type or types of analysis required
- Date and time of collection
- Sampler name
- Sample preservation (if required)
- Destination laboratory

The sampling team wore proper PPE during sampling. PPE consisted of, in part, company-issued clothing, safety glasses, and latex gloves. Sampling in radiological contamination areas sometimes necessitated modifications of the PPE requirements (as prescribed in work permits and directed by the project's health physics technician).

A.4.1 SOIL SAMPLES

Samples were collected in accordance with the Work Plan (DOE 2010) and addendum (DOE 2014). The field crew sampled the soil borings in accordance with DOE Prime Contractor-approved procedures, consistent with EPA guidance (EPA 2001). Soil was placed in a clean, stainless steel bowl and mixed thoroughly using a stainless steel spoon to homogenize the soil taken from the sample interval before sampling for other analyses.

Sample team members filled the sample containers and ensured that each lid was tightened securely. The sample containers then were placed in a cooler with an ice pack to maintain a preservation temperature of 4°C. Crew members recorded all required information in the sampling logbook.

A.4.2 FIELD QC SAMPLES

To ensure reliability of the analytical data and to meet the data quality objectives for the project, the following QC sample types were obtained during sample collection.

- Field Blanks—Field blanks served as a check for potential airborne environmental contamination at the sample site. For the field blanks, the sample crew typically filled sample bottles with deionized water for samples required for fixed-base laboratory analysis and with clean soil for samples required for field laboratory analysis in the project's sample staging area and transported the bottles to the field sample station where they were opened during the sampling process. Field blanks also were used as a reagent blank, as needed. Field blanks were collected at a frequency of 1 in 20 samples (5%) for each sample matrix.

- Field Duplicate Samples—Field duplicate samples determined the sampling variance. The sampling crew collected 1 duplicate for every 20 samples (5%), per matrix. The field duplicate was analyzed for the same set of analytical parameters as the sample it duplicated.

A.5. FIELD DECONTAMINATION

The field decontamination procedure, *Decontamination of Sampling Equipment and Devices* (CP4-ES-2702), determined the decontamination activities for the stainless steel spoons and bowls used in soil sampling. This procedure, as applied during the RI, is summarized as follows:

- Equipment first was cleaned with tap water and nonphosphate detergent, using a brush if necessary, to remove particulate matter and surface films.
- The equipment then was rinsed thoroughly with tap water, followed by an analyte-free water rinse, and then wiped with an isopropyl alcohol towelette.
- Cleaned sample equipment was allowed to air dry.
- Cleaned equipment was handled only by personnel wearing clean latex gloves to prevent recontamination.
- If cleaned sampling equipment was not reused immediately, it was wrapped in aluminum foil.

Large Equipment Decontamination (CP4-ER-2701) governed the cleaning of other sampling equipment such as the drill rigs and associated tooling. This procedure provides for the use of high-pressure steam as the primary cleaning agent. The on-site decontamination facility, C-752, supported cleaning activities for the drill rig and associated tooling during sampling.

A.6. WASTE MANAGEMENT

The Work Plan (DOE 2010) included a project-specific waste management plan to provide instruction regarding waste storage and disposition. A variety of wastes were generated during the field investigation, including sample residuals and associated waste derived from sample collection. The waste generated was stored in Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) waste storage areas within the CERCLA AOC during the characterization period and prior to disposal. Consistent with EPA Policy, the storage of waste within the CERCLA AOC does not trigger Resource Conservation and Recovery Act (RCRA) storage requirements (similarly, movement of waste within a CERCLA AOC does not trigger RCRA disposal requirements). As a best management practice, waste storage areas within the CERCLA AOC were managed in accordance with the substantive requirements of RCRA. Because this is a CERCLA project, the administrative requirements do not apply.

PPE was considered to fall into the same waste classification as the environmental media with which it came into contact. PPE, plastic, and paper were segregated by classification, collected in plastic bags, and labeled appropriately. These items then were handled as solid waste and dispositioned based on the waste classification of the residual soil samples.

Decontamination water that included small quantities of soil/mud was generated from cleaning the equipment. The water was collected and stored in a polyethylene tank and discharged to the Kentucky Pollutant Discharge Elimination System (KPDES) Outfall 001 after final characterization documented that the stored water met release criteria in the KPDES permit for Outfall 001.

Solid waste was containerized in 55-gal drums, or approved equivalent, that were lined with a thick plastic liner and placed in CERCLA waste storage areas. The amount of free liquid was minimized. Any substantial amount of free liquid was decanted and placed in an approved container. Drummed soils and other solid wastes were being disposed of in the C-746-U Landfill.

All clean trash (i.e., trash that was not chemically or radiologically contaminated) was segregated according to established guidelines and then collected and disposed of. Examples of clean trash are office paper, aluminum cans, packaging materials, glass bottles not used to store potentially hazardous chemicals, aluminum foil, and food items.

Based on sample analyses, existing data, or process knowledge, the waste was classified into one of the following categories:

- RCRA-listed hazardous waste
- RCRA-characteristic hazardous waste
- Polychlorinated biphenyl waste
- Low-level waste
- Mixed waste
- Nonhazardous waste

Waste minimization was implemented in accordance with Hazardous and Solid Waste Amendments of RCRA of 1984 as well as other requirements. Requirements specified in the waste management plan regarding waste generation, waste tracking, waste reduction techniques, and the waste reduction program, in general, also were implemented.

To support DOE's commitment to waste reduction, an effort was made during field activities to minimize waste generation as much as possible, largely through ensuring that potentially contaminated wastes were localized and did not come into contact with any clean media (which could create more contaminated waste). Waste minimization also was accomplished through waste segregation, selection of PPE, waste handling (spill control), and the use of alternative treatment standards.

A.7. ENVIRONMENT, SAFETY, AND HEALTH

A project-specific environment, safety, and health (ES&H) plan was included as Chapter 10 in the approved Work Plan (DOE 2010) and was used to provide instruction regarding safety and health of workers, the public, and the environment. The ES&H plan established the specific applicable standards and practices to be used during execution of the RI to protect the safety and health of workers, the public, and the environment. The document contained information about the sites, potential contaminants and hazards that may be encountered on-site, and hazards inherent in routine procedures. The list of contaminants was site-specific and based on previous investigations. The plan also outlined directly, or by reference, federal and state standards, pertinent consensus standards, and applicable contract requirements. The ES&H plan was implemented in accordance with 29 *CFR* § 1910.120, "Hazardous Waste Operations and Emergency Response." Additional health and safety requirements were incorporated into the ES&H plan for the various field activities through preparation of project-specific activity hazard analyses.

The project team held daily safety and plan of the day meetings at the beginning of each shift. This approach ensured that the planned daily activities were reviewed prior to execution and the potential

hazards were identified and discussed with the entire field team. These meetings are documented in the project work package and in the field logbooks.

A.8. FIELDWORK DOCUMENTATION

Field documentation was maintained throughout the RI in various types of documents and formats, including the field logbooks, sample labels, sample tags, chain-of-custody forms, and field data sheets. The following general guidelines for maintaining field documentation were implemented. Documentation requirements are listed below. Entries were written clearly and legibly using indelible ink.

- Corrections were made by striking through the error with a single line that did not obliterate the original entry. Corrections were dated and initialed.

- Dates and times were recorded using the format "mm/dd/yy" for the date and the military clock (i.e., 24-hour) for the time.

- Zeroes were recorded with a slash (/) to distinguish them from the letter O.

- Blank lines were prohibited. Information was recorded on each line or a blank line was lined out, initialed, and dated.

- No documents were altered, destroyed, or discarded, even if they were illegible or contained inaccuracies that required correction.

- Information blocks on field data forms were completed or a line was drawn through the unused section, and the area was dated and initialed.

- Unused logbook pages were marked with a diagonal line drawn from corner to corner and a signature and date was placed on the line.

- Photocopies of logbooks, field data sheets, and chain-of-custody forms were made and stored in the project file.

- The following information was recorded on the outside of the front cover of each logbook using indelible ink:

    — Project name
    — Unique logbook name and number
    — Client and contract number
    — Task and document control number
    — Activity or site name
    — Start and completion date of the logbook

Quality assurance personnel conducted periodic reviews of the data forms and logbooks (including data forms placed in the logbooks) prepared by field personnel to verify the following:

- Accuracy of entries;
- Legibility and clarity of entries;
- Completeness, to ensure that at least the minimum required information was recorded;

- Consistency of information recorded; and
- Signature and date of entries by the designated team member.

A.9. RECTIFICATION OF PLANNED SAMPLE LOCATIONS

A.9.1 INTRODUCTION

A Geographic Information System provided sample coordinates from maps of the intended sample locations in the Soils OU RI/FS Work Plan addendum (DOE 2014). Conventional survey methods were used to locate the center point sample coordinates at each grid within the SWMU.

A.9.2 DISCUSSION OF PLANNED SAMPLE LOCATIONS

Table A.2 is a summary of the number of samples planned and the number of samples collected during the 2010 field investigation for Soils OU RI 1 Report (DOE 2013) for SWMU 229. In 2015, only a judgmental grab sample was taken at a location based on highest count per minute during the gamma radiological walkover survey. Site conditions did not necessitate modifications of the sampling strategy for SWMU 229.

Table A.2. Samples Collected

SWMU/ AOC	Planned Grid Samples	Collected Grid Samples	Contingency/ Step-out Samples Anticipated	Contingency/ Step-out Samples Collected
229	18	18	0	0

Note: Sample totals are from the Soils OU RI 1 Report field investigation for SWMU 229 (DOE 2013).

A.10. REFERENCES

DOE (U.S. Department of Energy) 2010. *Work Plan for the Soils Operable Unit Remedial Investigation/Feasibility Study at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0120&D2/R2, U.S. Department of Energy, Paducah, KY, June.

DOE 2014. *Addendum to the Work Plan for the Soils Operable Unit Remedial Investigation/Feasibility Study at the* Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Remedial Investigation 2, Sampling and Analysis Plan, DOE/LX/07-0120&D2/R2/A1/R1, U.S. Department of Energy, Paducah, KY, August.

EPA (U.S. Environmental Protection Agency) 2001. *Environmental Investigation Standard Operating Procedures and Quality Assurance Manual*, U.S. Environmental Protection Agency, Region 4, Atlanta, GA, November.

APPENDIX B

DATA QUALITY ANALYSIS

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ACRONYMS

DQO	data quality objective
DQA	data quality analysis
EU	exposure unit
FOD	frequency of detection
FS	feasibility study
GWS	gamma walkover survey
MDC	minimum detectable concentrations
OU	operable unit
NAL	no action level
PAH	polycyclic aromatic hydrocarbon
RI	remedial investigation
SQL	sample quantitation limit
SWMU	solid waste management unit
SVOC	semivolatile organic compound
VOC	volatile organic compound
XRF	X-ray fluorescence

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Historical sampling for Solid Waste Management Unit (SWMU) 229 occurred during the sampling effort designed for the Soils Operable Unit (OU) Remedial Investigation (RI). The goals for this RI, as stated in the work plan (DOE 2010) and addendum (DOE 2014), include providing data for characterization of source zones, defining extent of contamination in soil, risk characterization, and evaluation of remedial alternatives. Sampling for the Soils OU RI included collection of laboratory analytical data with field data that included results from X-ray fluorescence (XRF) and polychlorinated biphenyl (PCB) field test kits. This section provides a review of the overall data set to determine potential data quality issues that limit the uses of some of these data to support decisions at these sites. Table B.1 provides a general overview of the data set.

Table B.1. Summary of Sampling

	Surface Fixed-base Laboratory	Surface Field Laboratory	Subsurface/ Shallow Fixed-base Laboratory	Subsurface/ Shallow Field Laboratory	Surface Historical Data	Subsurface/ Shallow Historical Data
Total:	1	0	0	0	21	19

Depth	Analytical Group	Number of RI 2 Addendum Samples	Number of Historical Samples (RI 1)
Surface*	VOCs	0	0
	SVOCs	0	2
	PCBs	0	19
	Metals	0	4
	Radionuclides	2	4
	Metals by XRF	0	19
	PCBs by test kit	0	2
Subsurface*	VOCs	0	0
	SVOCs	0	2
	PCBs	0	2
	Metals	0	2
	Radionuclides	0	2
	Metals by XRF	0	19
	PCBs by test kit	0	19

*Surface is defined as 0–1 ft bgs and Subsurface is defined as 1–16 ft bgs.

The field sampling strategy for the original RI included elements of stratified sampling, grid sampling, adaptive cluster sampling, composite sampling, and random sampling. These data, as described in detail for each exposure unit (EU), were collected consistent with the protocols documented in the work plan.

B.1. HISTORICAL DATA

The historical data set which the data quality analysis (DQA) evaluates is defined in the Soils OU RI/Feasibility Study (FS) Work Plan (DOE 2010) and in the Soils OU RI Report (DOE 2013). This evaluation will look only at whether the location from which the data were collected is representative of the SWMU area (i.e., was the sample collected within the area of the influence of the SWMU) and whether the data itself was analyzed to a quality adequate for decision making for this Soils OU RI 2 Addendum.

Some of the decision rules that will be used in the DQA when determining the usability of historical data were established in the RI/FS Work Plan. Those rules are the following:

- Historical data that have been qualified as rejected by data validation or by data assessment will not be included in the historical data set.
- Historical data that contain units inconsistent with the sampled media or with the analysis will not be included in the historical data set (e.g., a soil sample with analytical units reported in mg/L or a radiological result with units reported in mg/kg).
- Historical data for radionuclide results with no minimum detectable concentration recorded will not be included in the historical data set.
- Historical data for nonradionuclide results with no reported result and no detection limit recorded will not be included in the historical data set.
- Historical data for radionuclide results with a null or zero recorded as a counting error will not be included in the historical data set.
- Data assessment qualifiers previously placed on the data will be noted and applied as appropriate.
- A result will be considered a nondetect if it is qualified by the reporting laboratory with the following:
  - A "U" qualifier or a "<" qualifier or
  - An "A" qualifier if the result is a radiological result analyzed by a laboratory with codes "PGDP" or "PARGN."
- A result will be considered a nondetect if it has a "U" validation code or a "U" data assessment code.
- A radiological result may be considered a nondetect if the reported total propagated uncertainty is greater than the reported result.

Any exceptions to these rules will be documented in this DQA.

The historical data review for SWMU 229 follows a similar format as that for the Soils OU RI and Soils OU RI 2 Reports.

Comparisons are made to the child resident no action levels (NALs) and to background values reported in the Risk Methods Document (DOE 2015). Calculated values were added for total polycyclic aromatic hydrocarbons (PAHs), total PCBs, and total dioxins/furans, if necessary, according to the methodology described in the Risk Methods Document.

B.1.1 DATA EVALUATION AND SCREENING

Historical data for surface soils from this SWMU include metals, pesticides/PCBs, radionuclides, and semivolatile organic compounds (SVOCs). The historic data from the shallow subsurface soils include metals, pesticides/PCBs, radionuclides, and SVOCs. These data were collected from the following project(s):

- Soils OU XRF Group 1
- Soils OU RI/FS—Storage Areas
- Soils OU PCB Group 1

B.1.2 SAMPLING REPRESENTATIVE OF THE SWMU AREA

Figures in Section 5 of the main text illustrate the location of the historical data points associated with this SWMU. The grids and EUs for SWMU 229 also are shown on those figures. All soil and sediment data within those grids were selected and assigned to SWMU 229.

Indicator chemicals were removed from the data set [i.e., alpha activity, beta activity, uranium-235 (wt.%), and moisture].

In order to more comprehensively address the data set for all SWMUs, plutonium-239 data was evaluated as plutonium-239/240 and uranium-235/236 was evaluated as uranium-235.

B.1.3 USABILITY OF HISTORICAL DATA

Validation. Validation was performed for 10% of the Soils OU RI/FS project. Rejected data have been removed from the data set. Validation qualifiers applied to the remaining data were "=," "J," "U," and "UJ."

Data Assessment. No data assessment qualifiers were applied to the data for this SWMU.

B.1.4 UNITS OF RESULTS

Reported units within the data set are appropriate for the analytical types. Total uranium reported in µg/g has been revised from classification as a radiological analytical type to a metal.

B.1.5 DETECTION LIMITS/MINIMUM DETECTABLE CONCENTRATION

The historical data records indicate incomplete information, such as no reported results and no reported detection limits or minimum detectable concentrations (MDCs).

There are 21 chemicals that are nondetects and have their sample quantitation limit (SQL)/MDCs greater than background or the child resident NAL. SQL and MDC values are reported in the addendum to the work plan (DOE 2014). Those chemicals and referenced values are shown in Table B2.

Table B.2. Analytes with SQL or MDC Greater than Background or Child Resident NAL for SWMU 13

Chemical	Unit	Maximum SQL/MDC for Nondetects	NAL*	Background*	
				Surface	Subsurface
Inorganics					
Antimony	mg/kg	3.00E+01	3.13E+00	2.10E-01	2.10E-01
Arsenic	mg/kg	1.10E+01	2.67E-01	1.20E+01	7.90E+00
Cadmium	mg/kg	1.20E+01	5.07E+00	2.10E-01	2.10E-01
Chromium	mg/kg	8.50E+01	3.01E-01	1.60E+01	4.30E+01
Copper	mg/kg	3.50E+01	3.13E+02	1.90E+01	2.50E+01
Mercury	mg/kg	1.00E+01	2.35E+00	2.00E-01	1.30E-01
Nickel	mg/kg	6.50E+01	1.55E+02	2.10E+01	2.20E+01
Selenium	mg/kg	2.00E+01	3.91E+01	8.00E-01	7.00E-01
Silver	mg/kg	1.00E+01	3.91E+01	2.30E+00	2.70E+00
Thallium	mg/kg	4.40E-01	7.82E-02	2.10E-01	3.40E-01
Uranium	mg/kg	2.00E+01	2.34E+01	4.90E+00	4.60E+00
Vanadium	mg/kg	7.00E+01	3.93E+01	3.80E+01	3.70E+01
Organics					
Benz(a)anthracene	mg/kg	4.10E-01	6.19E-02		
Benzo(a)pyrene	mg/kg	8.20E-03	6.19E-03		
Benzo(b)fluoranthene	mg/kg	4.10E-01	6.19E-02		
Dibenz(a,h)anthracene	mg/kg	8.20E-03	6.19E-03		
Hexachlorobenzene	mg/kg	4.10E-01	1.26E-01		
Indeno(1,2,3-cd)pyrene	mg/kg	4.10E-01	6.19E-02		
PCB, Total	mg/kg	5.00E+00	7.82E-02		
Pentachlorophenol	mg/kg	2.00E+00	2.43E-01		
Radionuclides					
Plutonium-239/240	pCi/g	3.60E-02	3.87E+00	2.50E-02	

*NAL is for the Child Resident NAL at the lesser of ELCR of 1E-06 and HI of 0.1. NAL and background values are reported in the Risk Methods Document (DOE 2015).

B.1.6 RADIONUCLIDE COUNTING ERRORS

Regarding radionuclides at SWMU 229, historical data revealed that either an MDC or counting error was reported; therefore, no data were excluded based on the decision rules discussed in Section B.1.

B.1.7 NONDETECT RESULT QUALIFIERS

All usable data records that were considered nondetect were considered so due to laboratory qualification or validation qualification.

B.1.8 ASSIGNMENT OF HISTORICAL DATA TO RI SAMPLING GRIDS

The historic data has been assigned to grids as discussed. The assignments are listed in Table B.3.

Table B.3. Stations and Grids for Historical Data from SWMU 229

Station Name	Grid No.
SOU229-001	SOU229-001
SOU229-002	SOU229-002
SOU229-003	SOU229-003
SOU229-004	SOU229-004
SOU229-005	SOU229-005
SOU229-006	SOU229-006
SOU229-007	SOU229-007
SOU229-008	SOU229-008
SOU229-009	SOU229-009
SOU229-010	SOU229-010

Station Name	Grid No.
SOU229-011	SOU229-011
SOU229-012	SOU229-012
SOU229-013	SOU229-013
SOU229-014	SOU229-014
SOU229-RAD	SOU229-014
SOU229-015	SOU229-015
SOU229-016	SOU229-016
SOU229-017	SOU229-017
SOU229-018	SOU229-018

B.1.9 SUMMARY OF DETECTED CHEMICALS

A summary of detected chemicals is presented in Table B.4.

Table B.4. Summary of SWMU 229 Detected Chemicals

Chemical	FOD	Minimum Detected Result	Average Detected Result	Maximum Detected Result	FOD above NAL[a]	FOD above Bkgd[a]
Inorganics (mg/kg)						
Aluminum	4/4	3.60E+03	5.47E+03	6.51E+03	0/4	0/4
Antimony	35/42	4.07E+01	8.35E+01	1.50E+02	N/A	35/42
Arsenic	17/42	5.40E+00	9.07E+00	2.12E+01	N/A	3/42
Barium	42/42	6.16E+01	3.95E+02	6.16E+02	0/42	38/42
Beryllium	4/4	2.40E-01	4.43E-01	7.90E-01	N/A	1/4
Cadmium	11/42	1.80E-02	1.14E+01	2.12E+01	N/A	9/42
Calcium	4/4	1.30E+03	1.49E+05	2.38E+05	N/A	2/4
Chromium	9/42	8.20E+00	2.66E+01	4.80E+01	N/A	4/42
Cobalt	4/4	4.20E+00	5.18E+00	7.70E+00	4/4	0/4
Copper	6/42	4.50E+00	1.65E+01	5.19E+01	0/42	1/42
Iron	42/42	6.22E+03	1.08E+04	2.74E+04	42/42	0/42
Lead	41/42	7.29E+00	1.34E+01	2.72E+01	0/42	0/42
Magnesium	4/4	6.11E+02	5.62E+03	7.61E+03	N/A	1/4
Manganese	42/42	1.02E+02	2.94E+02	6.81E+02	36/42	0/42
Mercury	5/42	7.50E-03	3.37E+00	9.27E+00	N/A	2/42
Molybdenum	4/42	2.50E-01	5.45E-01	1.00E+00	0/42	N/A
Nickel	13/42	6.20E+00	5.81E+01	9.93E+01	N/A	9/42
Selenium	4/42	9.10E-01	1.03E+00	1.20E+00	0/42	4/42
Silver	4/42	2.50E-02	3.60E-02	4.20E-02	0/42	0/42
Sodium	4/4	5.19E+01	1.07E+02	1.32E+02	N/A	0/4
Uranium	23/48	1.50E+00	2.95E+01	1.56E+02	N/A	21/48
Vanadium	4/42	1.22E+01	1.95E+01	3.13E+01	N/A	0/42
Zinc	42/42	1.05E+01	8.87E+01	8.33E+02	N/A	16/42
Organics (mg/kg)						
2-Methylnaphthalene	1/4	2.10E-01	2.10E-01	2.10E-01	N/A	N/A

Table B.4. Summary of SWMU 229 Detected Chemicals (Continued)

Chemical	FOD	Minimum Detected Result	Average Detected Result	Maximum Detected Result	FOD above NAL[a]	FOD above Bkgd[a]
Acenaphthene	1/4	2.40E-01	2.40E-01	2.40E-01	0/4	N/A
Anthracene	1/4	3.70E-01	3.70E-01	3.70E-01	0/4	N/A
Benz(a)anthracene	2/4	9.60E-02	6.48E-01	1.20E+00	N/A	N/A
Benzo(a)pyrene	3/4	7.80E-03	3.99E-01	1.10E+00	N/A	N/A
Benzo(b)fluoranthene	2/4	2.00E-01	7.50E-01	1.30E+00	N/A	N/A
Benzo(ghi)perylene	2/4	8.80E-02	4.39E-01	7.90E-01	N/A	N/A
Benzo(k)fluoranthene	2/4	2.00E-01	7.50E-01	1.30E+00	N/A	N/A
Chrysene	2/4	2.90E-01	1.10E+00	1.90E+00	0/4	N/A
Dibenz(a,h)anthracene	2/4	2.90E-02	1.45E-01	2.60E-01	N/A	N/A
Dibenzofuran	1/4	3.00E-01	3.00E-01	3.00E-01	N/A	N/A
Fluoranthene	2/4	2.90E-01	2.70E+00	5.10E+00	0/4	N/A
Fluorene	1/4	2.70E-01	2.70E-01	2.70E-01	0/4	N/A
Indeno(1,2,3-cd)pyrene	2/4	5.90E-02	3.80E-01	7.00E-01	N/A	N/A
Naphthalene	1/4	9.00E-02	9.00E-02	9.00E-02	0/4	N/A
PAH, Total	3/4	7.80E-03	6.20E-01	1.69E+00	N/A	N/A
Phenanthrene	2/4	4.10E-02	2.42E+00	4.80E+00	0/4	N/A
Pyrene	2/4	2.50E-01	2.13E+00	4.00E+00	0/4	N/A
2-Methylnaphthalene	1/4	2.10E-01	2.10E-01	2.10E-01	N/A	N/A
Acenaphthene	1/4	2.40E-01	2.40E-01	2.40E-01	0/4	N/A
Anthracene	1/4	3.70E-01	3.70E-01	3.70E-01	0/4	N/A
Radionuclides (pCi/g)						
Americium-241	2/6	4.50E-02	5.95E-02	7.40E-02	N/A	N/A
Cesium-137	4/6	1.11E-01	2.29E-01	3.21E-01	N/A	0/6
Neptunium-237	2/3	2.17E-01	2.52E-01	2.87E-01	N/A	2/3
Plutonium-238	1/6	2.40E-02	2.40E-02	2.40E-02	N/A	0/6
Plutonium-239/240	4/6	7.60E-03	1.34E-01	2.69E-01	0/6	3/6
Technetium-99	5/6	4.64E+00	1.83E+01	4.34E+01	N/A	5/6
Thorium-228	6/6	4.70E-01	6.83E-01	9.30E-01	N/A	0/6
Thorium-230	6/6	6.68E-01	1.53E+00	2.42E+00	N/A	3/6
Thorium-232	6/6	3.88E-01	5.98E-01	8.40E-01	N/A	0/6
Uranium-234	6/6	8.60E-01	4.16E+00	1.22E+01	N/A	5/6
Uranium-235	6/6	2.90E-02	2.62E-01	8.40E-01	N/A	5/6
Uranium-238	6/6	8.80E-01	7.73E+00	2.49E+01	N/A	5/6

[a] NAL is for the Child Resident NAL as the lesser of ELCR of 1E-06 and HI of 0.1. NAL and background values are reported in the Risk Methods Document (DOE 2015).
"N/A" indicates a value is not available.

B.2. RI LABORATORY ANALYTICAL DATA

Consistent with the work plan, the following analytical data that are not considered usable for the RI:

- Data qualified as rejected by data validation.
- Data qualified as rejected by data assessment.

The sample collected for this addendum was not validated by a third party. Data validation was adequately performed for the historical data collected during the 2010 Soils OU RI. The data was, however, assessed following DOE Prime Contractor procedure PAD-ENM-5003, *Quality Assured Data*, as specified in the work plan addendum (DOE 2014).

B.3. GAMMA WALKOVER SURVEYS

Differences between the gamma walkover survey (GWS) and the judgmental fixed-base laboratory sample prevented an accurate comparison. Noted differences are the following:

1. The biased sample was a homogenized 0 to 6-inch single grab sample verses the GWS that provides measurements for an area of approximately a 1 m^2 area. In addition, the GWS measurement most likely would represent an activity to a depth of approximately 4 inches bgs.

2. Because shielding was not used for the gamma detector, the GWS potentially could be impacted by shine from the cylinder yards, as demonstrated by the 1992 and the 2009 Aerial Radiation Surveys. Soil samples collected in the same areas as the GWS are not impacted by shine from the cylinder yards.

B.4. REFERENCES

DOE (U.S. Department of Energy) 2010. *Work Plan for the Soils Operable Unit Remedial Investigation/Feasibility Study at the Paducah Gaseous Diffusion Plant Paducah, Kentucky*, LATA Environmental Services of Kentucky, DOE/LX/07-0120&D2/R2, June.

DOE 2013. *Soils Operable Unit Remedial Investigation Report at the Paducah Gaseous Diffusion Plant Paducah, Kentucky*, LATA Environmental Services of Kentucky, DOE/LX/07-0358&D2/R1, February.

DOE 2014. *Addendum to the Work Plan for the Soils Operable Unit Remedial Investigation/Feasibility Study at the Paducah Gaseous Diffusion Plant Paducah, Kentucky, Remedial Investigation 2, Sampling and Analysis Plan*, LATA Environmental Services of Kentucky, DOE/LX/07-0120&D2/R2/A1/R1, August.

DOE 2015. *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-0107&D2/R6&V1, U.S. Department of Energy, Paducah, KY, August.

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APPENDIX C

FATE AND TRANSPORT MODELING

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CONTENTS

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FIGURE

TABLES

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ACRONYMS

AT123D	Analytical Transient 1-,2-,3-Dimensional Model
bgs	below ground surface
OU	operable unit
PGDP	Paducah Gaseous Diffusion Plant
RGA	Regional Gravel Aquifer
RI	remedial investigation
SESOIL	Seasonal Soil Compartment Model
SWMU	solid waste management unit
UCRS	Upper Continental Recharge System

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C.1. INTRODUCTION

Seasonal Soil Compartment Model (SESOIL) and Analytical Transient 1-,2-,3-Dimensional Model (AT123D) groundwater and transport modeling were conducted as part of the Soils Operable Unit (OU) Remedial Investigation (RI) to evaluate the potential Regional Gravel Aquifer (RGA) groundwater impacts from residual soil contamination at the solid waste management unit (SWMU) boundary. This modeling effort evaluated the potential migration of technetium-99 (Tc-99). Figure C.1 illustrates the relationship of the RGA and the Upper Continental Recharge System (UCRS) at the Paducah Gaseous Diffusion Plant (PGDP).

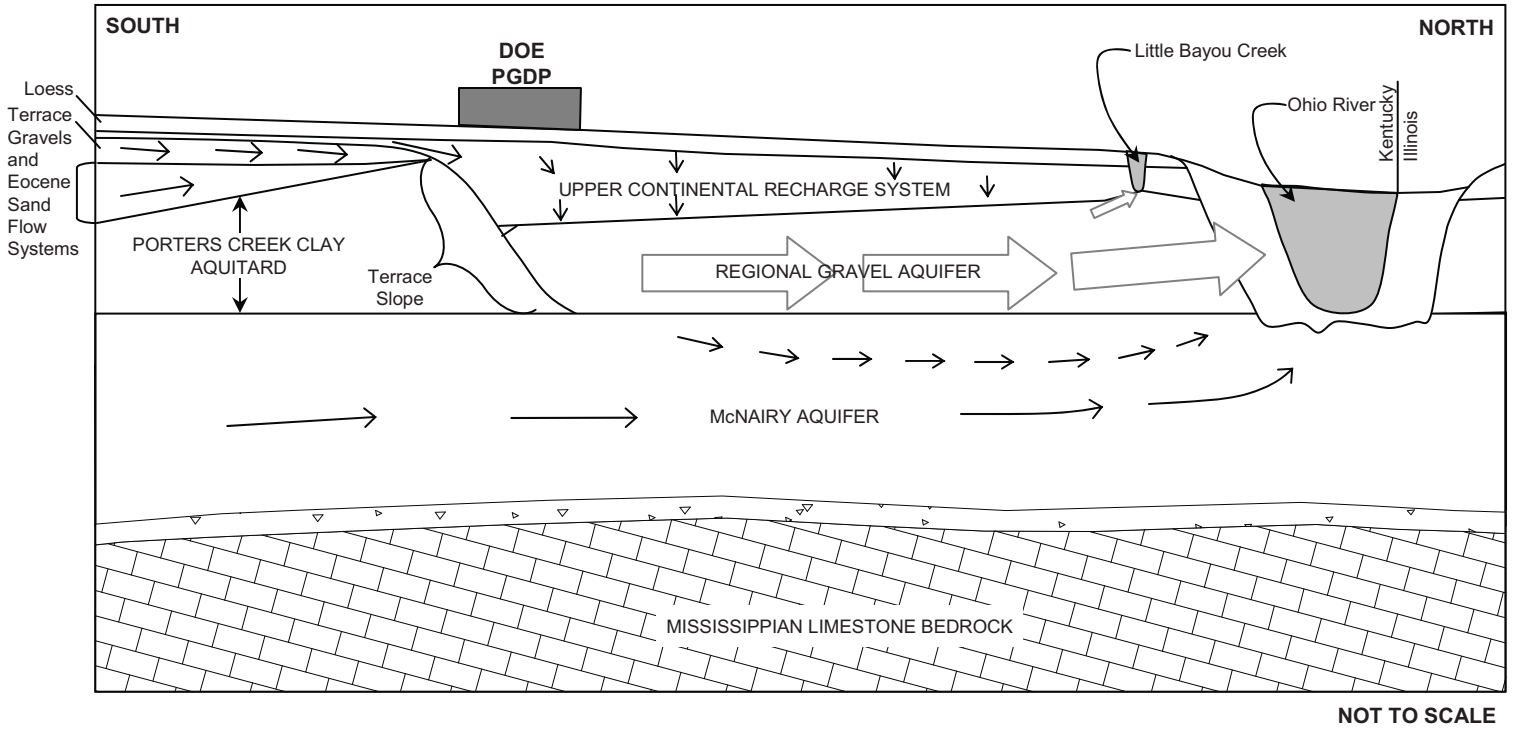
The contents of this report are as follows:

- Section C.2 discusses the technical approach used for determining the impacts of soil constituent concentrations on RGA groundwater.
- Section C.3 compiles and presents SWMU 229 soil sample results and soil and groundwater flow and contaminant transport parameters. SESOIL and AT123D model input data also are presented.
- Section C.4 presents SESOIL and AT123D modeling results.
- Section C.5 provides references used in the report.
- Attachment C1 of Appendix C provides a discussion of the screening used to identify which SWMU soil constituent combinations were subjected to modeling.
- Attachment C2 of Appendix C provides a three-dimensional analysis of the concentration data.
- Attachment C3 of Appendix C consists of the calculation package for the fate and transport modeling.

C.2. TECHNICAL APPROACH

The first step in this modeling effort was to evaluate SWMU soil constituent concentration data and determine which soil constituents posed a potential threat to RGA groundwater quality. The screening process followed the procedures outlined in the Soils OU RI Report (DOE 2013) and is documented in the Fate and Transport Section of this report, as supplemented by Attachments C1, C2, and C3.

Next, the average soil constituent concentration was determined for 0 ft–5 ft, 5 ft–10 ft, and 10 ft–15 ft depths, and these concentrations were used as input values for the SESOIL modeling. SESOIL-predicted UCRS temporal groundwater contaminant concentrations were then used as input to AT123D to predict downgradient RGA contaminant concentrations at the SWMU boundary.



Source: PRS 2009

U.S. DEPARTMENT OF ENERGY
DOE PORTSMOUTH/PADUCAH PROJECT OFFICE
PADUCAH GASEOUS DIFFUSION PLANT

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Figure C.1. Water-Bearing Zones near PGDP

C.3. DATA EVALUATION AND COMPILATION

This section compiles and presents soil sample results and soil and groundwater flow and contaminant transport parameters. SESOIL and AT123D model input data also are presented.

C.3.1 SOIL CONTAMINANT SCREENING

Soil contaminant screening (described in Attachment C1) was used to assess the soil contaminants that potentially could impact RGA groundwater quality (see list in Table C.3.1). These constituents were subjected to groundwater modeling to bound the potential for impacts to RGA groundwater.

Table C.3.1. Associated Soil Constituents Subjected to Modeling

SWMU	Contaminant
229	Tc-99

C.3.2 AVERAGE UCRS SOIL CONTAMINANT CONCENTRATIONS AND DISTRIBUTIONS

The PGDP soils database was evaluated to determine how many samples (Table C.3.2) had been collected at SWMU 229 previously identified as potentially problematic (Table C.3.1). Field duplicate samples were collected at some locations as per the project SAP or QAPP. Where field duplicate samples were collected, one result was selected for each location and depth interval using the following selection criteria: the maximum detected result was selected for locations and depths where both results were detected, the minimum reporting limit was selected for locations and depths where both samples were not detected, and the detected result was selected for locations and samples where one sample was reported as detected and the other as nondetect.

Table C.3.2. Soil Sample Summary[a]

SWMU	Size (acres)	Contaminant	Depth (ft bgs)	Number of Samples	Number of Analytical Detects
229	0.849	Tc-99	0–5	6[b]	5
			5–10	0	N/A
			10–15	0	N/A

[a] Table C.3.2 counts only one soil sample result selected based on the selection criteria: the maximum detected result was selected for locations and depths where both results were detected, the minimum reporting limit was selected for locations and depths where both samples were not detected, and the detected result was selected for locations and samples where one sample was reported as detected and the other as nondetect.
[b] Duplicates have been processed as described in Section C.3.2.
N/A = Not applicable; no samples exist at specified interval.

As per the Risk Methods Document (DOE 2015), the higher-concentration sample of the duplicate was retained in the data set and used in modeling. Given the small sample sizes, geostatistical evaluation was not used. Rather, soil concentration averages for the detections were calculated for 0 ft–5 ft, 5 ft–10 ft, and 10 ft–15 ft depths below ground surface (bgs) (Table C.3.3).

The area affected by soil contamination was determined by assuming that the area impacted was proportional to the ratio of the number of detects verses the total number of samples collected in a depth

interval at the SWMU. The ratio then was converted to a proportion, and the SWMU area was multiplied by the proportion to determine the impacted area (Table C.3.4). For example, at SWMU 229, at a depth interval of between 0 and 5 ft bgs, 5 of 6 soil samples had a detectable level of Tc-99 in soil. Based on the ratio, equal to a proportion of 0.833 (i.e., 5/6), the area affected by Tc-99 contamination was assumed to be 0.708 acres of the total SWMU size of 0.849 acres.

Table C.3.3. Average Soil Constituent Concentrations

SWMU	Contaminant	0 ft–5 ft bgs Average Concentration (µg/g)	5 ft–10 ft bgs Average Concentration (µg/g)	10 ft–15 ft bgs Average Concentration (µg/g)
229	Tc-99	1.23E-3 (20.9 pCi/g)	N/A	N/A

N/A = Not Applicable, no samples exist at specified interval.

Table C.3.4. Area of Soil Contamination

SWMU	SWMU Area (acres)	0 ft–5 ft bgs Contaminated Area (acres)	5 ft–10 ft bgs Contaminated Area (acres)	10 ft–15 ft bgs Contaminated Area (acres)
229 (Tc-99)	0.849	0.708	0	0

C.3.3 SESOIL AND AT123D INPUTS

The following section summarizes the input parameters used with the SESOIL and AT123D models. The units presented with the input data are those used with SESOIL and AT123D.

Table C.3.5 presents the UCRS properties used in the SESOIL model. It previously was agreed upon in the Soils OU Work Plan that the Soils OU would limit the soil depths used in the modeling to 15 ft bgs or less (DOE 2010). Thus, Soils OU SWMU-specific input at depths greater than 15 ft were not available for the SESOIL and AT123D simulations. With the exception of the percolation rate, which was obtained from SESOIL climate data, to overcome this limitation, SESOIL and AT123D general input parameters from the Soils OU RI (DOE 2013) were assumed to be representative of all the modeled sites for those depths greater than 15 ft.

Table C.3.5. General SESOIL Input Parameters

Input Parameter	Value	Source
Soil type	Silty clay	PGDP site-specific
Bulk density (g/cm^3)	1.46	Laboratory analysis
Annual Percolation rate (cm/year)	10.5	SESOIL Climate Data
Intrinsic permeability (cm^2)	1.65E-10	Calibrated
Disconnectedness index	10	Calibrated
Porosity	0.45	Laboratory analysis
Depth to RGA potentiometric surface (m)	16.76	Typical based on field observation
Organic carbon content ($f_{oc)}$) (%)	0.08	Laboratory analysis
Freundlich equation exponent	1	SESOIL default value

Chemical-specific parameters for Tc-99 (the soil constituent) are listed in Table C.3.6.

Table C.3.6. Chemical-Specific Parameters of the Site-Related Soil Constituents Used in SESOIL Modeling

Soil Constituent	Mol. Wt. (MW) (g/gmol)	Solubility in water (mg/L)	Diffusion in air (cm^2/s)	Diffusion in water (m^2/hr)	Henry's Constant ($atm.m^3/mol$)	K_{oc} (L/kg)	K_d (L/kg)	Degradation Half Life (years)
Tc-99	99	7.18E+03*	N/A	3.60E-07	N/A	N/A	0.2	2.13E+05

*Tc-99 solubility is derived from the geochemical database "thermo.com.V8.R6.230," which was prepared by Lawrence Livermore National Laboratory. The exact database used here is "llnl.dat 4023 2010-02-09 21:02:42Z," which was converted to PHREEQC format by Greg Anderson and David Parkhurst of the U.S. Geological Survey.

SESOIL uses the same contaminated soil area as an input parameter for all depth intervals in a given SWMU; however, as shown in Table C.3.4, the contaminated soil area in the Soils OU SWMU varies with depth. To adjust the evaluation to allow the modeling to meet the SESOIL requirement of constant contaminated soil areas, the estimated soil concentrations were adjusted by multiplying the concentrations by the ratio of the depth-specific soil contamination area to the largest soil contamination area for the SWMU. Doing so yields a result that adjusts the contaminant mass loading used in the uniform SESOIL areas to match the actual contaminant mass loading. The contaminated soil area was converted from acreage to square centimeters in order to meet SESOIL input parameters. Table C.3.7 lists the area-adjusted soil contaminant concentrations used in the SESOIL modeling.

Table C.3.7. Adjusted SESOIL Areas and Soil Constituent Concentrations

SWMU	Soil Constituent	Contaminated Area (cm^2)	0 to 152.4 cm bgs Average Concentration (µg/g)	152.4 to 304.8 cm bgs Average Concentration (µg/g)	308.4 to 457.2 cm bgs Average Concentration (µg/g)
229	Tc-99	2.86E+07	1.23E-03 (20.9 pCi/g)	0	0

Note: The contaminated area presented is the maximum area of the three soil intervals at each contaminated site (see Table C.3.4).

General AT123D input parameters are listed in Table C.3.8.

Table C.3.8. General AT123D Input Parameters

Input Parameter	Value	Source
Bulk density (kg/m^3)	1,670	Laboratory analysis
Effective porosity (unitless)	0.3	PGDP sitewide model calibrated value
Trichloroethene biological half-life (years)	10	RGA Biodegradation study (KCREE 2008)
Hydraulic conductivity (m/hour)	22.263	Historical sitewide model
Hydraulic gradient	0.0015	ArcGIS particle tracking shapefiles
RGA aquifer thickness (m)	9.14	Site average
Longitudinal dispersivity (m)	1.5	Template input files
Density of water (kg/m^3)	1,000	Default
Fraction of organic carbon (%)	0.02	Laboratory analysis
Well screen length (m)	3	Assumed a 10 ft well screen mixing zone

C.4. SESOIL AND AT123D RESULTS

SESOIL and AT123D simulation results are summarized in Table C.4.1. Based on the modeling results, the incremental contributions of Tc-99 currently present in soil at SWMU 229 do not have the potential to impact the RGA groundwater at the SWMU boundary at a concentration (340 pCi/L) that exceeds the screening criterion of 900 pCi/L (DOE 2013). Consistent with the Soils OU RI Report (DOE 2013), 900 pCi/L was the criterion used in screening to determine if the SWMU was modeled for Tc-99 transport. Although the model predicts that the Tc-99 associated with the vadose zone at SWMU 229 will leach to the RGA, the mass flux of Tc-99 from the vadose zone to the RGA is insufficient to cause RGA groundwater concentrations to exceed the 900 pCi/L screening criterion. Model predictions indicate that for SWMU 229, dissolved Tc-99 reaches the underlying saturated zone at 32.06 years and the SWMU boundary at 32.6 years. The peak predicted Tc-99 concentration occurs at 37.5 years.

Table C.4.1. SESOIL and AT123D Maximum Predicted Groundwater Concentrations

SWMU	Groundwater Constituent	Maximum RGA Groundwater Concentration at SWMU Boundary (µg/L)	Predicted Time to Reach SWMU Boundary (years)
229	Tc-99	2.0E-2 (340 pCi/L)	32.6

C.5. REFERENCES

DOE (U.S. Department of Energy) 2010. *Work Plan for the Soils Operable Unit Remedial Investigation/Feasibility Study at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0120&D2/R2, U.S. Department of Energy, Paducah, KY, June.

DOE 2013. *Soils Operable Unit Remedial Investigation Report at the Paducah Gaseous Diffusion Plant Paducah, Kentucky,* DOE/LX/07-0358&D2/R1, U.S. Department of Energy, Paducah, KY, February.

DOE 2015. *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* Volume 1, *Human Health, U.S. Department of Energy, Paducah, Kentucky,* DOE/LX/07-0107&D2/R6/V1, U.S. Department of Energy, Paducah, KY, July.

ATTACHMENT C1

DATA SCREENING

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C1. SCREENING FOR GROUNDWATER MODELING

Attachment C1 to Appendix C presents a summary of the multistage decision process established to identify which soil constituents were selected for evaluation using fate and transport modeling (hereafter referred to as "modeling") to estimate the potential for impacts to the Regional Gravel Aquifer (RGA) groundwater from contaminants in Soils Operable Unit (OU) solid waste management unit (SWMU) 229. The decision process is described further in the Methodology section (Section C.1.1) and involves the following:

1. Screening of SWMU 229 soil sampling results against the Paducah project-specific remedial guide (RG) soil screening levels (SSLs); and

2. Review of the site-related soil constituents that are not screened from further modeling to identify which SWMU soil constituent combinations were subjected to modeling.

An identification of certain process-related soil constituents to ensure an appropriate dilution attenuation factor (DAF) is used in the detailed vadose zone/groundwater modeling was performed for the Soils OU Remedial Investigation Report at the Paducah Gaseous Diffusion Plant (Soils OU RI Report) (DOE 2013). The RG SSLs were back-calculated from maximum contaminant levels (MCLs) (or risk-based values, if an MCL was not available) using the DAF. The DAF for SWMU 229 was identified from a deterministic calculation and set at 58 (see Attachment C2 to Appendix C, Soils Operable Unit Dilution Attenuation Factor of the Soils OU RI Report).

C1.1. METHODOLOGY

C1.1.1 SCREENING PROCESS

Analytical results for SWMU 229 were first screened against SSL values to identify which SWMU soil constituent combinations may need modeling. The screening steps are listed below.

1. Soils OU RG SSLs were calculated based on the MCL or residential groundwater-use no action level (NAL) as adjusted by multiplying by a DAF of 58.

2. The average concentration of each soil constituent was compared to the SSL and background. That comparison was used for the following:

    a. If the average concentration of each soil constituent did not exceed the SSL and background values, the screening did not indicate the need for modeling due to the *overall* potential for impacts.

    b. If the average soil constituent concentration did exceed both the SSL and background, the need for modeling was further evaluated if that soil constituent is included in the list of contaminants of concern (COCs) identified for groundwater (Table C1.1).

Table C1.1. Chemicals Identified in the GWOU FS as Contaminants of Concern for the RGA Residential Use of Groundwater (DOE 2001)

Aluminum	1,1,1-Trichloroethane	Americium-241
Antimony	1,1,2-Trichloroethane	Cesium-137
Arsenic	1,1-Dichloroethene	Neptunium-237
Beryllium	1,2-Dichloroethane	Radium-226
Boron	*cis*-1,2-Dichloroethene	Radon-222
Cadmium	*trans*-1,2-Dichloroethene	Tc-99
Chromium	2-Butanone	Uranium-234
Fluoride	4-Methyl-2-pentanone	Uranium-235
Iron	Acetone	Uranium-238
Lead	Acrylonitrile	
Lithium	Benzene	
Manganese	Bis(2-ethylhexyl)phthalate	
Molybdenum	Bromomethane	
Nickel	Carbazole	
Silver	Carbon tetrachloride	
Vanadium	Chlorobenzene	
	Chloroform	
	Chloromethane	
	Ethylbenzene	
	Methylene chloride	
	Aroclor 1254	
	Polychlorinated biphenyls	
	Tetrachloroethene	
	Trichloroethene	
	Vinyl chloride	
	Xylenes	

3. Information on the presence of a contaminant in RGA groundwater and whether the results of prior modeling indicated RGA groundwater concentrations of the contaminant consistent with background were considered when determining if detailed modeling of the residual soil contaminant was performed.

4. The individual soil constituent concentrations were compared to the SSL/background values; if at least three sample results from SWMU 229 exceeded the SSL/background concentrations, modeling of the SWMU soil constituent combination was considered. Some of these SWMU soil constituent combinations were evaluated further using Mining Visualization Software (MVS) (Version 9.85) (CTech Software 2014) to identify if the exceedances are indicative of hot spots and whether any of these SWMU soil constituent combinations needed to be subjected to modeling.

For those SWMU soil constituent combinations whose average concentration at that SWMU exceeded the screening levels listed above, the next step was to review those combinations against the groundwater COC list (Table C1.1), the groundwater data, and the other site-specific considerations (e.g., location of the SWMU relative to the groundwater data) to support a determination of those constituents that then were subjected to modeling. The determination of which soil constituent SWMU combinations to subject to modeling considered the nature of the soil constituents (e.g., are they naturally occurring compounds?) and whether there was an identified groundwater impact of that soil constituent in the vicinity of SWMU 229. Information provided in the assessment performed in the Soils OU RI Report also was incorporated into the screening process.

After following the above process, the decision was made to model technetium-99 (Tc-99) at SWMU 229. Tc-99 was modeled in accordance with the RMD, Section 3.3.4.3 (DOE 2015), though the screening process did not necessarily identify a groundwater impact attributable to SWMU 229.

C1.1.2 RG SSL DETERMINATION

The RG SSLs were determined using the U.S. Environmental Protection Agency (EPA)-established formulas listed below. These formulas and inputs are consistent with those used in the Risk Methods Document (DOE 2015). If an MCL has been established for the chemical constituent, then the RG SSLs are based on the MCL; if not, then they are based on the residential NAL for groundwater use.

For inorganic compounds,

$$C_t = C_w \left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b} \right)$$

Where:

C_t = screening level in soil (mg/kg)
C_w = target soil leachate concentration (mg/L) (MCL or residential NAL × 58 DAF)
K_d = soil-water partition coefficient (L/kg) (chemical-specific, see Table C1.1)
θ_w = water-filled soil porosity (L_{water}/L_{soil}) (0.3) (EPA 1996)
θ_a = air-filled soil porosity (L_{air}/L_{soil}) (0.13) (EPA 1996)
ρ_b = dry soil bulk density (kg/L) (1.5) (EPA 1996)
H' = dimensionless Henry's law constant [chemical-specific × 41 (conversion factor)] (value taken from EPA Web site http://www.epa.gov/safewater/consumer/pdf/mcl.pdf.)

For organic compounds,

$$C_t = C_w \left((K_{oc}\, f_{oc}) + \frac{\theta_w + \theta_a H'}{\rho_b} \right)$$

Where:

C_t = screening level in soil (mg/kg)
Cw = target soil leachate concentration (mg/L) (MCL or residential NAL × 58 DAF)
Koc = soil organic carbon-water partition coefficient (L/kg) (chemical-specific, taken from EPA Web site)
foc = organic carbon content of soil (kg/kg) (0.002) (EPA 1996)
θw = water-filled soil porosity (Lwater/Lsoil) (0.3) (EPA 1996)
θa = air-filled soil porosity (Lair/Lsoil) (0.13) (EPA 1996)
ρb = dry soil bulk density (kg/L) (1.5) (EPA 1996)
H' = dimensionless Henry's law constant [chemical-specific × 41 (conversion factor)] (value taken from EPA Web site http://www.epa.gov/safewater/consumer/pdf/mcl.pdf.)

C1.2. SCREENING, EVALUATION, AND RESULTS

C1.2.1 INITIAL SCREENING

Initial screening of the maximum detected value (only laboratory and validation qualifiers were considered in determining whether a result was detected) of soil constituents included determining if any of the results from SWMU 229 included a detected value greater than the RG SSL or subsurface background value. Only laboratory and validation qualifiers were considered in determining whether a result was detected. Chapter 4 and Appendix B of this Remedial Investigation Report give additional information regarding data quality and the use of data qualifiers for this project. A list of screening values is presented in Table C1.2.

Table C1.2. Soils OU Soil Screening Levels for Groundwater Modeling

Chemical	Target Conc. (mg/L or pCi/L)[a]	Target Ref.[b]	Subsurface Background Conc.[a]	K_d[c] (L/kg)	RG SSL (DAF 58)	UNITS
Metals						
Aluminum	1.04E+00	NAL	1.20E+04	1.50E+03	1.73E+05	mg/kg
Antimony	6.00E-03	MCL	2.10E-01	4.50E+01	1.57E+01	mg/kg
Arsenic	1.00E-02	MCL	7.90E+00	2.90E+01	1.69E+01	mg/kg
Barium	2.00E+00	MCL	1.70E+02	4.10E+01	4.78E+03	mg/kg
Beryllium	4.00E-03	MCL	6.90E-01	7.90E+02	1.83E+02	mg/kg
Boron	2.08E-01	NAL	N/A	3.00E+00	7.40E+01	mg/kg
Cadmium	5.00E-03	MCL	2.10E-01	7.50E+01	2.18E+01	mg/kg
Chromium	1.00E-01	MCL	4.30E+01	1.80E+06	1.04E+07	mg/kg
Cobalt	3.13E-04	NAL	1.30E+01	4.50E+01	1.57E+00	mg/kg
Copper	1.30E+00	MCL	2.50E+01	3.50E+01	2.65E+03	mg/kg
Iron	7.29E-01	NAL	2.80E+04	2.50E+01	2.04E+03	mg/kg
Lead	1.50E-02	MCL	2.30E+01	9.00E+02	7.83E+02	mg/kg
Manganese	2.45E-02	NAL	8.20E+02	6.50E+01	1.59E+02	mg/kg
Mercury	2.00E-03	NAL	1.30E-01	5.20E+01	1.68E+00	mg/kg
Molybdenum	5.21E-03	NAL	N/A	2.00E+01	1.17E+01	mg/kg
Nickel	2.08E-02	NAL	2.20E+01	6.50E+01	1.47E+02	mg/kg
Selenium	5.00E-02	MCL	7.00E-01	5.00E+00	1.51E+01	mg/kg
Silver	5.15E-03	NAL	2.70E+00	8.30E+00	4.55E+00	mg/kg
Thallium	2.00E-03	MCL	3.40E-01	7.10E+01	8.26E+00	mg/kg
Uranium[e]	3.00E-02	MCL	4.60E+00	4.50E+02	7.83E+02	mg/kg
Vanadium	7.06E-05	NAL	3.70E+01	1.00E+03	4.79E+02	mg/kg
Zinc	3.13E-01	NAL	6.00E+01	6.20E+01	2.16E+03	mg/kg

Table C1.2. Soils OU Soil Screening Levels for Groundwater Modeling (Continued)

Chemical	Target Conc. (mg/L or pCi/L)[a]	Target Ref.[b]	Subsurface Background Conc.[a]	K_d[c] (L/kg)	RG SSL (DAF 58)	UNITS
Radionuclides[e]						
Americium-241	5.04E-01	NAL	N/A	8.20E+00	5.55E+01	pCi/g
Cesium-137	1.71E+00	NAL	2.80E-01	1.00E+01	2.78E+01	pCi/g
Neptunium-237	7.63E-01	NAL	N/A	1.00E-01	3.11E+00	pCi/g
Plutonium-238	3.98E-01	NAL	N/A	5.00E+00	1.27E+01	pCi/g
Plutonium-239	3.87E-01	NAL	N/A	5.00E+00	1.23E+01	pCi/g
Tc-99	1.90E+01	NAL	2.80E+00	2.00E-01	4.41E-01	pCi/g
Thorium-230	5.72E-01	NAL	1.40E+00	2.00E+01	1.06E+02	pCi/g
Uranium-234	7.39E-01	NAL	1.20E+00	4.50E+02	2.87E+00	pCi/g
Uranium-235	7.28E-01	NAL	6.00E-02	4.50E+02	2.83E+00	pCi/g
Uranium-238	6.01E-01	NAL	1.20E+00	4.50E+02	2.34E+00	pCi/g
Organics (PCBs)						
PCB, Total	5.00E-04	MCL	N/A	1.56E+02	4.54E+00	mg/kg
Organics (Semivolatile)						
Acenaphthene	1.38E-02	NAL	N/A	1.01E+01	2.94E+01	mg/kg
Anthracene	6.39E-02	NAL	N/A	3.27E+01	3.05E+02	mg/kg
Bis(2-ethylhexyl) phthalate	6.00E-03	MCL	N/A	2.39E+02	8.33E+01	mg/kg
Fluoranthene	1.44E-02	NAL	N/A	1.11E+02	5.17E+02	mg/kg
Fluorene	8.91E-03	NAL	N/A	1.83E+01	2.89E+01	mg/kg
Hexachlorobenzene	1.00E-03	MCL	N/A	1.24E+01	7.31E-01	mg/kg
Naphthalene	1.76E-04	NAL	N/A	3.09E+00	3.15E-02	mg/kg
Nitroaniline, 2-	1.02E-02	NAL	N/A	5.51E-01	4.61E-01	mg/kg
Nitroso-di-N-propylamine, N-	8.03E-06	NAL	N/A	5.26E+00	4.69E-04	mg/kg
Pentachlorophenol	1.00E-03	MCL	N/A	9.92E+00	5.87E-01	mg/kg
Pyrene	5.81E-03	NAL	N/A	1.09E+02	6.82E+01	mg/kg
Total PAH [Benz(a)pyrene][d]	1.22E-05	NAL	N/A	3.54E+02	7.05E-01	mg/kg
Organics (Volatile)						
Benzene	5.00E-03	MCL	N/A	2.92E-01	1.48E-01	mg/kg
Carbon Tetrachloride	5.00E-03	MCL	N/A	8.78E-02	1.13E-01	mg/kg
Chloroform	8.00E-02	MCL	N/A	6.36E-02	1.29E+00	mg/kg
Dibromochloromethane	8.00E-02	MCL	N/A	6.36E-02	1.26E+00	mg/kg
Dichloroethane, 1,2-	5.00E-03	MCL	N/A	7.92E-02	8.22E-02	mg/kg
Dichloroethene, 1,1-	7.00E-03	MCL	N/A	6.36E-02	1.46E-01	mg/kg
Dichloroethene, 1,2-	2.24E-03	NAL	N/A	7.92E-02	2.73E-01	mg/kg
Dichloroethene, 1,2-*cis*-	7.00E-02	MCL	N/A	7.92E-02	1.19E+00	mg/kg
Dichloroethene, 1,2-*trans*-	1.00E-01	MCL	N/A	7.92E-02	1.71E+00	mg/kg
Ethylbenzene	7.00E-01	MCL	N/A	8.92E-01	4.55E+01	mg/kg
Tetrachloroethene	5.00E-03	MCL	N/A	1.90E-01	1.31E-01	mg/kg
Toluene	1.00E+00	MCL	N/A	4.68E-01	4.01E+01	mg/kg

Table C1.2. Soils OU Soil Screening Levels for Groundwater Modeling

Chemical	Target Conc. (mg/L or pCi/L)[a]	Target Ref.[b]	Subsurface Background Conc.[a]	K_d[c] (L/kg)	RG SSL (DAF 58)	UNITS
Trichloroethane, 1,1,1-	2.00E-01	NAL	N/A	8.78E-02	4.07E+00	mg/kg
Trichloroethane, 1,1,2-	5.00E-03	MCL	N/A	1.21E-01	9.41E-02	mg/kg
Trichloroethene	5.00E-03	MCL	N/A	1.21E-01	1.04E-01	mg/kg
Vinyl Chloride	2.00E-03	MCL	N/A	4.35E-02	4.00E-02	mg/kg
Xylene, Mixture	1.00E+01	MCL	N/A	7.66E-01	5.71E+02	mg/kg
Xylene, m,p-	1.00E+01	NAL	N/A	7.51E-01	1.09E+00	mg/kg
Xylene, o-	4.85E-02	NAL	N/A	7.66E-01	1.10E+00	mg/kg

N/A = not available or not applicable; not used in this screening.
Conc. = Concentration. Concentration units as noted in the units column.
Ref. = Reference
Bckgd. = Background
[a] Target concentrations for soil constituents without an MCL and subsurface background values are taken from the Risk Methods Document (DOE 2015).
[b] MCLs are taken from the EPA Web site: http://www.epa.gov/safewater/consumer/pdf/mcl.pdf.
[c] K_d values are taken from the EPA Web site http://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search, consistent with the Risk Methods Document, except for Tc-99 and uranium. The Tc-99 and uranium Kd values are set at levels consistent with the Burial Grounds Operable Unit to reflect the PGDP site. The model input parameters are found in Table B.2 and Table B.3 of the *Remedial Investigation for the Burial Grounds Operable unit at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0030&D2/R1, February 2010.
[d] RG SSL (DAF 58) are taken from Table A.7a of the Risk Methods Document (DOE 2015).
[e] RG SSL (DAF 58) for radionuclides are taken from Table A.7b of the Risk Methods Document (DOE 2015) at 10^{-6} risk.

The overall average value of the soil constituent for SWMU 229 was calculated using both detected values and nondetected values (nondetected values at one-half the reported value). These values were used as reported and not segregated into grid values. If the overall average value of the soil constituent for SWMU 229 was below the background value or the RG SSL, then the soil constituent was screened out from consideration for modeling for general fate and transport. The fate and transport modeling utilizes a weighted average value of the concentration of the chemical as the source term value (see Appendix C, Attachment C3); thus, the modeled value for the RGA concentration at the SWMU boundary is expected to be below the target (MCL or risk-based) concentration if the average soil concentration is below the SSL.

If the average soil constituent concentration was found to be above both the background value and the RG SSL, then the soil constituent subsequently was evaluated against the groundwater COCs (Table C1.1) and against the information available about RGA groundwater impacts (see Section C1.3). For example, this evaluation resulted in screening out those constituents that are not RGA groundwater COCs (e.g., cobalt) or those soil constituents that are not typically detected in RGA groundwater (e.g., silver). Additionally, if there were three or more exceedances of both the background value and the RG SSL, and the constituent is an RGA groundwater COC, and the constituent is typically detected in RGA groundwater, the soils results were evaluated against any patterns of detection in RGA groundwater to identify whether SWMU 229 might have been a source of the RGA exceedances. The additional information for this screening and the results of this screening are presented in the following sections.

C1.2.2 HOT SPOT SCREENING

To determine if hot spots exist within the SWMU that might pose a localized threat to groundwater, the constituents for SWMU 229 where the average concentration exceeded the RG SSL and the background

concentration, where the constituent is considered to be an RGA groundwater COC (as presented in C1.2), where the constituent is typically detected in RGA groundwater (see discussion in Section C1.3.3 of the Soils OU RI Report), and where there were three or more individual result exceedances of the RG SSL and the background concentration, the results were evaluated and soil constituents were selected for further evaluation.

For the selected soil constituents, the results of this evaluation were summarized graphically. These graphs are presented in Attachment C2 to Appendix C. The selected SWMU soil constituent combinations were evaluated using MVS and plotted by depth and spatially to support an evaluation of whether a hot spot exists and whether it may present a potential risk to RGA groundwater.

C1.2.3 SCREENING SUMMARY, OVERALL AVERAGE

Table C1.3 provides the results of the screening where the overall average concentration of a soil constituent exceeds both the respective SSL and the background concentration.

The results of the screening are summarized in Table C1.3 to find a total of two constituents (Tc-99 and uranim-234) for SWMU 229 that exceeded screening values.

As discussed in the Soils OU RI Report (DOE 2013), although widely distributed, the frequency of exceedance for each soil constituent and the distribution of the exceedances do not indicate impacts to the RGA from soils in SWMU 229 for the reasons discussed below. Nevertheless, Tc-99 and uranium-234 were evaluated further against the RGA groundwater data (see Section C1.3) to identify whether these soil constituents at SWMU 229 were subjected to fate and transport modeling.

C1.2.4 ADDITIONAL SCREENING

The screenings were extended by reviewing the soil constituents and site-specific information, including an evaluation based in part upon the presence of these soil constituents in PGDP RGA groundwater as COCs (see Table C1.1). The discussion of this screening is presented below. As discussed in the Soils OU RI Report (DOE 2013), detailed modeling was completed for Tc-99, at SWMU 26. The SWMU 26 modeling was used to predict the potential for Tc-99 to migrate to the RGA groundwater from SWMU 229. SWMU 229 was modeled due to its having an average Tc-99 concentration above the RGA groundwater SSL combined with its proximity to the Tc-99 RGA groundwater plume.

No modeling was conducted for antimony, iron, mercury, naphthalene, neptunium-237, silver, Total PCBs, phenanthrene, uranium-235, or uranium-238 because the soil constituent did not fail screening, the soil constituent is not an issue for PGDP groundwater, or the concentration of the soil constituent in groundwater is controlled by other factors as discussed in Section C1.3.

Uranium-234 exceeded both the SSL and background concentrations at SWMU 229 and exhibited clustering when the results were viewed in 3-dimensions; however, the average concentration of uranium-234 (302 pCi/g) when converted to uranium (883 mg/kg) was less than the average concentration for SWMU 81 (2,502 mg/kg), which was modeled in the Soils OU RI Report (DOE 2013) where the results of the modeling showed that uranium did not reach the RGA groundwater in the 1,000-year SESOIL modeling period. Based on this, uranium-234 was not modeled at SWMU 229.

Table C1.3. SWMU 229 Soil Constituent Combinations That Survive Screening and Are Considered for Modeling Based on Overall Average Concentration

#	SWMU	Analyte	Units	No. Samples	Average Concentration[a]	Maximum Concentration[a]	Subsurface Background Concentration[b]	RG SSL Concentration (DAF 58)[c]	Screening Value (Higher of RG SSL or Background)
2	229	Tc-99	pCi/g	7	2.09E+01	4.34E+01	2.80E+00	4.41E-01	2.80E+00

RG SSL= Remedial Guide Soil Screening Level

[a] Concentration units as noted in the units column.

[b] Subsurface background concentration values are taken from the Risk Methods Document (DOE 2015).

[c] Subsurface RG SSL (DAF 58) as shown in Table C1.2.

The results of the modeling are presented in Appendix C. Additional evaluation of hot spot candidates is discussed below and presented in Appendix C, Attachment C2.

C1.3. REVIEW OF SOIL CONSTITUENTS AGAINST RGA GROUNDWATER DATA

Naturally-occurring metals and other soil constituents exceed screening criteria at SWMU 229. This section of the document summarizes the evaluation of these soil constituents against the RGA groundwater data to determine whether the SWMU is an apparent source of RGA contamination or whether the measured RGA concentrations are consistent with groundwater background concentrations (see the Soils OU RI Report for additional information).

As detailed in the Soils OU RI Report (DOE 2013), the following dissolved-phase constituents are not subject to modeling:

- Antimony
- Arsenic
- Beryllium
- Cadmium
- Chromium
- Cobalt/Cobalt-60
- Iron
- Lead
- Manganese
- Mercury
- Molybdenum
- Neptunium-237
- Nickel
- Plutonium-239/240
- Silver
- Total PCBs
- Uranium
- Uranium-238
- Vanadium
- Zinc

A review of the Tc-99 groundwater plume (see Figure 3.6 of the main text) indicates the Tc-99 groundwater concentrations greater than MCLs in RGA groundwater are from the vicinity of C-400; however, SWMU 229 has average soil concentrations that exceed the RG SSL and soil background concentration. Additionally, SWMU 229 is located (at least in part) near the RGA Tc-99 plume. Thus, it is possible that the SWMU could be a secondary source of Tc-99. SWMU 229 was modeled due to its having an average Tc-99 concentration above the RGA groundwater SSL combined with its proximity to the Tc-99 RGA groundwater plume.

C1.4. SUMMARY OF EVALUATION THAT IDENTIFIED SWMU/AOC SOIL CONSTITUENTS TO BE SUBJECTED TO MODELING

Based upon the performed screening evaluation, SWMU 229 was modeled for Tc-99 due to its proximity to the Tc-99 RGA groundwater plume.

No modeling was conducted for antimony, iron, mercury, naphthalene, neptunium-237, nickel, silver, Total PCBs, phenanthrene, uranium-235, or uranium-238 because the soil constituent did not fail screening, the soil constituent is not a problem for PGDP groundwater, or the concentration of the soil constituent in groundwater is controlled by other factors.

Uranium-234 was not modeled at SWMU 229 as the average concentration was less than the average concentration for SWMU 81 (2,502 mg/kg), which was modeled in the Soils OU RI Report (DOE 2013) where the results of the modeling showed that uranium did not reach the RGA groundwater in the 1,000-year SESOIL modeling period. Based on this, uranium-234 was not modeled at SWMU 229.

C1.5. SCREENING SUMMARY, HOT SPOT IDENTIFICATION

The soil constituents subjected to further hot spot analysis are identified in Table C1.4 and are summarized in Appendix C, Attachment C2.

Table C1.4. SWMU Soil Constituent Combinations Subjected to Further Analysis

#	SWMU	Soil Constituent	Location
1	229	Tc-99	NW corner of PGDP; lithology consistent with DAF of 58

Table C1.5 provides the results of the screening process that identifies SWMU soil constituent combinations that have at least three results that exceed both the respective RG SSL and background concentration, where the constituent is considered to be an RGA groundwater COC (as presented in C1.2), where the constituent is typically detected in RGA groundwater (see the 2013 Soils OU RI Report), where there were three or more individual result exceedances of the RG SSL and the background concentration. This screening was performed to identify hot spots that may pose a threat to groundwater and was supported by graphical or MVS evaluation, presented in Attachment C2.

Table C1.5. SWMU 229—Groundwater Screening (Potential Hot Spots)

#	SWMU	Analysis	Unit	No. of Detects	No. of Samples	Average[a,b] (Avg.)	Maximum[a,c] (Max.)	Subsurface Bckgrnd. Conc.[a,d]	RG SSL [a,e] (DAF 58)[f]	Ave.> Screen[g]?	Max.> Screen[h]?	How Many?[i]	Included in the list of COCs?[j]	Potential RGA Groundwater Impact?[k]
2	229	Tc-99	pCi/g	7	8	2.09E+01	4.34E+01	2.80E+00	4.41E-01	YES	YES	7	Yes	Yes

RG SSL= remedial guide soil screening level
[a] Concentration units as noted in the units column.
[b] Average concentration using half the detection limit for nondetected samples.
[c] Maximum detected concentration.
[d] Subsurface background concentration values are taken from the Risk Methods Document (DOE 2015).
[e] Subsurface RG SSL [dilution attenuation factor (DAF) 58] calculated as noted above, consistent with EPA Web site: http://www.epa.gov/safewater/consumer/pdf/mcl.pdf. RG SSL for uranium and Tc-99 calculated in similar manner but based on Kd value of 450 for uranium and 0.2 for Tc-99 to be consistent with the BGOU RI modeling, DOE/LX/07-0030&D2/R1.
[f] DAF values can be found in Appendix C, Attachment C2, of the Soils OU RI (DOE 2013).
[g] Average concentration exceeds both the subsurface background concentration and the subsurface RG SSL.
[h] Maximum concentration exceeds both the subsurface background concentration and the subsurface RG SSL.
[i] Number of detected samples that exceed both the subsurface background concentration and the subsurface RG SSL.
[j] Soil constituent is included in the list of contaminants of concern (COCs) identified for groundwater (Table C1.1).
[k] As determined in the Soils RI Report (DOE 2013).

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C1.6. REFERENCES

CTech Software 2014. Mining Visualization System Version 9.93, C Tech Development Corporation.

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ATTACHMENT C2

DATA SUMMARY AND EVALUATION

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C2. DATA SUMMARY AND EVALUATION

In this attachment to Appendix C, the Solid Waste Management Unit (SWMU) 229 results are discussed for those soil constituents with exceedances of the Remedial Guide (RG) Soil Screening Level (SSL) or background concentrations to identify whether they should be subjected to fate and transport modeling. Although few SWMU soil constituent combinations were subjected to modeling because they did not exceed the screening criteria (see Attachment C1), the information presented in this attachment has been developed to support the feasibility study (FS).

C2.1. SWMU 229

Data for SWMU 229 consist of both historical data and Remedial Investigation (RI)-collected data. SWMU 229 exceedances of the RG SSL include the following soil constituents: antimony, mercury, naphthalene, phenanthrene, technetium-99 (Tc-99), uranium-234, uranium-235, and uranium-238.

Antimony was detected in 35 of 42 samples. The detections are shown in Figure C2.1.1. The average concentration[1] over SWMU 229 for antimony is greater than both the RG SSL and the background concentration. Antimony was evaluated as part of the Groundwater Operable Unit (GWOU) FS and identified as a contaminant of concern (COC) in the groundwater plumes associated with Paducah Gaseous Diffusion Plant (PGDP) (DOE 2001). The evaluation presented in Attachment C1 to Appendix C of the Soils OU RI Report (DOE 2013) did not identify any antimony impacts to Regional Gravel Aquifer (RGA) groundwater; therefore, antimony does not meet the screening criteria for fate and transport modeling for SWMU 229.

[1] As discussed in Appendix C Attachment C1, the overall average value of the soil constituent was calculated using both detected values and nondetected values (nondetected values at one-half the reported value).

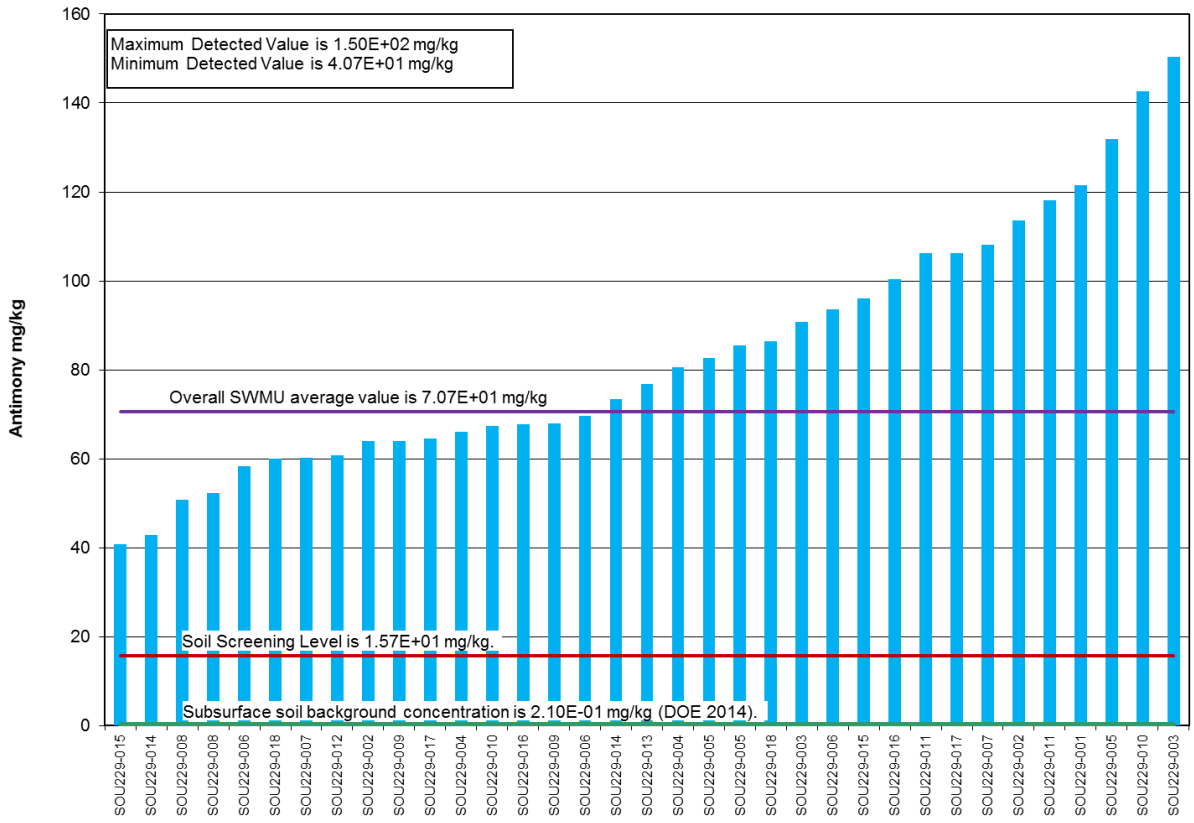

Figure C2.1.1. Antimony Detections at SWMU 229

Arsenic was detected in 17 of 42 samples. The detections are shown in Figure C2.1.2. The average concentration over SWMU 229 for arsenic is below both the background concentration and the RG SSL; therefore, arsenic does not meet the screening criteria for fate and transport modeling for SWMU 229.

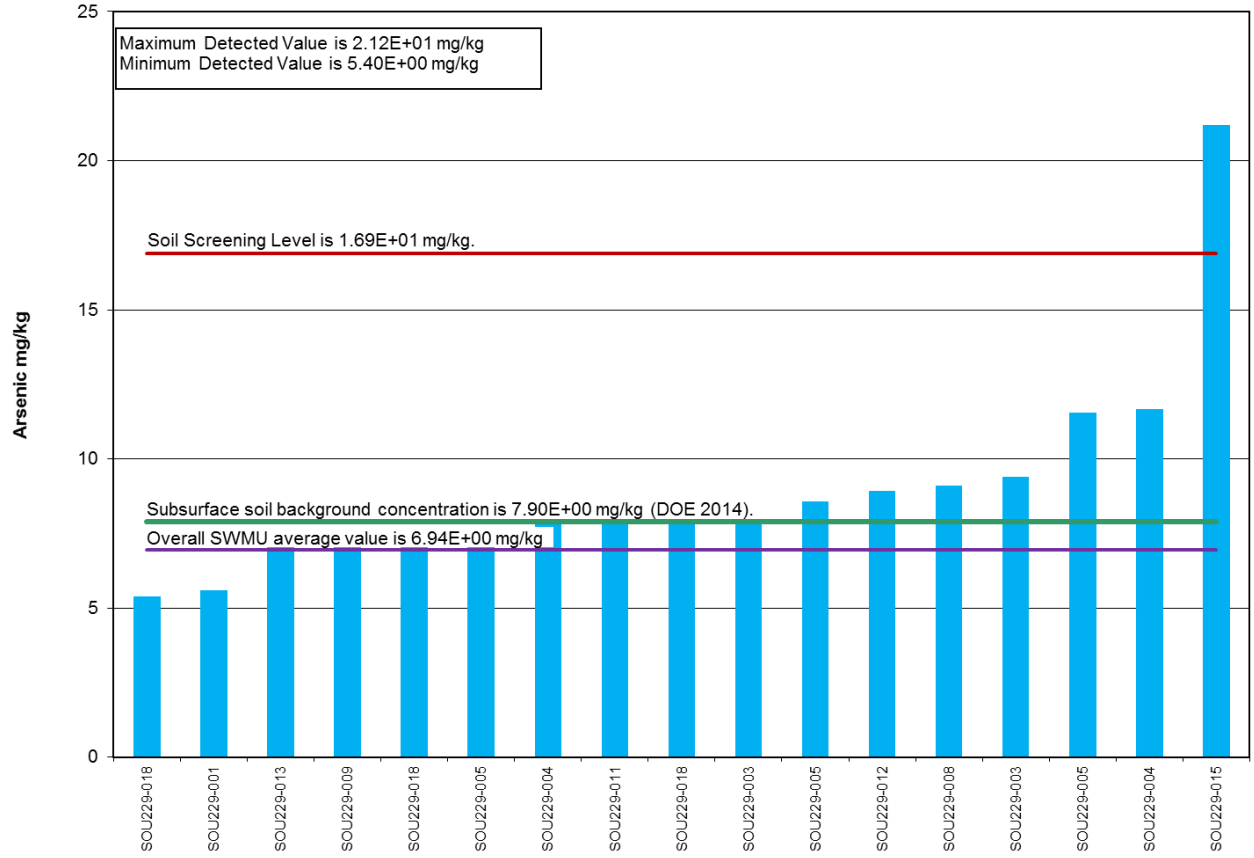

Figure C2.1.2. Arsenic Detections at SWMU 229

Cobalt was detected in all four of the samples. The detections are shown in Figure C2.1.3. The average concentration at SWMU 229 for cobalt is greater than the RG SSL, but less than the background concentration; therefore, cobalt does not meet the screening criteria for fate and transport modeling for SWMU 229.

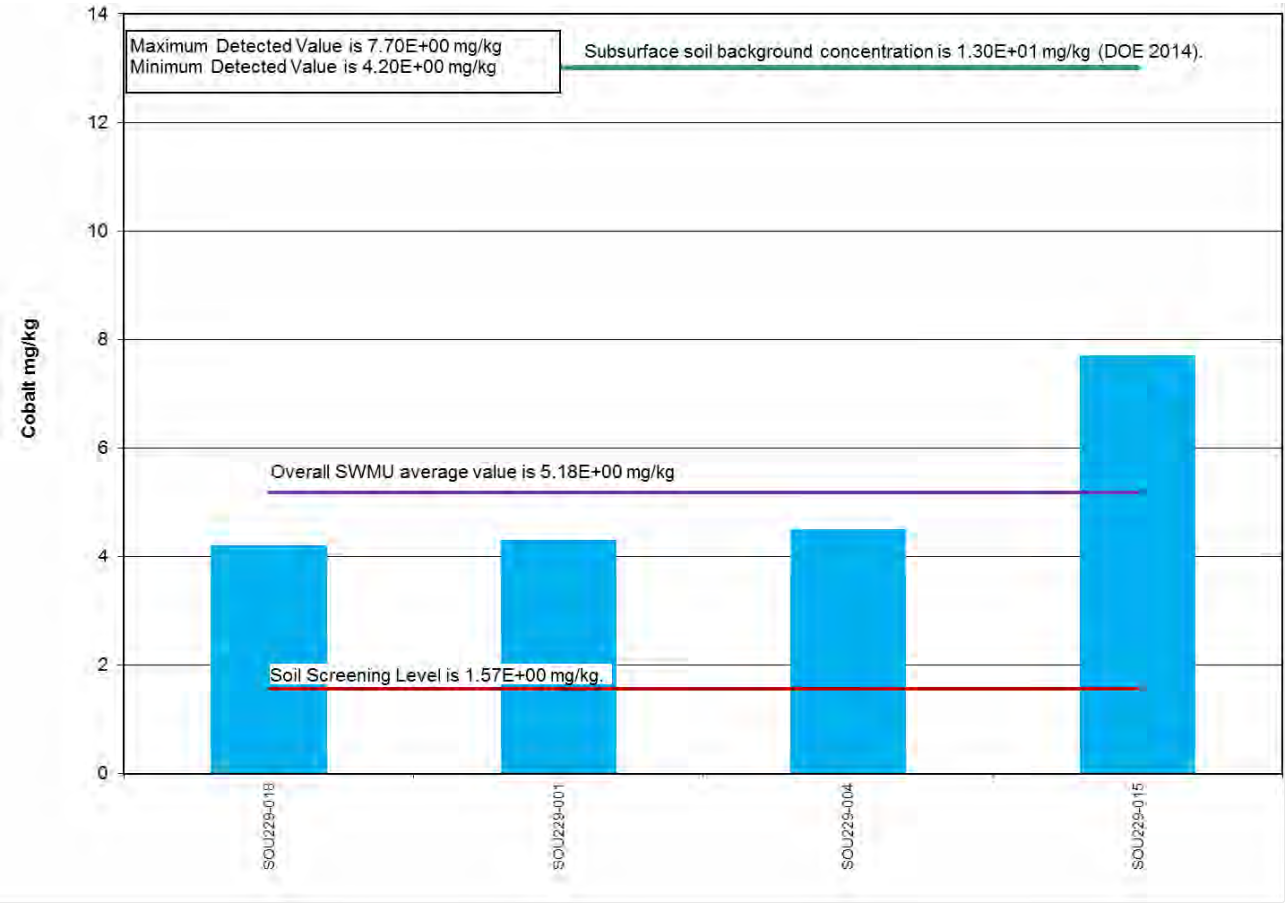

Figure C2.1.3. Cobalt Detections at SWMU 229

Iron was detected in all 42 of the samples. The detections are shown in Figure C2.1.4. The average concentration over SWMU 229 for iron is greater than the RG SSL, but less than the background concentration; therefore, iron does not meet the screening criteria for fate and transport modeling for SWMU 229.

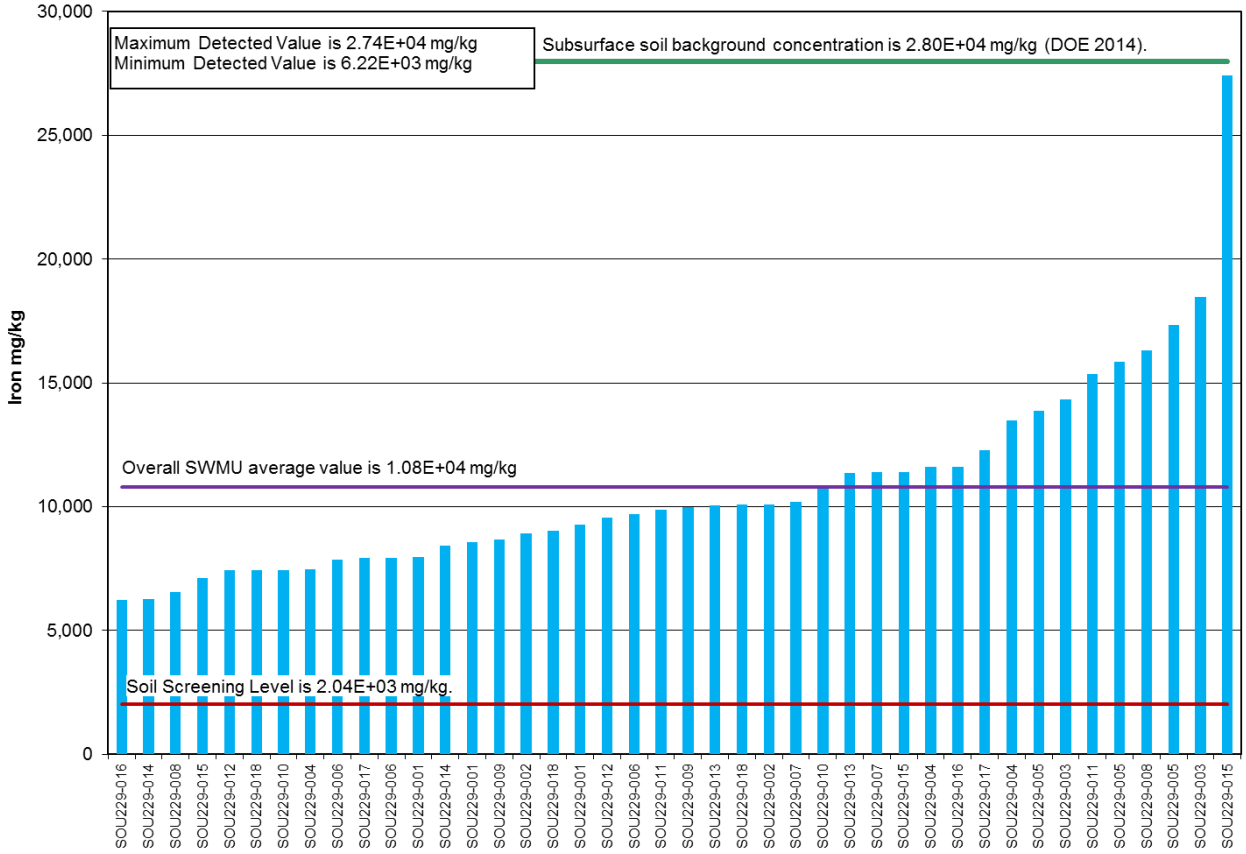

Figure C2.1.4. Iron Detections at SWMU 229

Manganese was detected in all 42 of the samples. The detections are shown in Figure C2.1.5. The average concentration over SWMU 229 for manganese is greater than the RG SSL, but less than the background concentration; therefore, manganese does not meet the screening criteria for fate and transport modeling for SWMU 229.

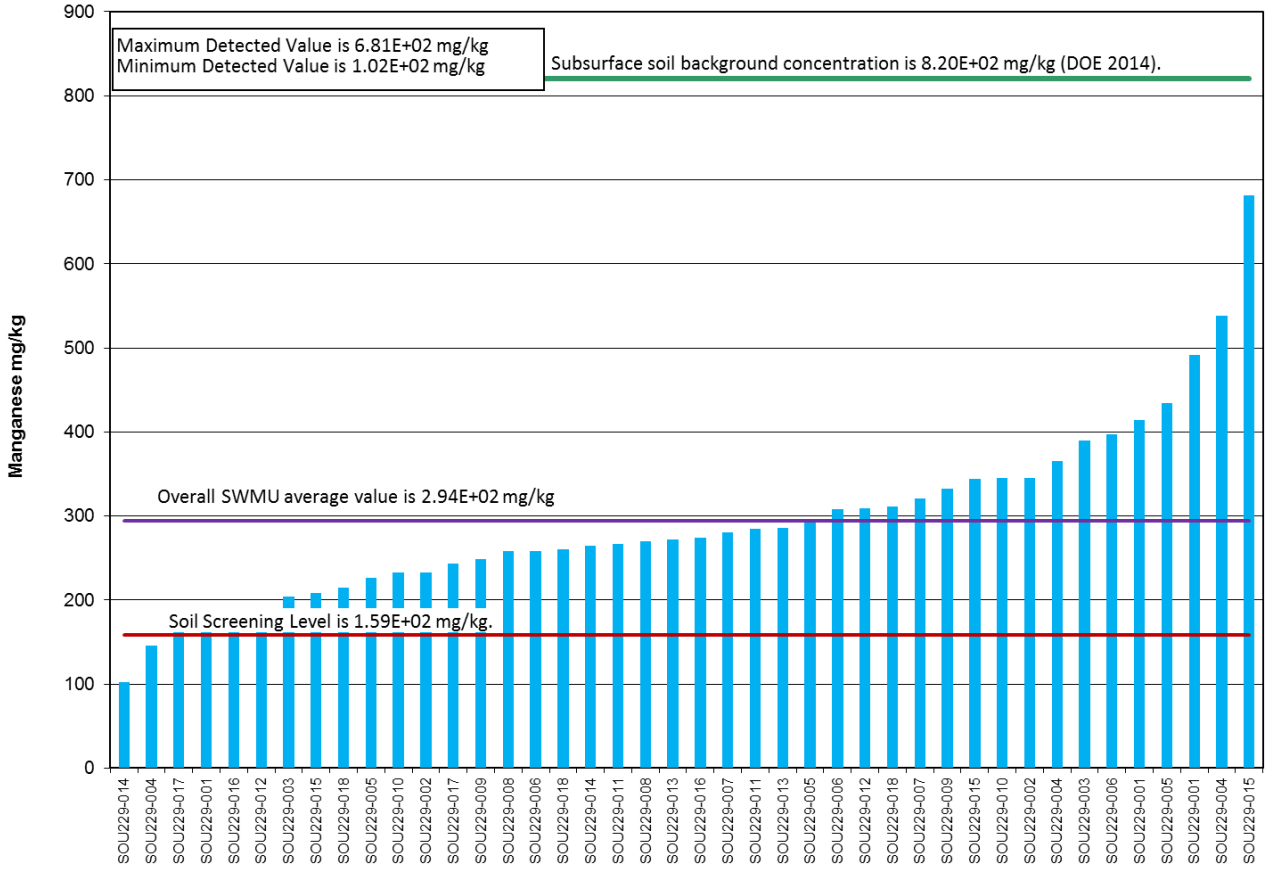

Figure C2.1.5. Manganese Detections at SWMU 229

Mercury was detected in 5 of 42 samples. The detections are shown in Figure C2.1.6. The average concentration over SWMU 229 for mercury is greater than both the RG SSL and the background concentration. Mercury was not identified as a COC in the groundwater plumes associated with PGDP (DOE 2001); therefore, mercury does not meet the screening criteria for fate and transport modeling for SWMU 229.

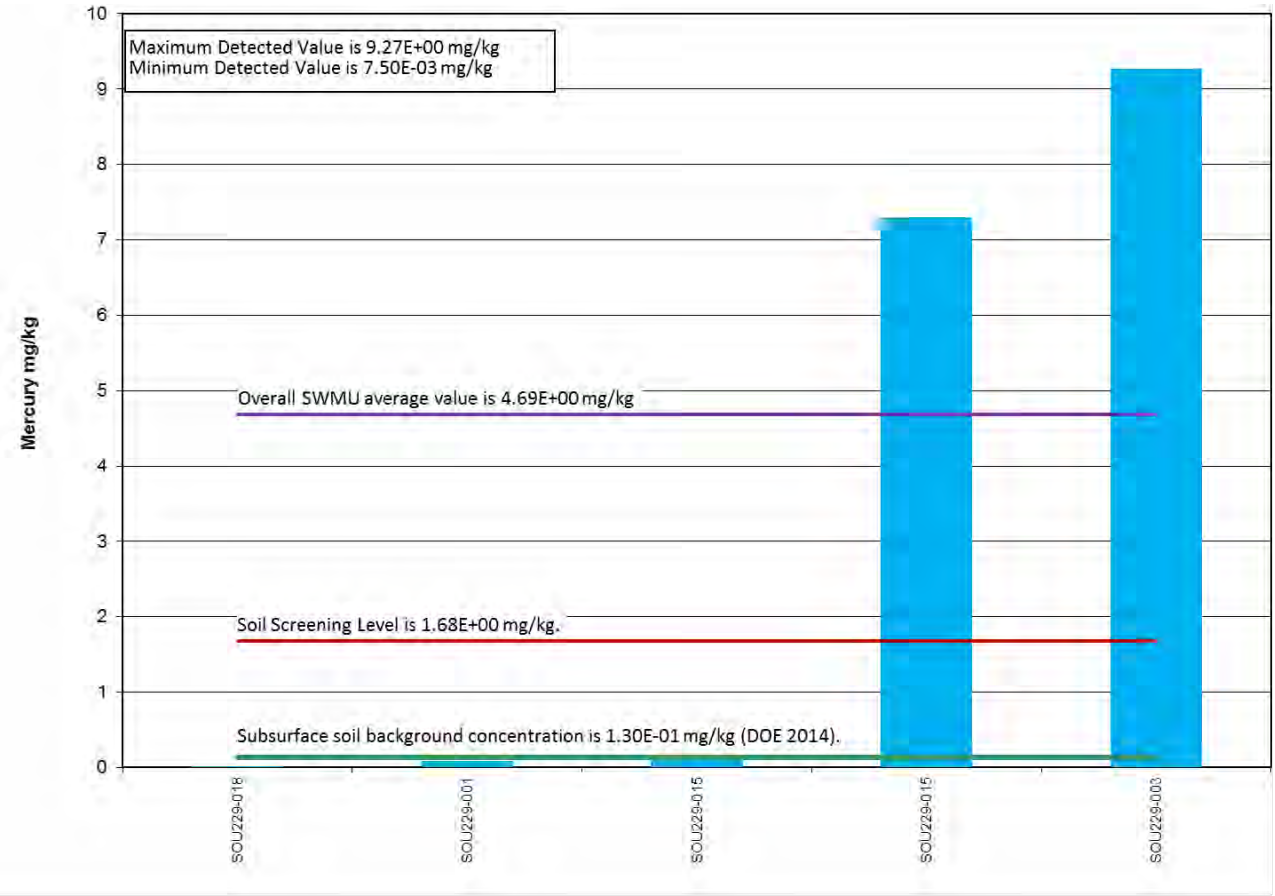

Figure C2.1.6. Mercury Detections at SWMU 229

Naphthalene was detected in one of four samples. The detection is shown in Figure C2.1.7. Although the average concentration (equal to the single detection) over SWMU 229 for naphthalene is greater than the RG SSL, naphthalene was not identified as a COC in the groundwater plumes associated with PGDP (DOE 2001). Naphthalene does not meet the screening criteria for fate and transport modeling for SWMU 229.

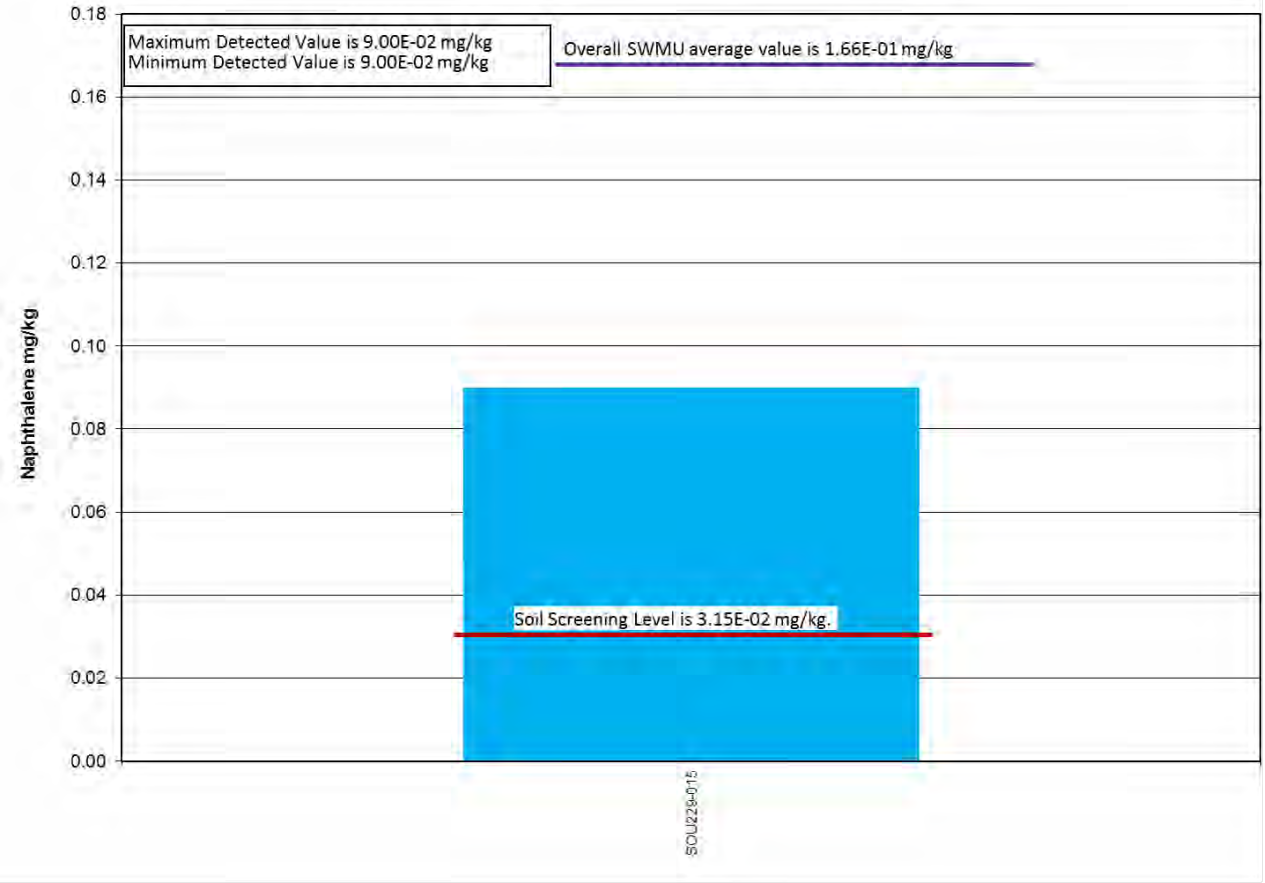

Figure C2.1.7. Naphthalene Detections at SWMU 229

Phenanthrene was detected in two of four samples. The detections are shown in Figure C2.1.8. Although the average concentration over SWMU 229 for phenanthrene is greater than the RG SSL, phenanthrene was not identified as a COC in the groundwater plumes associated with PGDP (DOE 2001). Phenanthrene does not meet the screening criteria for fate and transport modeling for SWMU 229.

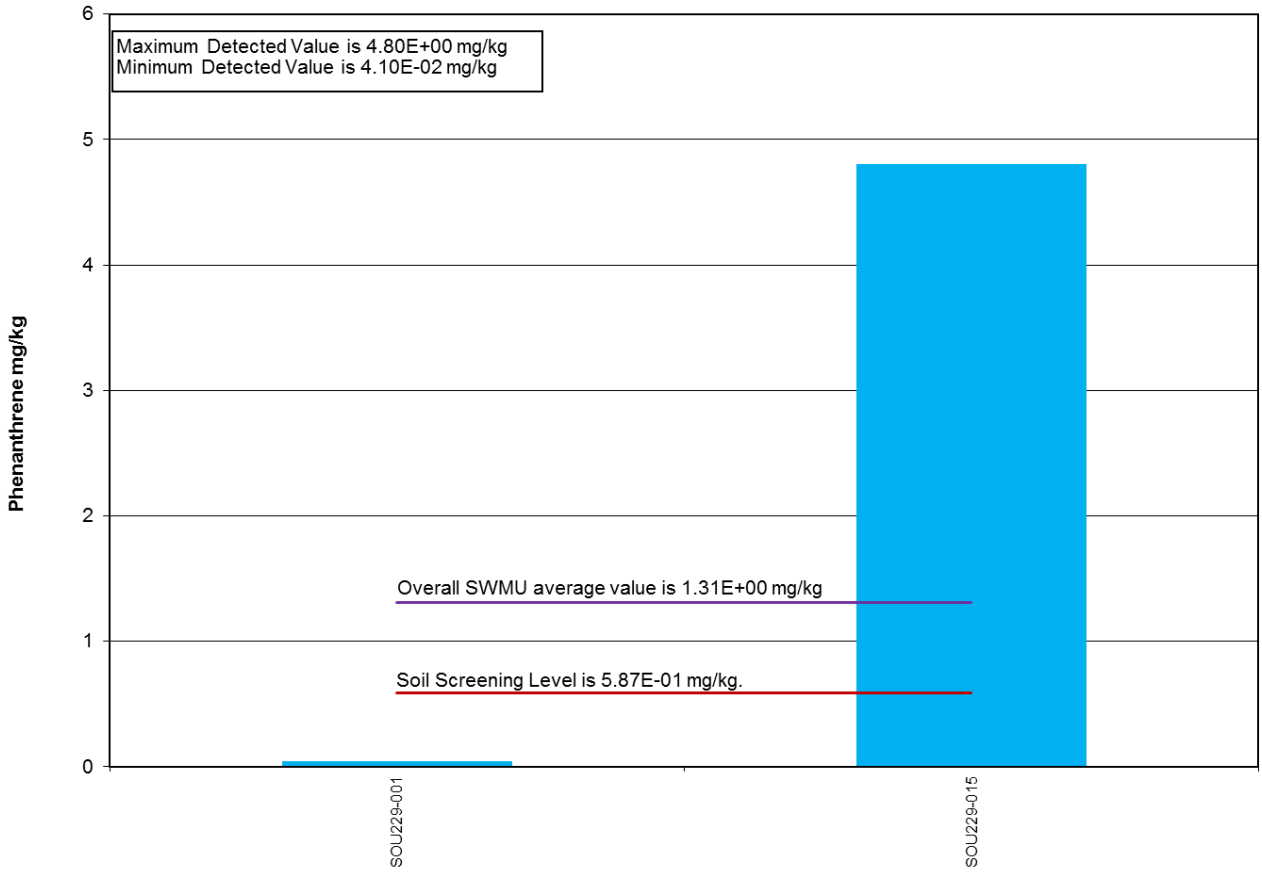

Figure C2.1.8. Phenanthrene Detections at SWMU 229

Tc-99 was detected in seven of eight samples. The detections are shown in Figure C2.1.9. The average activity concentration over SWMU 229 for Tc-99 is greater than both the RG SSL and the background activity concentration. Tc-99 was evaluated as part of the GWOU FS and identified as a COC in the groundwater plumes associated with PGDP (DOE 2001). Because of the presence of Tc-99 in RGA groundwater and the close proximity of SWMU 229 to the Tc-99 plume, SWMU 229 may be a secondary source of Tc-99. Seven samples exceed both the background activity concentration and the RG SSL; therefore, a hot spot evaluation was performed.

Mining Visualization System 3-D software was used to evaluate the distribution of Tc-99 across SWMU 229. Figure C2.1.10 shows the distribution of Tc-99 at 0–5 ft bgs. A hot spot does appear to be present.

Tc-99 in SWMU 229 appears to meet the screening criteria for fate and transport modeling.

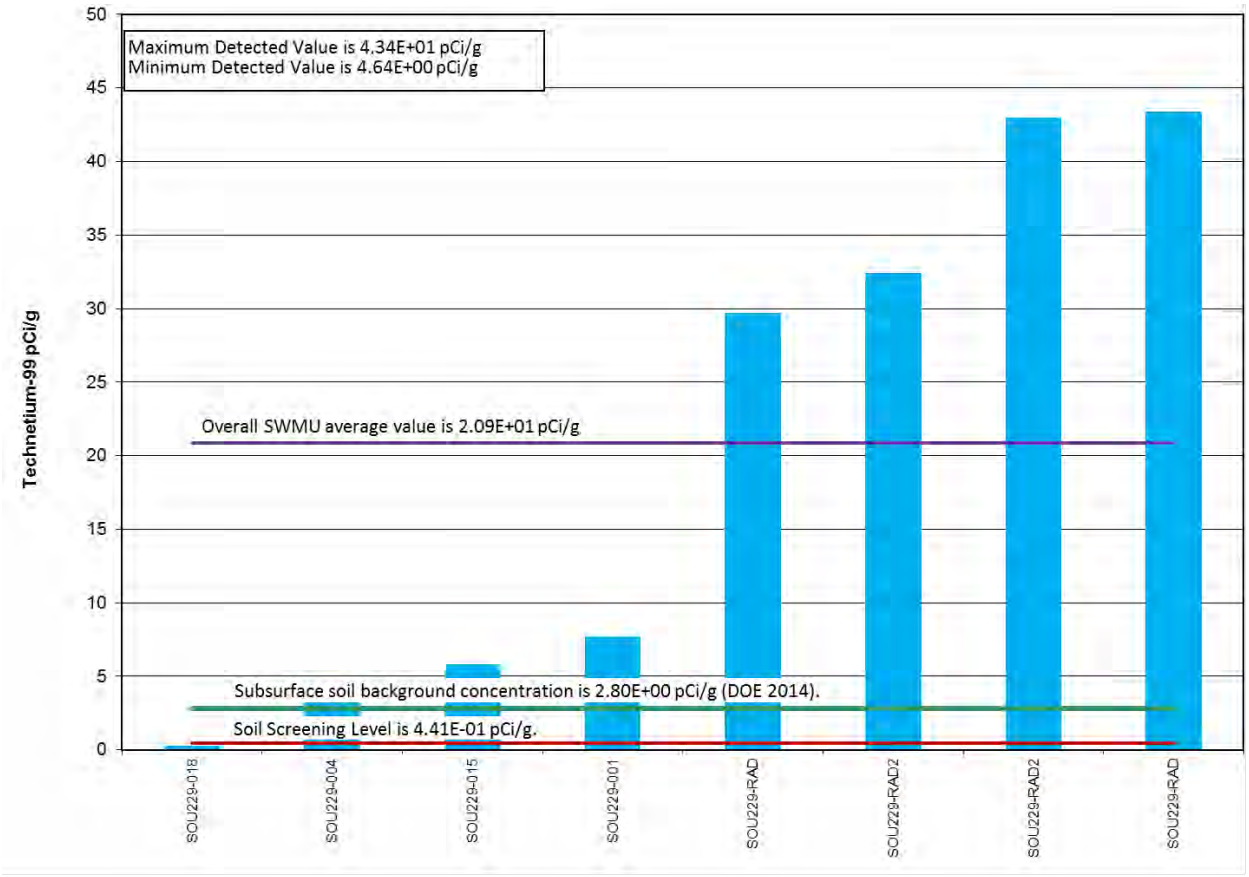

Figure C2.1.9. Tc-99 Detections at SWMU 229

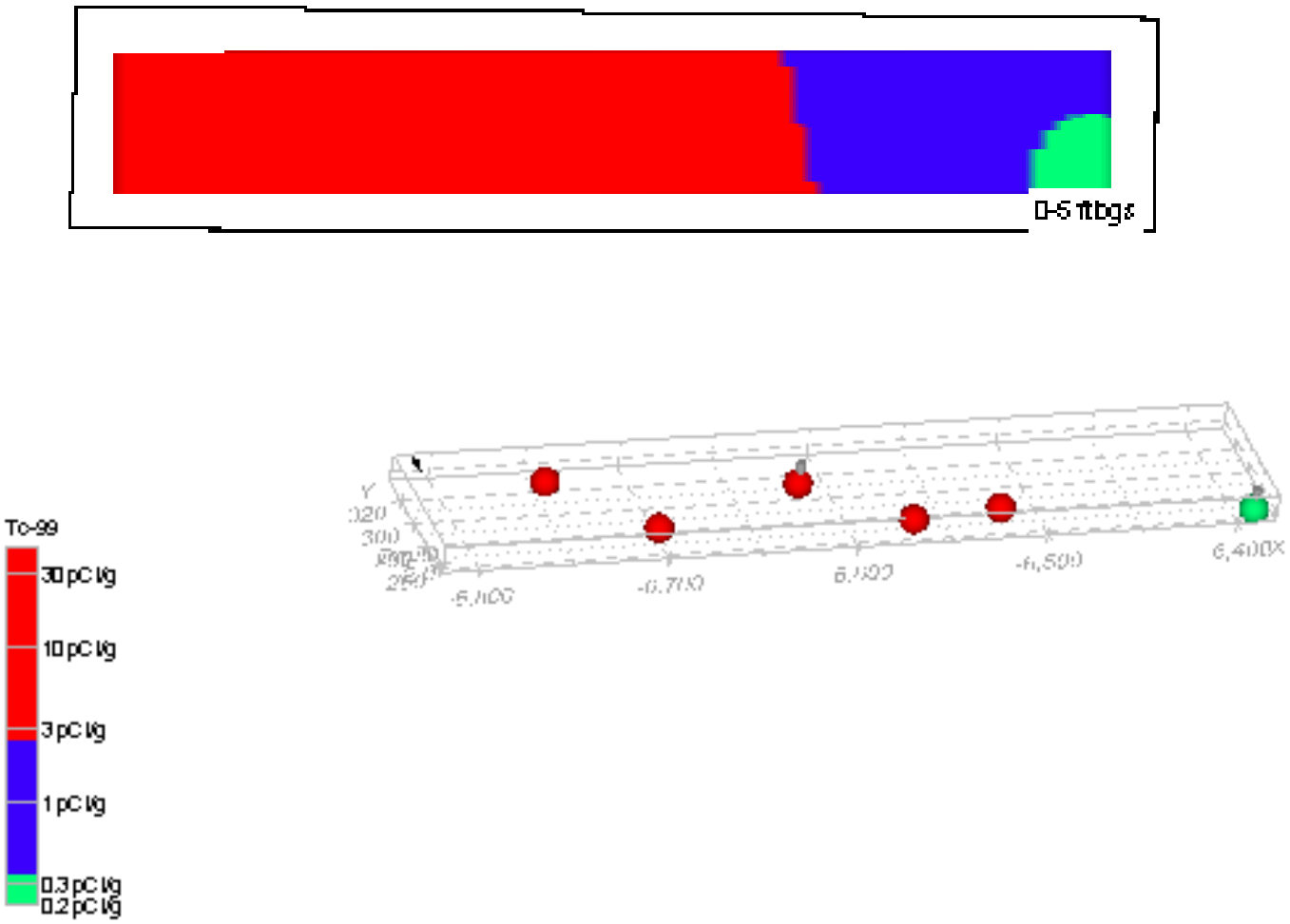

Figure C2.1.10. Distribution of Tc-99 at SWMU 229

Uranium-234 was detected in all eight of the samples. The detections are shown in Figure C2.1.11. The average activity concentration over SWMU 229 for uranium-234 is greater than both the background activity concentration and the RG SSL. Uranium-234 was evaluated as part of the GWOU FS and identified as a COC in the groundwater plumes associated with PGDP (DOE 2001). Additionally, uranium was modeled at SWMU 81 [presented in the Soils OU RI Report (DOE 2013)], which did not identify any uranium-234 impacts to RGA groundwater; therefore, uranium-234 fate and transport modeling was not performed for SWMU 229.

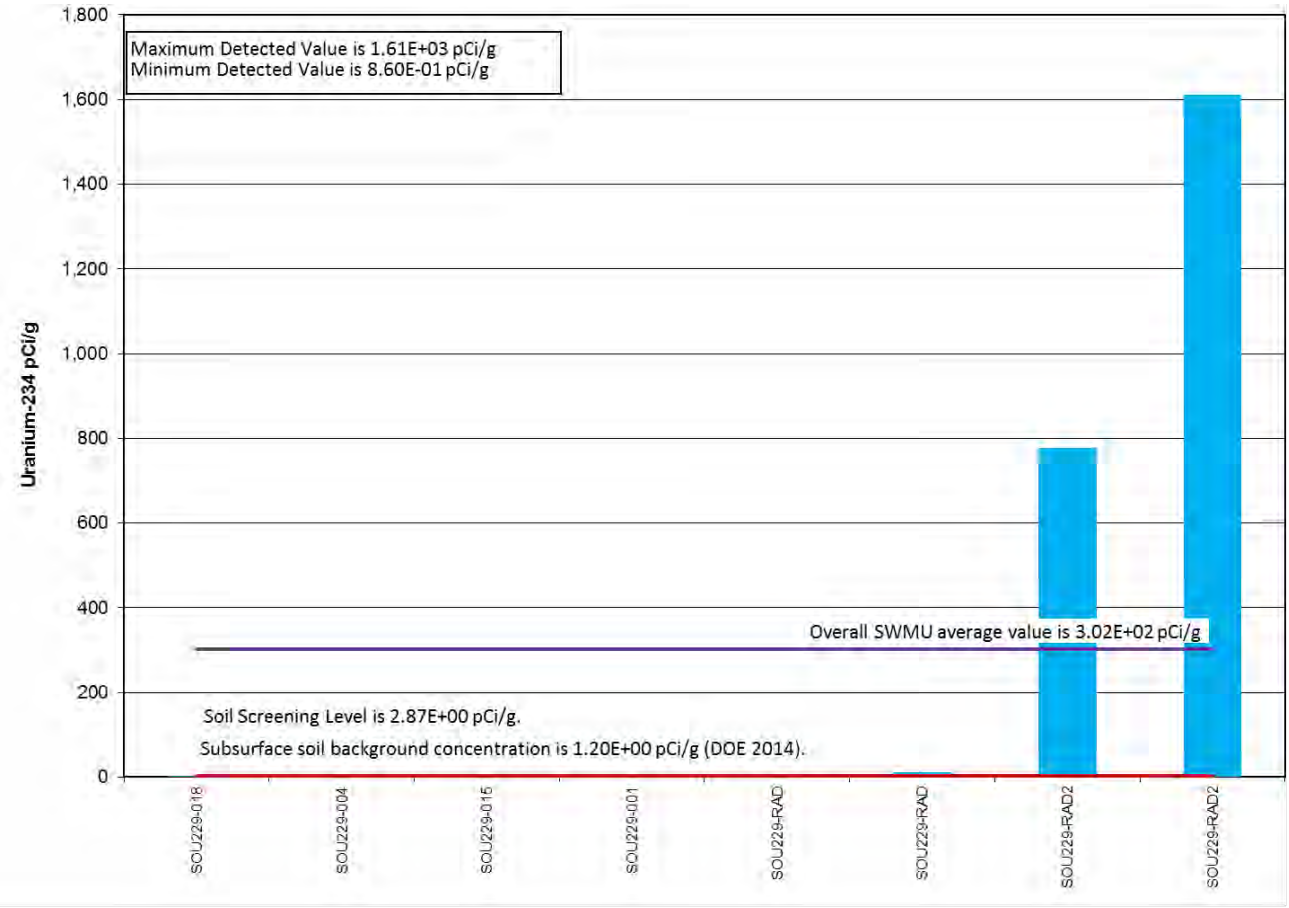

Figure C2.1.11. Uranium-234 Detections at SWMU 229

Uranium-235 was detected in all eight of the samples. The detections are shown in Figure C2.1.12. The average activity concentration over SWMU 229 for uranium-235 is greater than both the RG SSL and the background activity concentration. Uranium-235 was evaluated as part of the GWOU FS and identified as a COC in the groundwater plumes associated with PGDP (DOE 2001). Only two samples exceed both the background concentration and the RG SSL; therefore, uranium-235 does not meet the screening criteria for fate and transport modeling for SWMU 229.

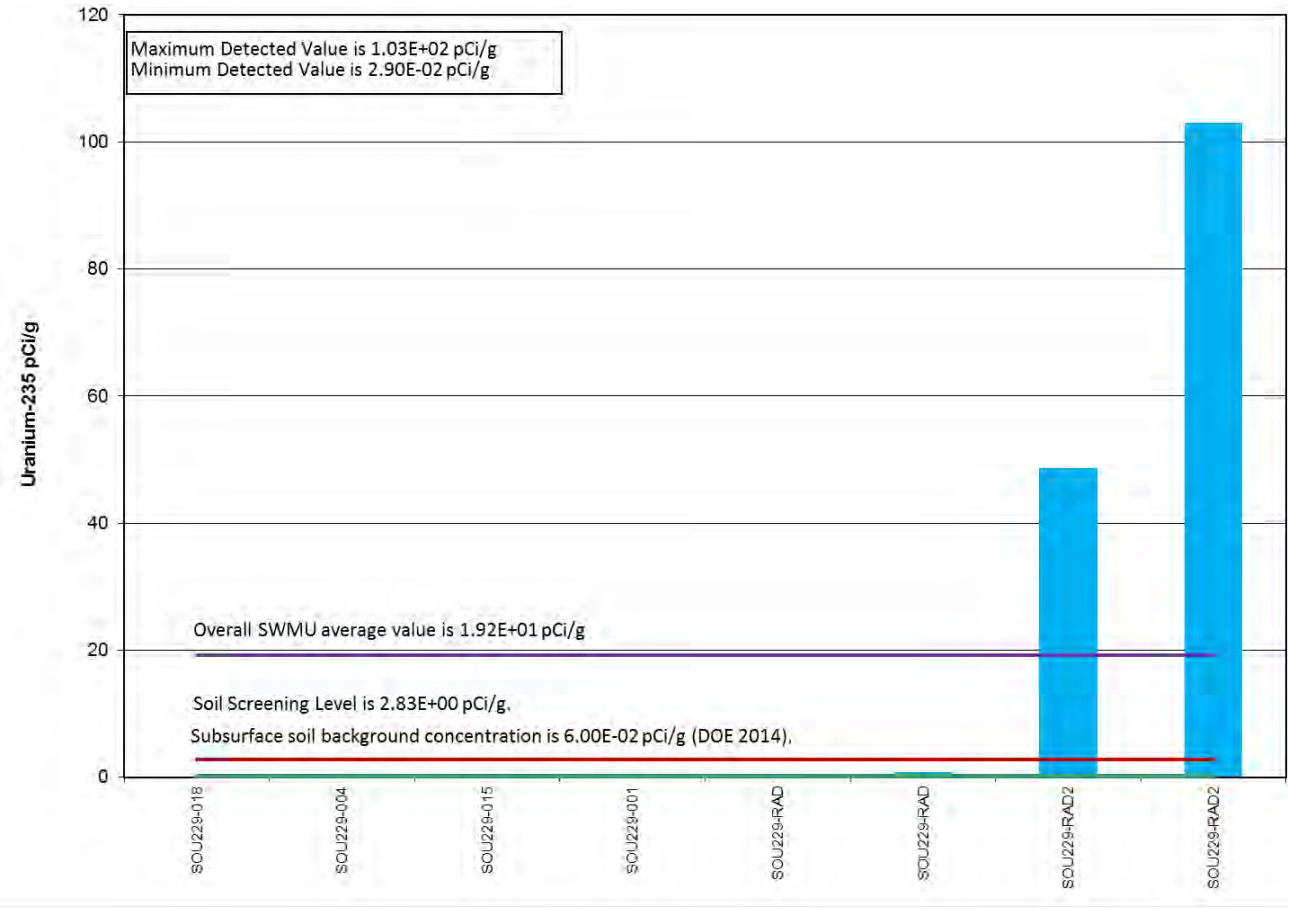

Figure C2.1.12. Uranium-235 Detections at SWMU 229

Uranium-238 was detected in all eight of the samples. The detections are shown in Figure C2.1.13. The average activity concentration over SWMU for uranium-238 is greater than both the background activity concentration and the RG SSL. Uranium-238 was evaluated as part of the GWOU FS and identified as a COC in the groundwater plumes associated with PGDP (DOE 2001). The evaluation presented in Attachment C1 to Appendix C of the soils OU RI Report (DOE 2013) did not identify any uranium-238 impacts to RGA groundwater; therefore, uranium-238 does not meet the screening criteria for fate and transport modeling for SWMU 229.

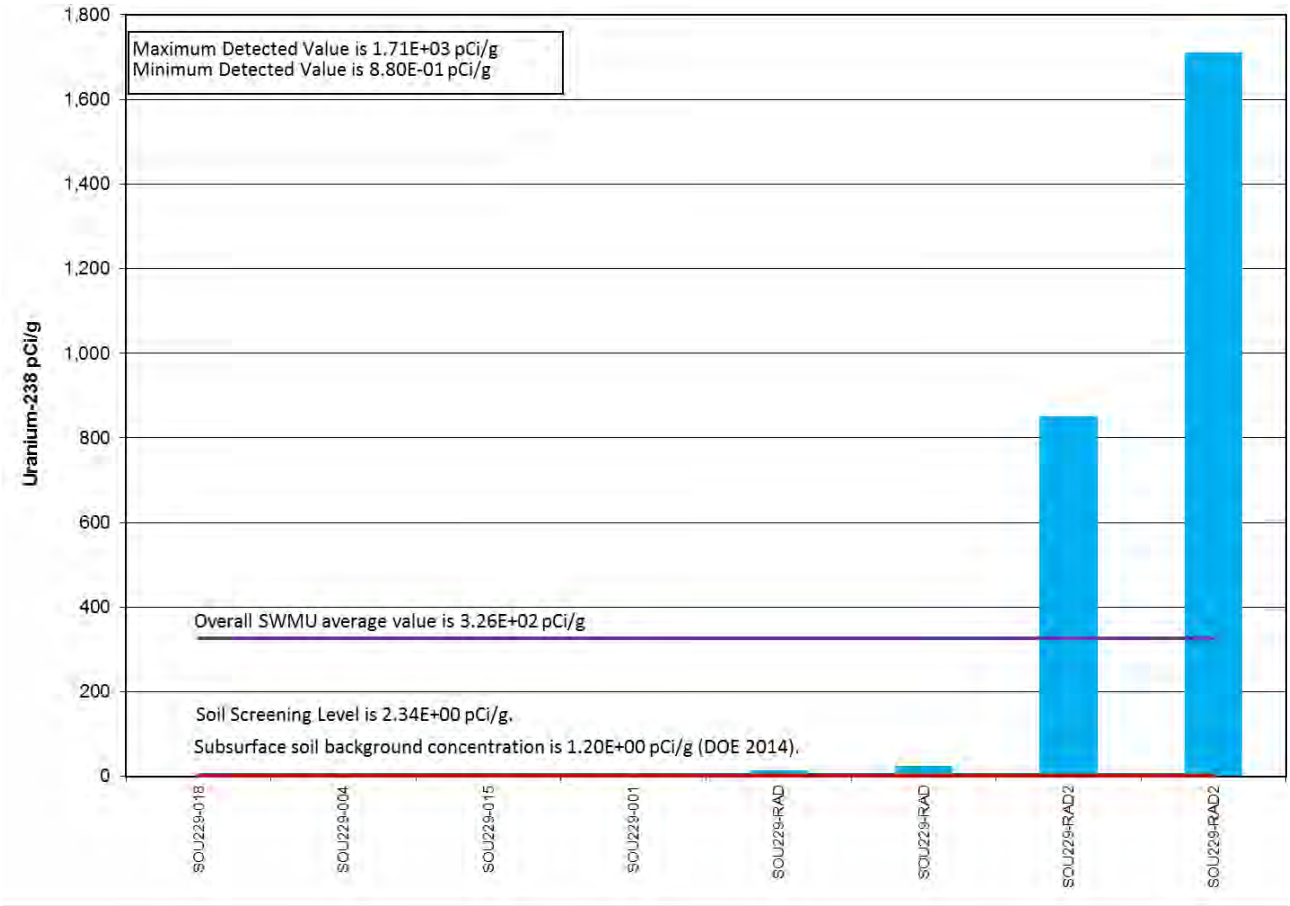

Figure C2.1.13. Uranium-238 Detections at SWMU 229

C2.2. REFERENCES

DOE 2001. *Feasibility Study for the Groundwater Operable Unit at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1857&D2, U.S. Department of Energy, Paducah, KY, August.

DOE 2013. *Soils Operable Unit Remedial Investigation Report at the Paducah Gaseous Diffusion Plant Paducah, Kentucky,* DOE/LX/07-0358&D2/R1, U.S. Department of Energy, Paducah, KY, February.

ATTACHMENT C3

CALCULATION PACKAGE

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C3.1. CALCULATIONS SUMMARY

This attachment provides an example of the calculations used in performing the groundwater modeling. Seasonal Soil Compartment Model (SESOIL) and Analytical Transient 1-,2-,3-Dimensional Model (AT123D) groundwater and transport modeling were conducted as part of the Soils Operable Unit (OU) Remedial Investigation (RI) to determine potential Regional Gravel Aquifer (RGA) groundwater concentrations of technetium-99 (Tc-99), emanating from Solid Waste Management Unit (SWMU) 229 at the SWMU boundary.

The input files were developed in the graphic user interface SEVIEW v 7.1.17. These input parameters are shown in Table C3.1. It previously was agreed upon in the Soils OU Work Plan that the Soils Project would be limited to soil depths of 15 ft below ground surface (bgs) or less. Thus, site-specific input at depths greater than 15 ft was not available for the SESOIL and AT123D simulations; therefore, input parameters were developed in the Soils OU RI Report (DOE 2013). These same parameters, with the exception of the percolation rate, which was obtained from SESOIL climate data, were used in this report as described in "Appendix C Fate and Transport Modeling" prepared as part of the Soils OU RI Report (Appendix C) (DOE 2013).

Additional input parameters were provided in Appendix C; the RI Report for Waste Area Grouping 27 (DOE 1999); and the RI Report for the Burial Grounds Operable Unit at PGDP (DOE 2010). The remainder of data (flow path from source to points of exposure, source area size) was provided in ArcGIS files depicting particle tracking and flow paths, which were derived from information provided in the 2008 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model (PRS 2008).

Input concentrations are summarized in Appendix C main text Tables C3.2–C3.4. Table C3.2 lists reported average concentrations that were calculated using samples having detected concentrations. Table C.3.7 (Appendix C main text) presents the calculated adjusted soil contaminated area for each contaminant, which is the maximum area (of the three intervals) as listed in Table C.3.4 (Appendix C main text). Adjusted interval concentrations (Table C.3.7, Appendix C main text) were calculated using the ratio of SWMU total area to maximum impacted soil area as well as the ratio of number of detects to the total number of samples. That ratio then was applied to the Table C.3.3 (Appendix C main text) average concentration for each interval. For example, the calculation of SWMU 229 Tc-99 at a depth of between 0 cm to 152.4 cm bgs is as follows:

$$1.23\text{E}-03\ \frac{\mu g}{g} \times \frac{0.849\ \text{acres (total area)}}{0.708\ \text{acres (max interval area)}} \times \frac{5\ \text{samples with Tc}-99\ \text{detection}}{6\ \text{total Tc}-99\ \text{samples}}$$

$$= 1.23\text{E}-03\ \mu g/g$$

Tc-99 concentrations were reported in units of activity (pCi/g) as well as on a mass basis. The activity was converted from mass concentration (µg/g) using the following formulas:

$$\lambda = \ln(2)/t_{1/2}$$

where (from PRS 2010):

λ is the Tc-99 decay constant = 1.03×10^{-13} s
$t_{1/2}$ is the half-life of Tc-99 = 6.72×10^{12} s

The specific activity (SA) in disintegrations per second per gram (dps/g) is found by:

$$SA = N_A(\lambda)/M = 6.27 \times 10^8 \text{ dps/g}$$

where:

N_A is Avogadro's number = 6.02×10^{23} mol^{-1}
M is atomic mass (Tc-99 = 98.9 g/mol)

The unit conversion of dps to Curies (Ci) is 3.7×10^{10} dps/Ci, which equals an SA of 0.017 Ci/g or 1.7×10^4 pCi/µg. Activity concentrations then are calculated by multiplying the mass concentration (µg/g) by the SA (1.7×10^4 pCi/µg).

Therefore,

$$1.23\text{E}-03 \ \frac{\mu g}{g} * 1.7\text{E}+04 \frac{pCi}{\mu g} = 20.9 \ \frac{pCi}{g}$$

C3.2. REFERENCES

DOE (U.S. Department of Energy) 1999. *Remedial Investigation Report for Waste Area Grouping 27 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1777&D2, U.S. Department of Energy, Paducah, KY, June.

DOE 2010. *Remedial Investigation Report for the Burial Grounds Operable Unit at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky*, DOE/LX/07-0030&D2/R1, U.S. Department of Energy, Paducah, KY, February.

DOE 2013. *Soils Operable Unit Remedial Investigation Report at the Paducah Gaseous Diffusion Plant Paducah, Kentucky,* U.S. Department of Energy, Paducah, KY, DOE/LX/07-0358&D2/R1, February.

Harbaugh, A. W., E. R. Banta, M. C. Hill, and M. G. McDonald 2000, MODFLOW-2000, Version 1.19.01, the U.S. Geological Survey Modular Ground-Water Model–Users Guide to Modularization Concepts and Groundwater Flow Process, U.S. Geological Survey, Open-File Report 00-92.

PRS (Paducah Remediation Services, LLC) 2010. *2008 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model*, PRS-ENR-0028, Paducah Remediation Services, LLC, Kevil, KY.

Table C3.1. SEVIEW Input Parameters

Parameter (Units)	Value	Source
SESOIL Parameters		
Temperature (Celsius) (Oct–Sept)	15.28 8.39 3.33 2.06 3.67 8.11 14.72 19.39 23.89 25.56 24.94 21.17	Template input files
Cloud Cover (Fraction) (Oct–Sept)	0.45 0.55 0.65 0.70 0.65 0.65 0.60 0.60 0.55 0.50 0.45 0.45	Template input files
Relative Humidity (Fraction) (Oct–Sept)	0.70 0.70 0.75 0.75 0.70 0.65 0.65 0.70 0.70 0.70 0.70 0.70	Template input files
Short Wave Albedo (Fraction) (Oct–Sept)	0.17 0.18 0.20 0.22 0.20 0.19 0.17 0.17 0.17 0.17 0.17 0.17	Template input files
Evapotranspiration (cm/day) (Oct–Sept)	0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00	Template input files
Precip (cm/month) (Oct–Sept)	9.98 10.67 15.19 16.08 12.19 15.32 13.72 10.26 12.85 10.54 7.39 11.38	Template input files
Storm Length (Days) (Oct–Sept)	0.32 0.45 0.49 0.47 0.41 0.40 0.37 0.30 0.25 0.25 0.23 0.27	Template input files
# of Storms (Storms/Month) (Oct–Sept)	4.50 5.00 5.62 5.29 5.84 6.65 6.82 7.38 5.85 6.15 5.28 4.60	Template input files
Rainy Season (Days) (Oct–Sept)	30.40 30.40 30.40 30.40 30.40 30.40 30.40 30.40 30.40 30.40 30.40 30.40	Template input files
Water Solubility (mg/L)	Tc-99 = 7,180	SEVIEW Chemical Database
Henry's Law Constant (M^3–Atm/Mol)	Tc-99 = 0	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
K_{oc} Adsorption–Desorption (µg/G)/(µg/Ml)	0	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010 for Tc-99/SEVIEW Chemical Database for Cr, Ni, and Total PCBs
K_d Adsorption (µg/G)/(µg/Ml)	Tc-99 = 0.2	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
K_d Desorption (µg/G)/(µg/Ml)	0	Template input files
Chemical Valence (G/Mole)	0	Template input files
Base Hydrolysis Rate Constant (1/Day)	0	Template input files
Liquid Phase Biodegradation Rate (1/Day)	Tc-99 = 8.92E-09	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
Solid Phase Biodegradation Rate (1/Day)	Tc-99 = 8.92E-09	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
Water Diffusion Coefficient (cm^2/Sec)	Tc-99 = 1.0E-06	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010

Table C3.1. SEVIEW Input Parameters (Continued)

Parameter (Units)	Value	Source
Air Diffusion Coefficient (cm^2/Sec)	Tc-99 = 0	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
Molecular Weight (G/Mole)	Tc-99 = 99	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
Neutral Hydrolysis Rate Constant (1/Day)	0	Template input files
Acid Hydrolysis Rate Constant (1/Day)	0	Template input files
Ligand Dissociation Constant (-)	0	Template input files
Moles Ligand/Mole Chemical (-)	0	Template input files
Molecular Weight Ligand (G/Mol)	0	Template input files
Soil Bulk Density (G/cm^3)	1.46	Template input files
Intrinsic Permeability (cm^2)	1.6E-10	Template input files
Soil Pore Disconnectedness Index (-)	10	Template input files
Effective Porosity (Fraction)	0.45	Template input files
Organic Carbon Content (Percent)	0.08	Template input files
CEC (Milliequivalents/100 G Dry Soil)	0	Template input files
Freundlich Exponent (-)	1	Template input files
Load Area (mm^2)	Tc-99 SWMU 29 = 2.86E+07	ArcGIS shapefiles
Site Latitude (Decimal Degrees)	37.1	Template input files
Number of Layers	4	Template input files
Upper Soil Layer Thickness (cm)/Number Of Sublayers	152.4/1	Template input files
Second Soil Layer Thickness (cm)/Number Of Sublayers	152.4/1	Template input files
Third Soil Layer Thickness [(cm)/Number of Sublayers]	152.4/1	Template input files
Lower Soil Layer Thickness (cm)/Number of Sublayers	1219.2/10	Template input files
Ph (Upper, Second, Third, And Lower Layer)	7	Template input files
Intrinsic Permeability (cm^2) (Upper, Second, Third, and Lower Layer)	0	Template input files
Ratio of Liquid Phase Biodegradation to Upper Layer (Fraction) (Upper, Second, Third, and Lower Layer)	1	Template input files
Ratio of Solid Phase Biodegradation to Upper Layer (Fraction) (Upper, Second, Third, and Lower Layer)	1	Template input files
Organic Carbon Ratio to Upper Layer (Fraction) (Upper, Second, Third, and Lower Layer)	1	Template input files
CEC Ratio to Upper Layer (Fraction) (Upper, Second, Third, and Lower Layer)	1	Template input files
Freundlich Exponent Ratio to Upper Layer (Fraction) (Upper, Second, Third, and Lower Layer)	1	Template input files

Table C3.1. SEVIEW Input Parameters (Continued)

Parameter (Units)	Value	Source
Adsorption Coefficient Ratio to Upper Layer (Fraction) (Upper, Second, Third and Lower Layer)	1	Template input files
Layer 1–4 All Years VOLF1 (Fraction) (Oct–Sept)	1	Template input files
Layer 1 All Years ISRM (Fraction) and ASL1 (Fraction) (Oct–Sept)	0	Template input files
Layer 1–4 All Years POLIN1, TRANS1, SINK1, LIG1 (µg/cm^2)	0	Template input files
Layer 1, Layer 2, Layer 3, and Layer 4 Adjusted Sublayer Tc-99 Concentrations (µg/G)	SWMU 229 = 1.23E-03, 0, 0	Concentration average of Tc-99 data collected in SWMU 229 from 0–5, 5–10, and 10–15 ft bgs. Assumed concentration between 15 ft bgs and water table is zero.
AT123D		
Hydraulic Conductivity (M/Hr)	22.263	Historical sitewide model
Effective Porosity (-)	0.3	PGDP sitewide model calibrated value
Soil Bulk Density (gg/m^3)	1670	Laboratory analysis
Hydraulic Gradient (M/M)	0.0015	ArcGIS particle tracking shapefiles
Number Of Eigenvalues	1000	Template input files
Longitudinal, Transverse, and Vertical Dispersivity (M)	1.5, 0.15, 0.003	Template input files
Aquifer Width (M)	Infinite	Template input files
Aquifer Depth (M)	9.14	Site Average
Organic Carbon Content (%)	0.02	Laboratory analysis
Water Diffusion Coefficient (m^2/Hr)/(cm^2/S)	3.60E-07/1.0E-06	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
First Order Decay Coefficient (1/hr)/(1/d)	Tc-99 = 3.716E-10/8.92E-09	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
Carbon Adsorption Coefficient, K_{oc} (µg/G)/(µg/Ml)	0	Forces model to use K_d
Distribution Coefficient, K_d (m^3/Kg)	0.00005	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
Sol H_20	7,180	Remedial Investigation Report for the Burial Grounds Operable Unit at PGDP, Paducah, KY, Feb. 2010
Starting Time Step	1	Desired time interval
Ending Time Step	11989	Desired time interval
Print Interval	1	Desired print interval
X-Axis Coordinates (M)	655.8	Desired observation coordinates (SWMU 229 boundary)
Y-Axis Coordinates (M)	663.515	Centerline of SWMU 229
Z-Axis Coordinates (M)	0, 1.5, 3	Desired observation depths
Release Coordinates Start/End X (meters)	571.2, 658.40	Model space chosen coordinates

Table C3.1. SEVIEW Input Parameters (Continued)

Parameter (Units)	Value	Source
Release Coordinates Start/End Y (meters)	647.1, 679.93	Model space chosen coordinates
Release Coordinates Start/End Z (meters)	0, 0	Model space chosen coordinates
Initial Concentration (mg/L)	0	Assumption: conc.= 0 at time = 0
Single Mass Load (kg)	0	Assumption: conc.= 0 at time = 0
Model Time Step (Hours)	730	SESOIL default, one month
Continuous Release	492	Number of time steps required for 41 year simulation
Load Release Rate (kg/hr)	Output from SESOIL	SESOIL**

*In keeping with the convention documented in Appendix C to the Soils OU RI, the average concentrations were assumed to be present across the entire SWMU within the associated depth interval as each sample was reported to have a detection of Tc-99.
**Input for AT123D is derived directly from SESOIL output files.

Table C3.2. SWMU 229 Tc-99 Soil Data

Sample ID Depth Interval 0–5'	Date	Easting (ft)	Northing (ft)	Start Depth (ft bgs)	End Depth (ft bgs)	Activity (pCi/g)	Concentration (µg/g)
SOU229001SA001	7/1/2010	-6748.9835	311.3463	0	1	8	4.55E-04
SOU229004SA004	7/2/2010	-6613.9848	310.7694	1	4	4.64	2.73E-04
SOU229015SA001	7/2/2010	-6524.1779	265.3852	0	1	5.81	3.42E-04
SOU229RADSD001	10/6/2010	-6569.1775	265.5775	0	1	43.4	2.55E-03
SOU229RADSB001D	10/2/2015	-6704.1762	266.1544	0	1	43	2.53E-03

Note: The concentration used in the 0–5 ft interval in the SWMU 229 SESOIL model is a simple arithmetic average of available data within that interval.

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APPENDIX D

BASELINE HUMAN HEALTH RISK ASSESSMENT

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CONTENTS

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FIGURES

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TABLES

ACRONYMS

ABS	dermal absorption factor
AT	average time
bgs	below ground surface
BHHRA	Baseline Human Health Risk Assessment
BW	body weight
CAS	Chemical Abstract Service
CDI	chronic daily intake
COC	contaminant of concern
COPC	chemical or radionuclide of potential concern
CSM	conceptual site model
DMSA	U.S. Department of Energy Material Storage Area
DOE	U.S. Department of Energy
DQA	data quality analysis
EC	exposure concentration
ED	exposure duration
EF	exposure frequency
ELCR	excess lifetime cancer risk
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
EU	exposure unit
GI	gastrointestinal tract
HEAST	Health Effects Assessment Summary Tables
HI	hazard index
HQ	hazard quotient
IRIS	Integrated Risk Information System
IUR	inhalation unit risk
KDEP	Kentucky Department for Environmental Protection
NAL	no action level
NCEA	National Center for Environmental Assessment
OREIS	Oak Ridge Environmental Information System
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PbB	blood lead
PGDP	Paducah Gaseous Diffusion Plant
POC	pathway of concern
POE	point of exposure
RAGS	Risk Assessment Guidance for Superfund
RAIS	Risk Assessment Information System
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RGA	Regional Gravel Aquifer
RGO	remedial goal option
RI	remedial investigation
RME	reasonable maximum exposure
SAP	Sampling and Analysis Plan
SF	slope factor

SQL	sample quantitation limit
SSL	soil screening level
SWMU	solid waste management unit
TEF	toxicity equivalence factor
TPU	total propagated uncertainty
UCRS	Upper Continental Recharge System
VOC	volatile organic compound
WKWMA	West Kentucky Wildlife Management Area
XRF	X-ray fluorescence

BASELINE HUMAN HEALTH RISK ASSESSMENT

This baseline human health risk assessment (BHHRA) addresses one solid waste management unit (SWMU) that initially was included in the Soils Operable Unit (OU) remedial investigation (RI) (DOE 2010). During development of the RI Report, it was decided that insufficient information was available for several of the SWMUs/areas of concern included in the RI and a second RI (RI 2) was planned. Sampling for RI 2 activities generally followed the initial work plan (DOE 2010), with exceptions noted in the Soils OU RI 2 Sampling and Analysis Plan (SAP) Addendum (DOE 2014). This BHHRA uses information collected during the two Soil OU RIs to characterize the baseline risks posed to human health from contact with contaminants in soil at SWMU 229 and at locations to which contaminants may migrate. A summary of the data is presented Section 5 of the main text.

Part of Goal 3 for the Soils OU RI 2, as presented in the Soils OU Work Plan (DOE 2010), was to determine if contaminants at the Soils OU units are present at levels sufficiently high to pose a risk to human health or the environment. Risk assessments for potential residential, industrial, excavation, and recreational scenarios are presented here. The sampling information collected during the RIs and in earlier investigations, the analyses of these data presented in Chapter 5 of the RI Report, and the results of this BHHRA will be used to determine if response actions are appropriate for SWMU 229 and to screen among response action alternatives. This risk assessment also includes modeled concentrations of contaminants in the Regional Gravel Aquifer (RGA) to support the refinement of an assessment of potential risks to human health and the environment through groundwater for contaminant concentrations exceeding the respective soil screening levels (SSLs) for the RGA (see Appendix C).

The methods and presentations used in this BHHRA are consistent with those presented in *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant* (DOE 2015a). The Risk Methods Document integrates the human health risk assessment guidance from the U.S. Environmental Protection Agency (EPA) and the Kentucky Department for Environmental Protection (KDEP) and incorporates instructions contained in regulatory agency comments on earlier risk assessments performed for Paducah Gaseous Diffusion Plant (PGDP). Screening levels for this RI Report Addendum are presented in Table A.4 of the Risk Methods Document (DOE 2015a).

Consistent with the 2015 revision to the Risk Methods Document, the SWMU 229 BHHRA is presented in nine sections, as described below.

- The first section (D.1) reviews the results of previous risk assessments that are useful in understanding the potential risks posed to human health by contaminants at or migrating from the source areas.

- The second section (D.2) includes identification of chemicals or radionuclides of potential concern (COPCs).

- The third section (D.3) documents the exposure assessment for the sources, including the following:

  — The characterization of the exposure setting,

  — Identification of exposure pathways,

  — Consideration of land use,

  — Determination of potential receptors,

— Delineation of exposure points and routes [including development of the conceptual site model (CSM)], and

— Calculation of chronic daily intakes (CDIs) and exposure concentrations (ECs).

- The fourth section (D.4) presents the following:

  — The toxicity assessment, including information on the noncarcinogenic (i.e., systemic toxicity or hazard) and carcinogenic effects of the COPCs, and

  — The uncertainties in the toxicity information.

- The fifth section (D.5) reports the following:

  — The results of the risk characterization for current and future land uses; and
  — Identifies contaminants, pathways, and land use scenarios of concern.

- The sixth section (D.6) contains qualitative and quantitative analyses of the uncertainties affecting the results of the BHHRA.

- The seventh section (D.7) summarizes the methods used in the BHHRA and presents the BHHRA's conclusions and observations.

- The eighth section (D.8) uses the results of the BHHRA to develop site-specific risk-based remedial goal options (RGOs).

- The ninth section (D.9) contains references.

The overall risk assessment process is presented in Figure D.1, which graphically displays the steps identified in the preceding section.

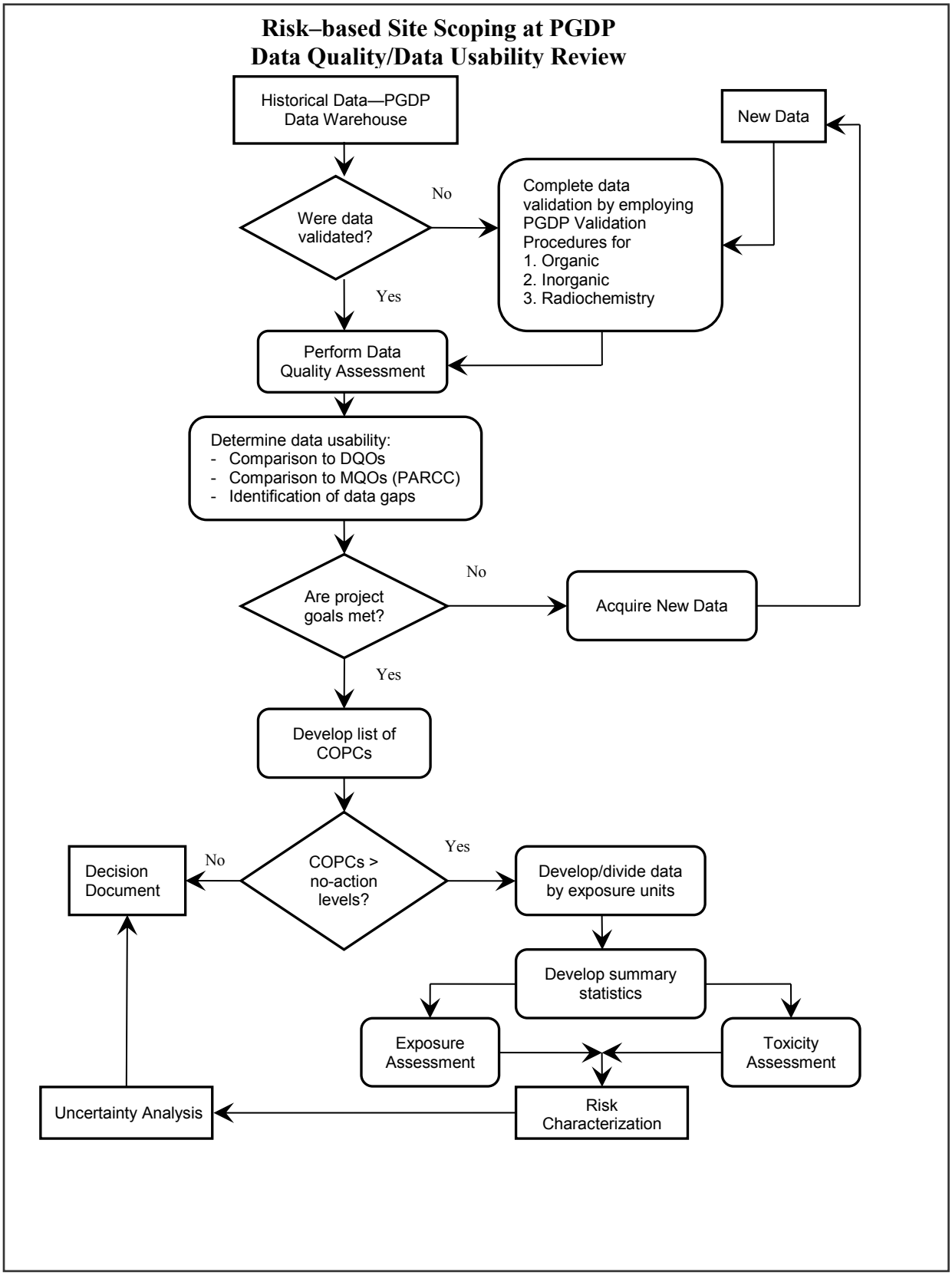

Figure D.1. BHHRA Flow Chart

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D.1. RESULTS OF PREVIOUS STUDIES

Resource Conservation and Recovery Act (RCRA)-regulated items have been removed from SWMU 229 and placed in proper storage. The U.S. Department of Energy (DOE) Material Storage Area (DMSA) has been fully characterized and contains no fissionable material (DOE 2003). No prior risk assessments have been performed for this SWMU.

D.2. IDENTIFICATION OF COPCS

The process used to determine the list of COPCs used in the BHHRA is described in the following subsections. Specifically, these subsections describe the sources of data, the procedures used to screen the data, and the methods used to derive exposure point concentrations (EPCs) under both current and future conditions. Additionally, this section describes the site characterization data used in the exposure assessment performed in Section D.3.

The SWMU 229 evaluation in the Nature and Extent section of the main text focused on summarizing the representative analytical results for surface and subsurface soils. The process for highlighting chemicals of greatest potential interest, consistent with the work plan, considered background concentrations, action levels and no action levels (NALs) (for the industrial worker), and groundwater protection SSLs for the Upper Continental Recharge System (UCRS) and RGA. This screening was independent of COPC identification for this BHHRA.

D.2.1 SOURCES OF DATA

Data used in the BHHRA describing current contaminant concentrations in surface and subsurface soil at SWMU 229 that were sampled during the summer of 2010 and the summer of 2014 were derived from the recently completed Soils OU RI sampling and RI 2 sampling (DOE 2010 and DOE 2014), acquired from the Paducah Oak Ridge Environmental Information System (OREIS) database. The nature and extent of contamination in surface and subsurface soils are described in Section 5 of this report.

D.2.2 GENERAL DATA EVALUATION CONSIDERATIONS

This section describes the data evaluation steps that were used to ensure that the soil data were appropriate for use in BHHRAs. A general description of the eight steps used and their outcome in relation to the SWMU 229 BHHRA data set are provided in this section. A graphical presentation of this process is shown in Figure D.2.

D.2.2.1 Evaluation of Sampling

Data were examined to ensure that sampling methods were adequate for determining the nature and extent of contamination and were representative of site conditions. It was determined that samples of the Soils OU RI and Soils OU RI 2 were collected using appropriate methods that were consistent with each project's work plan.

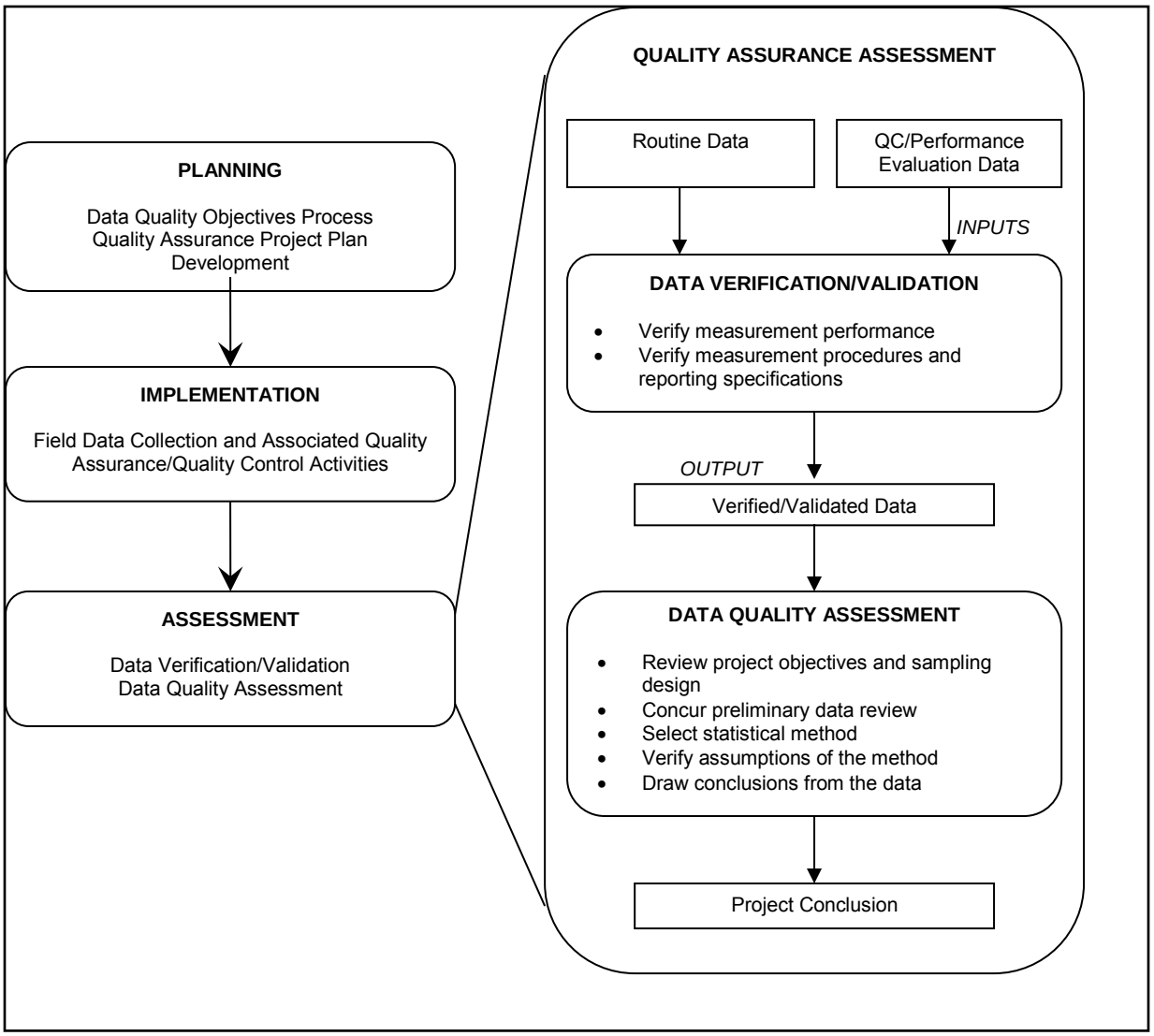


Figure D.2. Data Evaluation Steps

D.2.2.2 Evaluation of Analytical Methods

Methods used to collect and analyze the selected surface soil and subsurface soil samples were evaluated to determine if they were those approved by EPA. As described in work plans and project reports (see Section 5 of the main text and Appendix B), the analytical methods used for surface and subsurface soil samples meet these requirements.

The data evaluation and COPC identification steps include a comprehensive evaluation of the analytical data collected during the nature and extent definition for a site. The data collection and evaluation by media were included as part of the nature and extent discussion section. The data quality analysis (DQA) section (Appendix B) identifies the quality assurance/quality control-related issues to determine which data are useable for evaluations performed in the RI. The data used for the COPC selection were validated in accordance with the DQA.

To address the data set for the SWMUs more comprehensively, plutonium-239 data were evaluated as plutonium-239/240 and uranium-235/236 were evaluated as uranium-235.

The Soils OU RI and Soils OU RI 2 data include field screening such as X-ray fluorescence (XRF) data. The primary use of such data is for site characterization, but this survey-type data [called field data in the RI Work Plan (DOE 2010)] also can play a role in risk-based decision making. Survey-type data assist in determining the distribution of COPCs and can be used to identify which sets of laboratory data should be combined to develop site average contaminant concentrations. The XRF data were evaluated to determine if some or all could be combined with laboratory data for use in the risk assessment to determine the average concentrations for contaminants by evaluating whether the laboratory and XRF data possess similar detection limits and analytical uncertainty. This analysis was conducted (included in Appendix B) and indicated that a subset of XRF data qualified for use in the risk assessment in conjunction with the laboratory data. Similarly, use of XRF data was applied to historical data. The Risk Methods Document (DOE 2015a) allows for use of this type of data after the DQA is performed. Any uncertainties associated with the results that impact potential decisions are highlighted in the Uncertainties section.

D.2.2.3 Evaluation of Sample Quantitation Limits

The sample quantitation limits (SQLs) used in the analyses of the selected soil samples were examined to determine if these limits were below the concentration at which the contaminant may pose a risk to human health. Generally, the SQLs for each analyte met this goal. Table D.1 presents a comparison between each undetected analyte's maximum SQLs for soil for the RI 2 data set and the analyte's residential use no action screening value. The implications of this finding upon risk characterization (presented in this BHHRA) are discussed in Section D.6, Uncertainty in the Risk Assessment.

Consistent with the Risk Methods Document (DOE 2015a), if the maximum SQL for an analyte over all samples within a medium exceeded the no action screening value, then the data for that analyte was deemed of uncertain quality, and a qualitative assessment for that analyte was performed; this information can be found in Section D.6. In developing the qualitative assessment for such chemicals, the maximum SQL for the chemical is used in the qualitative assessment if historical or process knowledge indicates that the chemical potentially could be present. If historical or process knowledge indicates that the chemical is not expected to be present, one-half of the SQL is used in the qualitative assessment (EPA 1991). The qualitative analysis is presented in Section D.6, Uncertainty in the Risk Assessment.

D.2.2.4 Evaluation of Data Qualifiers and Codes

The soil data used in the BHHRA were tagged with various qualifiers and codes. Tagged data were evaluated following rules in Exhibits 5-4 and 5-5 of the Risk Assessment Guidance for Superfund (RAGS) (EPA 1998). Generally, this resulted in the retention of all results for which the identity of the analyte was certain even if there was substantial uncertainty in the analyte concentration within an individual sample. The qualifiers and codes attached to the soil data used in the BHHRA are defined in Table D.2.

Data rejected by validation were not used in the human health and screening ecological risk assessments. The Soils OU RI data rejected by validation for SWMU 229 were three neptunium-237 analyses. Neptunium-237 data still are available for each exposure unit (EU), thus the rejection of these data points has little importance.

Table D.1. Comparison between Undetected Analyte's Maximum SQLs and Site-Specific Soil Screening Levels[a]

Analyte	Frequency of Detection[b]	Maximum SQL	No Action Screening Value[c]	Units	Screening Value Exceeded?
Inorganic Compounds					
Antimony	35/42	30	3.13	mg/kg	Yes
Arsenic	17/42	11	0.267	mg/kg	Yes
Cadmium	11/42	12	5.07	mg/kg	Yes
Chromium	9/42	85	0.301	mg/kg	Yes
Copper	6/42	35	313	mg/kg	No
Lead	41/42	13	400	mg/kg	No
Mercury	5/42	10	2.35	mg/kg	Yes
Molybdenum	4/42	15	39.1	mg/kg	No
Nickel	13/42	65	155	mg/kg	No
Selenium	4/42	20	39.1	mg/kg	No
Silver	4/42	10	39.1	mg/kg	No
Thallium	0/4	0.44	0.0782	mg/kg	Yes
Uranium	23/48	20	23.4	mg/kg	No
Vanadium	4/42	70	39.3	mg/kg	Yes
PCBs					
PCB, Total	0/42	5	0.0782	mg/kg	Yes
Semivolatile Organic Compounds					
2-Nitrobenzenamine	0/4	2	33.2	mg/kg	No
Acenaphthene	1/4	0.41	171	mg/kg	No
Acenaphthylene	0/4	0.41	171	mg/kg	No
Anthracene	1/4	0.41	854	mg/kg	No
Bis(2-ethylhexyl)phthalate	0/4	0.41	14.3	mg/kg	No
Fluoranthene	2/4	0.41	114	mg/kg	No
Fluorene	1/4	0.41	114	mg/kg	No
Hexachlorobenzene	0/4	0.41	0.126	mg/kg	Yes
Naphthalene	1/4	0.41	3.83	mg/kg	No
N-Nitroso-di-n-propylamine	0/4	0.0082	0.0287	mg/kg	No
PAH, Total	3/4	0.0082	0.00619	mg/kg	Yes
Pentachlorophenol	0/4	2	0.243	mg/kg	Yes
Phenanthrene	2/4	0.41	171	mg/kg	No
Pyrene	2/4	0.41	85.4	mg/kg	No
Radionuclides					
Americium-241	2/6	0.022	3.03	pCi/g	No
Cesium-137	4/6	0.087	0.116	pCi/g	No
Neptunium-237	2/3	0.053	0.239	pCi/g	No
Plutonium-238	1/6	0.046	4.42	pCi/g	No
Plutonium-239/240	4/6	0.036	3.87	pCi/g	No
Technetium-99	5/6	0.44	117	pCi/g	No

[a] Results shown are over all soil samples collected within the SWMU.
[b] Number of detected results over total number of samples collected within the SWMU.
[c] Risk-based screening values are from DOE 2015a. The screening values are the lesser of the HI and excess lifetime cancer risk (ELCR) NALs used for the child resident of 0.1 and 1E-06, respectively.

Table D.2. Definitions of Qualifiers and Codes Present in the OREIS Data Set Used for the SWMU 229 BHHRA

Qualifier	Definition	Data Used?
Field = VALIDATION (Validation Qualifier)		
=	Validated result that is detected and unqualified.	Yes
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.	Yes
R	Result rejected due to quality deficiency.	No
U	The analyte was analyzed for, but was not detected above the reported sample quantitation limit.	Yes
X	Not validated; refer to RSLTQUAL field for more information.	Yes
Field = RSLTQUAL (Result Qualifier)		
Blank	Result not qualified.	Yes
*	Duplicate analysis is not within control limits.	Yes
B	Inorganic: The result is less than the project contract required detection limit, but greater than the instrument detection limit.	Yes
E	Inorganic: Estimated value; matrix interference.	Yes
	Organic: Concentration exceeds calibration range of gas chromatograph/mass spectrometer.	Yes
J	Estimated value, tentatively identified compound, or less than specified detection limit.	Yes
N	Inorganic: Spike recovery not within control limits.	Yes
	Organic: Applied to TIC results, except generic characteristics.	Yes
U	ALL ANALYSIS TYPES EXCEPT RADS: Not detected; RADS: Value reported is < minimum detectable activity and/or total propagated uncertainty (TPU).	Yes
X	Used when more than five qualifiers are required for a result.	Yes

D.2.2.5 Elimination of Chemicals Not Detected

Consistent with the Risk Methods Document (DOE 2015a), any analyte passing the earlier screens and not detected in at least one sample using an appropriate SQL was eliminated from the data set. These data are not considered further in this BHHRA.

D.2.2.6 Examination of Toxicity of Detected Analytes

Each analyte's maximum detected concentration in the data set was compared to that analyte's residential use no action human health risk-based screening value for soil. These screening values are provided in the Risk Methods Document (DOE 2015a). Analytes not provided in the Risk Methods Document are listed in Attachment D1.

D.2.2.7 Examination of Analyte Maximum Concentrations for Essential Human Nutrients Detected in Site Samples to Recommended Dietary Allowances for Children

Seven analytes known to be essential nutrients and known to be toxic only at extremely high concentrations were removed from the data set. These analytes were calcium, chloride, iodine, magnesium, phosphorus, potassium, and sodium. Consistent with the Risk Methods Document (DOE 2015a), no other analytes were removed from the data set based upon the essential nutrient screen.

D.2.2.8 Comparison of Analyte Maximum Concentrations and Activities Detected in Site Samples to Analyte Concentrations and Activities Detected in Background Samples

Consistent with the 2015 revision to the Risk Methods Document, a background screen was used to develop the BHHRA data set. Table D.3 shows the current PGDP background concentration for surface and subsurface soils used in the screening process.

Table D.3. Provisional Background Concentrations for Surface and Subsurface Soil at PGDP

Analyte	Background Value	
Inorganic Chemicals (mg/kg)	**Surface**	**Subsurface**
Aluminum	13,000	12,000
Antimony	0.21	0.21
Arsenic	12	7.9
Barium	200	170
Beryllium	0.67	0.69
Cadmium	0.21	0.21
Calcium	200,000	6,100
Chromium (III)	16	43
Cobalt	14	13
Copper	19	25
Iron	28,000	28,000
Lead	36	23
Magnesium	7,700	2,100
Manganese	1,500	820
Mercury	0.2	0.13
Nickel	21	22
Potassium	1,300	950
Selenium	0.8	0.7
Silver	2.3	2.7
Sodium	320	340
Thallium	0.21	0.34
Uranium	4.9	4.6
Vanadium	38	37
Zinc	65	60
Radionuclide (pCi/g)	**Surface**	**Subsurface**
Cesium-137	0.49	0.28
Neptunium-237[a]	0.1	---
Plutonium-238[a]	0.073	---
Plutonium-239[a]	0.025	---
Potassium-40	16	16
Radium-226	1.5	1.5
Strontium-90[a]	4.7	---
Technetium-99	2.5	2.8
Thorium-228	1.6	1.6
Thorium-230	1.5	1.4
Thorium-232	1.5	1.5
Uranium-234	1.2[b]	1.2[b]
Uranium-235	0.06[b]	0.06[b]
Uranium-238	1.2	1.2

Notes: Cells with "---" indicated data are not available or not applicable.
Values contained in this table are taken from the Risk Methods Document (DOE 2015a), but have not been approved for all uses by the PGDP Risk Assessment Working Group; therefore, the values presented here are provisional values and subject to change.
[a] Concentrations for these radionuclides in subsurface soil were not derived.
[b] The values listed for uranium-234 and uranium-235 are not from the 1996 background study, but are derived from the natural isotopic abundance ratio and the uranium-238 values. The values for these radionuclides that appeared in the 2001 version of the Risk Methods Document (DOE 2001) were the upper tolerance limits of measured values for the individual isotopes as reported in the PGDP background study (DOE 1997).

D.2.2.9 RI Analytes

For this project, both historical RI data and RI 2 data were combined into one dataset; however, only those analytes listed in the approved Soils OU RI Work Plan (DOE 2010) were evaluated for this BHHRA. Data were downloaded from the Paducah OREIS database in November 2015. Data from within the grids and EUs for SWMU 229 that were in the approved work plan were downloaded. Appendix B addresses data quality and applicability of the historical data. The potential for undetermined risk from historical data not evaluated during this BHHRA is addressed in the Uncertainties Section, D.6.

D.2.3 RISK ASSESSMENT SPECIFIC DATA EVALUATION

This section discusses details associated with the surface soil data set, the subsurface soil data set, and groundwater modeling data set used to examine potential current and future ELCRs and HIs to human health presented in this BHHRA.

D.2.3.1 Current Conditions

The specific processes used to evaluate data and calculate EPCs under current conditions are described in this section. The analyte's names were checked to ensure that names and Chemical Abstract Service (CAS) numbers were uniform. This activity was performed so that the analyte names and CAS numbers in the data set matched those used in the PGDP toxicity database presented in the Risk Methods Document (DOE 2015a).

D.2.3.2 Evaluation of Concentrations for Soil

The following describes the processes that were used in the surface and subsurface COPC selection. For this screening and the subsequent BHHRA, surface soil was defined as 0–1 ft below ground surface (bgs) and subsurface soil was defined as 0–16 ft bgs. All surface soil samples at the sites were evaluated together as soil whether the sample came from the SWMU surface area or the surrounding ditches.

SWMU 229 was divided into two EUs consistent with the Risk Methods Document (DOE 2015a). EUs are areas within a site that, because of similar levels of contamination or because of expected human activity patterns, can be assessed reasonably using one EPC for each COPC. EUs typically are 0.5 acre in size.

- *Convert units of measure to a consistent basis.* The units of measure used for analyte classes (i.e., inorganic chemicals, organic compounds, and radionuclides) were assigned consistent units of measure. The units of measure used were mg/kg for inorganic chemicals and organic compounds and pCi/g for radionuclides. This activity was performed so that the units of measure in the data set matched those found in the equations that are used to calculate CDIs and ECs as part of the BHHRA.

- *Categorize all sample results as detects or nondetects.* Each result was coded either detected or nondetected based upon the data qualifier codes present in the data set. Any data assigned a "U" or "UJ" qualifier was considered to be nondetected. All radiological data were considered detects for this project and used at the reported value. This coding subsequently was used to calculate the frequency of detection statistics and to assign surrogate values to results listed as nondetects.

- *Analyze duplicate samples.* Duplicate samples were available for some sample analyses. In cases where the value from the original sample and its duplicate both were detected values, the greater of the results from the original sample and its duplicate was retained in the data set. In cases where one value was a detected value and the other was a nondetect, the detected value was retained in the data set. Finally, when both values were listed as nondetects, the lesser of the two detection limits was retained in the data set.

- *Compare maximum detected concentrations to human health screening values.* The maximum detected result for each analyte within the SWMU 229 EUs was compared to NAL screening values for soil use as part of the toxicity screen. Analytes with a maximum detected value less than the analyte's NAL were not retained as COPCs. The values used to screen surface and subsurface soil were the direct contact residential child NAL values are provided in the 2015 Risk Methods

Document (DOE 2015a). The EPA residential screening levels for lead in soil (400 mg/kg) were used to screen lead to determine if it is a COPC. For all scenarios, polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbon (PAHs) were screened and evaluated in the BHHRA using the Total PCB values and Total PAH values calculated following the Risk Methods Document (DOE 2015a).

- *Compare maximum detected concentrations to PGDP background soil levels for metals and radionuclides.* The maximum detected result for each analyte within each of the SWMU 229 EUs was compared to the background levels of metals and radionuclides (Table D.3) that have been negotiated with EPA and KDEP. [Surface soil background levels were used for all but the outdoor worker (exposed to surface and subsurface soil) and the excavation worker where subsurface soil background levels were used for screening.] Analytes with a maximum detected value less than the analyte's associated background value are not retained as COPCs.

- *Remove essential nutrients from the data sets.* Results for the seven essential nutrients listed earlier were removed from the data sets.

- *Remove protactinium-234m, potassium-40, and thorium-234 from the data sets.* All results for protactinium-234m were removed to prevent double-counting its contribution to cancer risk through use of a toxicity value for uranium-238 that includes its short-lived progeny. All potassium-40 and thorium-234 results were removed to be consistent with the Risk Methods Document and earlier BHHRAs prepared for PGDP (DOE 2015a).

Analytes retained as surface soil COPCs under current conditions are presented for each SWMU 229 EU in Table D.4. Analytes retained as subsurface soil COPCs under current conditions are presented for each SWMU 229 EU in Table D.5. Tables D.4 and D.5 include a listing of all detected analytes in soil samples. In addition to the analyte's name, human health risk-based screening value, and background value, each table also contains the analyte's frequency of detection, whether it was chosen as a COPC, and the COPC's EPCs for use in the risk and hazard calculations.

Table D.4. Surface Soil COPCs for SWMU 229

Chemical	Maximum Concentration	Units	# of Analyses	# of Detects	Surface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
EU 1							
Aluminum	3600	mg/kg	1	1	13000	7740	No (A,B)
Antimony	150.45	mg/kg	10	8	0.21	3.13	Yes
Arsenic	11.66	mg/kg	10	7	12	0.267	No (B)
Barium	616.18	mg/kg	10	10	200	1530	No (A)
Benzo(ghi)perylene	0.088	mg/kg	1	1			No (C)
Beryllium	0.24	mg/kg	1	1	0.67	15.6	No (A,B)
Cadmium	21.18	mg/kg	10	3	0.21	5.07	Yes
Calcium	238000	mg/kg	1	1	200000		No (E)
Chromium	8.2	mg/kg	10	1	16	0.301	No (B)
Cobalt	4.3	mg/kg	1	1	14	2.34	No (B)
Copper	6	mg/kg	10	1	19	313	No (A,B)
Fluoranthene	0.29	mg/kg	1	1		114	No (A)
Iron	17336.5	mg/kg	10	10	28000	5480	No (B)
Lead	27.24	mg/kg	10	9	36	400	No (A,B)
Magnesium	6990	mg/kg	1	1	7700		No (B,E)
Manganese	538.61	mg/kg	10	10	1500	183	No (B)
Mercury	0.0906	mg/kg	10	1	0.2	2.35	No (A,B)
Molybdenum	0.25	mg/kg	10	1		39.1	No (A)

Table D.4. Surface soil COPCs for SWMU 229 (Continued)

Chemical	Maximum Concentration	Units	# of Analyses	# of Detects	Surface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
Nickel	91.37	mg/kg	10	4	21	155	No (A)
PAH, Total	0.15679	mg/kg	1	1		0.00619	Yes
Phenanthrene	0.041	mg/kg	1	1		171	No (A)
Pyrene	0.25	mg/kg	1	1		85.4[d]	No (A)
Selenium	0.91	mg/kg	10	1	0.8	39.1	No (A)
Silver	0.025	mg/kg	10	1	2.3	39.1	No (A,B)
Sodium	132	mg/kg	1	1	320		No (B,E)
Uranium	155.81	mg/kg	10	9	4.9	23.4	Yes
Vanadium	12.2	mg/kg	10	1	38	39.3	No (A,B)
Zinc	832.98	mg/kg	10	10	65	2350	No (A)
Cesium-137	0.111	pCi/g	3	2	0.49	0.116	No (A,B)
Neptunium-237	1.69	pCi/g	2	2	0.1	0.239	Yes
Plutonium-239/240	0.257	pCi/g	3	1	0.025	3.87	No (A)
Technetium-99	43	pCi/g	3	3	2.5	117	No (A)
Thorium-228	0.625	pCi/g	3	3	1.6		No (B)
Thorium-230	1.5	pCi/g	3	3	1.5	5.22	No (A)
Thorium-232	0.573	pCi/g	3	3	1.5		No (B)
Uranium-234	1610	pCi/g	3	3	1.2	5.93	Yes
Uranium-235	103	pCi/g	3	3	0.06	0.347	Yes
Uranium-238	1710	pCi/g	3	3	1.2	1.28	Yes
EU 2							
2-Methylnaphthalene	0.21	mg/kg	1	1		11.4[d]	No (A)
Acenaphthene	0.24	mg/kg	1	1		171	No (A)
Aluminum	6210	mg/kg	1	1	13000	7740	No (A,B)
Anthracene	0.37	mg/kg	1	1		854	No (A)
Antimony	108.2	mg/kg	9	9	0.21	3.13	Yes
Arsenic	21.2	mg/kg	9	4	12	0.267	Yes
Barium	500.49	mg/kg	9	9	200	1530	No (A)
Benzo(ghi)perylene	0.79	mg/kg	1	1			No (C)
Beryllium	0.79	mg/kg	1	1	0.67	15.6	No (A)
Cadmium	20.13	mg/kg	9	3	0.21	5.07	Yes
Calcium	193000	mg/kg	1	1	200000		No (B,E)
Chromium	29.14	mg/kg	9	2	16	0.301	Yes
Cobalt	7.7	mg/kg	1	1	14	2.34	No (B)
Copper	51.93	mg/kg	9	2	19	313	No (A)
Dibenzofuran	0.3	mg/kg	1	1		5.57[d]	No (A)
Fluoranthene	5.1	mg/kg	1	1		114	No (A)
Fluorene	0.27	mg/kg	1	1		114	No (A)
Iron	27400	mg/kg	9	9	28000	5480	No (B)
Lead	22.53	mg/kg	9	9	36	400	No (A,B)
Magnesium	7270	mg/kg	1	1	7700		No (B,E)
Manganese	681	mg/kg	9	9	1500	183	No (B)
Mercury	0.172	mg/kg	9	1	0.2	2.35	No (A,B)
Molybdenum	1	mg/kg	9	1		39.1	No (A)
Naphthalene	0.09	mg/kg	1	1		3.83	No (A)
Nickel	99.25	mg/kg	9	5	21	155	No (A)
PAH, Total	1.6949	mg/kg	1	1		0.00619	Yes
Phenanthrene	4.8	mg/kg	1	1		171	No (A)
Pyrene	4	mg/kg	1	1		85.4[d]	No (A)
Selenium	1.1	mg/kg	9	1	0.8	39.1	No (A)
Silver	0.036	mg/kg	9	1	2.3	39.1	No (A,B)
Sodium	113	mg/kg	1	1	320		No (B,E)
Uranium	74.5	mg/kg	11	5	4.9	23.4	Yes
Vanadium	31.3	mg/kg	9	1	38	39.3	No (A,B)
Zinc	182.63	mg/kg	9	9	65	2350	No (A)
Americium-241	0.074	pCi/g	3	2		3.03	No (A)

Table D.4. Surface soil COPCs for SWMU 229 (Continued)

Chemical	Maximum Concentration	Units	# of Analyses	# of Detects	Surface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
Cesium-137	0.321	pCi/g	3	3	0.49	0.116	No (B)
Neptunium-237	0.287	pCi/g	3	2	0.1	0.239	Yes
Plutonium-238	0.024	pCi/g	3	1	0.073	4.42	No (A,B)
Plutonium-239/240	0.269	pCi/g	3	3	0.025	3.87	No (A)
Technetium-99	43.4	pCi/g	3	3	2.5	117	No (A)
Thorium-228	0.613	pCi/g	3	3	1.6		No (B)
Thorium-230	2.42	pCi/g	3	3	1.5	5.22	No (A)
Thorium-232	0.647	pCi/g	3	3	1.5		No (B)
Uranium-234	12.2	pCi/g	3	3	1.2	5.93	Yes
Uranium-235	0.84	pCi/g	3	3	0.06	0.347	Yes
Uranium-238	24.9	pCi/g	3	3	1.2	1.28	Yes

[a] See Table D.3.
[b] Risk-based screening values are from DOE 2015a. The screening values are the lesser of the HI and ELCR NALs used for the child resident of 0.1 and 1E-06, respectively.
[c] Explanations for chemicals not being COPCs are listed below.
A – Maximum result is less than child resident NAL.
B – Maximum result is less than background value.
C – No toxicity information is available for screening.
E – Chemical is an essential nutrient.
[d] See Attachment D1 for screening value.

Table D.5. Subsurface Soil COPCs for SWMU 229

Chemical	Maximum Concentration	Units	# of Analyses	# of Detects	Subsurface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
EU 1							
Aluminum	6510	mg/kg	2	2	12000	7740	No (A,B)
Antimony	150.45	mg/kg	19	16	0.21	3.13	Yes
Arsenic	11.66	mg/kg	19	11	7.9	0.267	Yes
Barium	616.18	mg/kg	19	19	170	1530	No (A)
Beryllium	0.43	mg/kg	2	2	0.69	15.6	No (A,B)
Cadmium	21.18	mg/kg	19	5	0.21	5.07	Yes
Calcium	238000	mg/kg	2	2	6100		No (E)
Chromium	47.61	mg/kg	19	4	43	0.301	Yes
Cobalt	4.5	mg/kg	2	2	13	2.34	No (B)
Copper	19.32	mg/kg	19	3	25	313	No (A,B)
Iron	18484.46	mg/kg	19	19	28000	5480	No (B)
Lead	27.24	mg/kg	19	18	23	400	No (A)
Magnesium	6990	mg/kg	2	2	2100		No (E)
Manganese	538.61	mg/kg	19	19	820	183	No (B)
Mercury	9.27	mg/kg	19	2	0.13	2.35	Yes
Molybdenum	0.39	mg/kg	19	2		39.1	No (A)
Nickel	91.37	mg/kg	19	7	22	155	No (A)
Selenium	1.2	mg/kg	19	2	0.7	39.1	No (A)
Silver	0.041	mg/kg	19	2	2.7	39.1	No (A,B)
Sodium	132	mg/kg	2	2	340		No (B,E)
Uranium	155.81	mg/kg	19	12	4.6	23.4	Yes
Vanadium	20.9	mg/kg	19	2	37	39.3	No (A,B)
Zinc	832.98	mg/kg	19	19	60	2350	No (A)
Benzo(ghi)perylene	0.088	mg/kg	1	1			No (C)
Fluoranthene	0.29	mg/kg	1	1		114	No (A)
PAH, Total	0.15679	mg/kg	1	1		0.00619	Yes
Phenanthrene	0.041	mg/kg	1	1		171	No (A)
Pyrene	0.25	mg/kg	1	1		85.4[d]	No (A)
Cesium-137	0.111	pCi/g	3	2	0.28	0.116	No (A,B)
Neptunium-237	1.69	pCi/g	2	2		0.239	Yes

Table D.5. Subsurface soil COPCs for SWMU 229 (Continued)

Chemical	Maximum Concentration	Units	# of Analyses	# of Detects	Subsurface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
Plutonium-239/240	0.257	pCi/g	3	1		3.87	No (A)
Technetium-99	43	pCi/g	4	4	2.8	117	No (A)
Thorium-228	0.86	pCi/g	4	4	1.6		No (B)
Thorium-230	1.5	pCi/g	4	4	1.4	5.22	No (A)
Thorium-232	0.84	pCi/g	4	4	1.5		No (B)
Uranium-234	1610	pCi/g	4	4	1.2	5.93	Yes
Uranium-235	103	pCi/g	4	4	0.06	0.347	Yes
Uranium-238	1710	pCi/g	4	4	1.2	1.28	Yes
EU 2							
Aluminum	6210	mg/kg	2	2	12000	7740	No (A,B)
Antimony	108.2	mg/kg	19	19	0.21	3.13	Yes
Arsenic	21.2	mg/kg	19	5	7.9	0.267	Yes
Barium	500.49	mg/kg	19	19	170	1530	No (A)
Beryllium	0.79	mg/kg	2	2	0.69	15.6	No (A)
Cadmium	20.13	mg/kg	19	4	0.21	5.07	Yes
Calcium	193000	mg/kg	2	2	6100		No (E)
Chromium	48	mg/kg	19	5	43	0.301	Yes
Cobalt	7.7	mg/kg	2	2	13	2.34	No (B)
Copper	51.93	mg/kg	19	3	25	313	No (A)
Iron	27400	mg/kg	19	19	28000	5480	No (B)
Lead	22.53	mg/kg	19	19	23	400	No (A,B)
Magnesium	7610	mg/kg	2	2	2100		No (E)
Manganese	681	mg/kg	19	19	820	183	No (B)
EU 2							
Mercury	7.3	mg/kg	19	3	0.13	2.35	Yes
Molybdenum	1	mg/kg	19	2		39.1	No (A)
Nickel	99.25	mg/kg	19	6	22	155	No (A)
Selenium	1.1	mg/kg	19	2	0.7	39.1	No (A)
Silver	0.042	mg/kg	19	2	2.7	39.1	No (A,B)
Sodium	131	mg/kg	2	2	340		No (B,E)
Uranium	74.5	mg/kg	21	6	4.6	23.4	Yes
Vanadium	31.3	mg/kg	19	2	37	39.3	No (A,B)
Zinc	182.63	mg/kg	19	19	60	2350	No (A)
2-Methylnaphthalene	0.21	mg/kg	1	1		11.4[d]	No (A)
Acenaphthene	0.24	mg/kg	1	1		171	No (A)
Anthracene	0.37	mg/kg	1	1		854	No (A)
Benzo(ghi)perylene	0.79	mg/kg	1	1			No (C)
Dibenzofuran	0.3	mg/kg	1	1		5.57[d]	No (A)
Fluoranthene	5.1	mg/kg	1	1		114	No (A)
Fluorene	0.27	mg/kg	1	1		114	No (A)
Naphthalene	0.09	mg/kg	1	1		3.83	No (A)
PAH, Total	1.6949	mg/kg	2	2		0.00619	Yes
Phenanthrene	4.8	mg/kg	1	1		171	No (A)
Pyrene	4	mg/kg	1	1		85.4[d]	No (A)
Americium-241	0.074	pCi/g	3	2		3.03	No (A)
Cesium-137	0.321	pCi/g	3	3	0.28	0.116	Yes
Neptunium-237	0.287	pCi/g	3	2		0.239	Yes
Plutonium-238	0.024	pCi/g	3	1		4.42	No (A)
Plutonium-239/240	0.269	pCi/g	4	4		3.87	No (A)
Technetium-99	43.4	pCi/g	3	3	2.8	117	No (A)
Thorium-228	0.93	pCi/g	4	4	1.6		No (B)
Thorium-230	2.42	pCi/g	4	4	1.4	5.22	No (A)
Thorium-232	0.647	pCi/g	4	4	1.5		No (B)

Table D.5. Subsurface soil COPCs for SWMU 229 (Continued)

Chemical	Maximum Concentration	Units	# of Analyses	# of Detects	Subsurface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
Uranium-234	12.2	pCi/g	4	4	1.2	5.93	Yes
Uranium-235	0.84	pCi/g	4	4	0.06	0.347	Yes
Uranium-238	24.9	pCi/g	4	4	1.2	1.28	Yes

[a] See Table D.3.
[b] Risk-based screening values are from DOE 2015a. The screening values are the lesser of the HI and ELCR NALs used for the child resident of 0.1 and 1E-06, respectively.
[c] Explanations for chemicals not being COPCs are listed below.
A – Maximum result is less than child resident NAL.
B – Maximum result is less than background value.
C – No toxicity information is available for screening.
D – Chemical is not evaluated individually, it is evaluated as part of total PAHs.
E – Chemical is an essential nutrient.
[d] See Attachment D1 for screening value.

EPCs were calculated for each EU for those constituents that are retained as COPCs. Both SWMU/EU combinations for SWMU 229 had less than 10 grids; therefore, the maximum grid result was used as the EPC. Grid values were determined following guidance in the work plan. Basically, the maximum detected result from within the grid applies to the grid. If not detected, the minimum detection limit applies to the grid.

D.2.3.3 Evaluation of Modeled Concentrations for Groundwater

Groundwater modeling was done in a similar manner as the process described above for surface/subsurface soil. SSLs are risk-based soil concentrations considered to be protective of groundwater (DOE 2015a). These SSLs were derived as described in Appendix C and used to screen soil sampling results to select COPCs for RGA groundwater. One analyte was retained as a COPC and is presented in Appendix C. The selected analyte (technetium-99) then was modeled as described in Appendix C.

D.3. EXPOSURE ASSESSMENT

This section describes the exposure assessment used to determine the pathways of exposure that were considered for the surface and subsurface soil at SWMU 229. Specifically, the exposure assessment process is delineated, the exposure settings of the Soils OU are described, the routes of exposure are outlined, and the daily intakes and doses are derived. The ultimate products presented in this section are the CSM for the Soils OU and the CDIs and ECs used when calculating ELCR and HI in Section D.5.

D.3.1 DESCRIPTION OF THE EXPOSURE ASSESSMENT PROCESS

Exposure is the contact of an organism with a chemical or physical agent. The magnitude of exposure (i.e., dose) is determined by measuring or estimating the amount of an agent available at exchange boundaries (e.g., gut, skin, etc.) during a specified period. Exposure assessment is a process that uses information about the exposure setting and human activities to develop CSMs under current and potential future conditions.

The first step in the exposure assessment is to characterize the exposure setting. This includes describing the activities of the human population (on or near a site) that may affect the extent of exposure and the physical characteristics of the site. During this process, sensitive subpopulations that may be present at

the site or that may be exposed to contamination migrating from the site also are considered. Generally, site characterization results in a qualitative evaluation of the site and the surrounding population.

The second step in the exposure assessment is to identify exposure pathways. Exposure pathways describe the path a contaminant travels from its source to an individual. A complete exposure pathway includes all links between the source and the exposed population; therefore, a complete pathway consists of a source of release, a mechanism of release, a transport medium, a point of potential human contact, and an exposure route.

The third step in the exposure assessment is to calculate dose by quantifying the magnitude, frequency, and duration of exposure for the populations for the exposure pathways selected for quantitative evaluation. This step involves using the EPCs developed for each COPC to quantify the pathway-specific CDIs and ECs for that COPC.

D.3.2 CHARACTERIZATION OF THE EXPOSURE SETTING

The first step in evaluating exposure is to characterize surface features, meteorology, geology, demography and land use, ecology, hydrology, and hydrogeology of the area inhabited by potential receptors. These aspects are discussed in Chapter 3 of this report. A physical description of SWMU 229 is summarized within this exposure assessment to support later discussions of the conceptual model and its uncertainties.

DMSA OS-18 (SWMU 229) is located north of C-746-F in the northwest portion of the plant site. SWMU 229 is approximately 0.806 acres.

This area was established soon after plant construction to store excess railroad supplies, parts, components, etc. Later it became an area for storing various excess materials. In 2001, DOE began characterization and remediation of the materials in the DMSAs. RCRA-regulated items have been removed from the SWMU and placed in proper storage. This DMSA now qualifies as a Phase 3 DMSA because it has been fully characterized and contains no fissionable material (DOE 2003).

D.3.3 DEMOGRAPHY AND LAND USE

The land use for SWMU 229 is industrial. Under current use, because of access restrictions, only plant workers and authorized visitors are allowed access to the areas located inside the limited area. As discussed in the PGDP Site Management Plan (DOE 2015b), foreseeable future land use of PGDP industrial area is expected to be industrial. The land use of the surrounding West Kentucky Wildlife Management Area (WKWMA) also is not expected to change; it will remain recreational and available to the outdoor worker.

At present, both recreational and residential land uses occur in areas surrounding PGDP. Recreational use occurs in WKWMA. WKWMA is used primarily for hunting and fishing, but other activities include horseback riding, field trials, hiking, and bird watching. An estimated 7,500 fishermen visit the area annually, according to the Kentucky Department of Fish and Wildlife Resources manager of the WKWMA (DOE 2015a). Residential use near the plant and in areas to which the groundwater from the PGDP may migrate is rural residential and includes agricultural activities. Response actions have eliminated exposure of these rural residents to contaminated groundwater. More urban residential use occurs in the villages of Heath, Grahamville, and Kevil, which are within 3 miles of DOE property boundaries, but outside of the area that may be impacted by the Soils OU. The closest major urban area is the municipality of Paducah, Kentucky, which has a population of approximately 25,000 and is

approximately 10 miles from PGDP. Other municipalities in the region near PGDP are Cape Girardeau, Missouri, which is approximately 40 miles west of the plant; and the cities of Metropolis and Joppa, Illinois, which are across the Ohio River from PGDP. Total population within a 50-mile radius of the plant is approximately 534,000 people, with about 89,000 people living within 10 miles. The population of McCracken County, in which PGDP lies, is estimated at 66,000 people.

D.3.4 IDENTIFICATION OF EXPOSURE PATHWAYS

The general principles of the exposure assessment, as addressed in the Risk Methods Document (DOE 2015a), provide the basis for the evaluations provided in this assessment. This subsection describes the potential exposure scenarios and receptors. Only the receptors potentially exposed to each media and location were evaluated. The exposure scenarios evaluated represent potential future scenarios, because most of the exposure assumptions are based on conservative input factors for the administered or absorbed dose estimations. Thus, most, if not all, exposure scenarios represent future hypothetical exposure assumptions, because current exposures are minimal or are not occurring at the site. As a result, the exposure assumptions either are the available default values or are conservatively selected based on assumed receptor behavior.

The current on-site land use is industrial, and this can be expected to continue in the foreseeable future; however, the expected exposure frequencies and durations may be higher in the future than duration and frequency of the current exposure. Additionally, use of groundwater drawn from the RGA at SWMU 229 is not expected; however, uses of areas surrounding PGDP indicate that it would be prudent to examine a range of land uses to provide decision makers with estimates of the risk that may be posed to humans under alternate uses. To provide consideration of a range of land uses, the BHHRA reports the hazards and risks for current and several hypothetical future uses, consistent with regulatory guidance.

The exposure scenarios and receptors evaluated in this BHHRA are pertinent to the activities conducted at the Soils OU. Default land use scenarios (e.g., current and future industrial and hypothetical future residential) and additional scenarios (e.g., recreational, excavation, and outdoor worker) were evaluated for each of the EUs.

A future on-site rural resident is not a likely land use scenario because land use controls are in place that prevent residential exposure at the site. More likely future on-site scenarios may include recreational uses (hunting), considering the WKWMA is adjacent to a buffer area that surrounds the industrial areas of the site. Further, although unauthorized access to the area (trespassing) is unlikely under current conditions, evaluation of this scenario could be represented under the assessment of the recreational user. Current and future industrial worker, outdoor worker, and excavation worker all are considered in this assessment.

As discussed in the Risk Methods Document (DOE 2015a), risks from water drawn from the UCRS will not be presented in the main body of the risk assessment.

The exposure factors primarily are based on a reasonable maximum exposure (RME) assumption. The intent of the RME assumption is to estimate the highest exposure level that reasonably could be expected to occur (EPA 1989; EPA 1991). The RME assumptions were developed by EPA to represent an upper-bound estimate for the plausible exposures. In keeping with the EPA guidance (EPA 1991), the variables chosen for a baseline RME scenario for the intake rate, exposure frequency (EF), and exposure duration (ED) are generally upper-bounds. Other variables, such as body weight (BW) and exposed skin surface area are generally central tendency or average values. The conservatism built into the individual variables ensures that the entire estimate for the contact rate is more than sufficiently conservative.

The scenarios described in the following subsections assume that 100% of a receptor's time is spent in contact with the contaminated medium at the site. For all sites, a worker is assumed to spend all of a workday in the area, which is a conservative estimate for the intake from a given site.

The averaging time (AT) for noncancer evaluation is computed as the product of ED (years) multiplied by 365 days per year, to estimate an average daily dose over the entire exposure period (EPA 1989). For the cancer evaluation, AT is computed as the product of 70 years, the assumed human lifetime, multiplied by 365 days per year, to estimate an average daily dose prorated over a lifetime, regardless of the frequency or duration of exposure. This methodology assumes that the risk from a short-term exposure to a high dose of a given carcinogen is equivalent to a long-term exposure to a correspondingly lower dose, provided that the total lifetime doses are equivalent. For example, the current and future exposure scenarios represent exposures mostly under future hypothetical scenarios, because exposed soils are limited at most of these sites and a maintenance worker or a recreational visitor would not spend the amount of time assumed in the exposure assumptions. The more conservative exposure assumptions used are for conservatism in the potential exposure evaluations during site management. Thus, the estimated intake or exposure doses apply mostly to the future hypothetical exposure scenarios. The scenarios are discussed in the following text.

D.3.4.1 Potential Receptor Populations

The receptors and exposure factors are summarized in Table D.6, with an overview presented following. Exposure factors were updated from the most recent Risk Methods Document (DOE 2015a), consistent with agreements made with the PGDP Risk Assessment Working Group. These updated exposure factors are reflected in Table D.6 and will be published in the 2016 Risk Methods Document.

Chemical-specific values are listed in Attachment D2. The dermal absorption (ABS) factors used are from the KDEP values presented in the 2015 Risk Methods Document. Because these factors apply only to COPCs evaluated for dermal toxicity, these ABS factors are presented in Attachment D2 along with the dermal toxicity values.

Current On-site and Off-site Industrial Workers. The current on-site industrial worker exposure scenario was evaluated for direct contact to surface soils (0 ft–1 ft). The current worker differs from the future industrial worker only by a lower EF equivalent to the current maintenance schedule for these areas [14 days for current on-site industrial worker (such as maintenance worker) versus 250 days for future industrial worker default scenario]. For workers outside the limited area, the workers also are assumed to have direct contact with surface soils (0 ft–1 ft) under current conditions. This limited frequency reflects the size (roughly 0.5 acre or less for each EU) and limited activities at SWMU 229.

Future Industrial Workers. The future industrial worker exposure scenario 0 ft–1 ft was evaluated using standard default assumptions as outlined in the Risk Methods Document (DOE 2015a) (e.g., 80-kg adult who works 8 hours per day, approximately 5 days per week, year-round on-site, for a total of 250 days per year for 25 years). No ingestion of or contact with groundwater was assumed for the future industrial worker (only for the resident).

Future Recreational Users. Per the Risk Methods Document (DOE 2015a), recreational uses (child, teen, adult) are focused primarily on sediments, where areas are more attractive for wading. However, a plausible future use on-site and off-site is for recreational use, specifically hunting (deer, rabbits, quail). Hunters are assumed primarily to be teens and adults, and direct contact to soils for these receptors is assumed to be limited because repeated contact with contaminated media at sites less than 0.5 acre would be unlikely for hunting activities. This pathway was evaluated as a basis for SWMU-specific decisions in

Table D.6. Exposure Factors Used for Intake Calculations in BHHRA[a]

Pathway Variable	Units	Current Industrial Worker	Future Industrial Worker	Outdoor Worker	Excavation Worker	Adult Resident	Child Resident	Adult Recreational User	Teen Recreational User	Child Recreational User
EF	days/year	14	250	185	185	350	350	104	140	140
ED	years	25	25	25	5	20	6	10	10	6
BW	kg	80	80	80	80	80	15	80	44[b]	15
AT—cancer	days	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365	70 × 365
AT—noncancer	days	365 × 25	365 × 25	365 × 25	365 × 5	365 × 20	365 × 6	365 × 10	365 × 10	365 × 6
Incidental Ingestion of Soil/Sediment										
Incidental ingestion rate	mg/day	50	50	480	480	100	200	100	100	200
Fraction ingested		1	1	1	1	1	1	1	1	1
Dermal Contact with Soil/Sediment										
Body surface area exposed	m^2/day	0.3527[c]	0.3527[c]	0.3527[c]	0.3527[c]	0.6032	0.2373[c]	0.6032	0.75	0.2373[c]
Soil-to-skin adherence factor	mg/cm^2–day	1	1	1	1	1	1	1	1	1
Inhalation of Vapors and Particulates Emitted from Soil/Sediment										
Total inhalation rate	m^3/hour	2.5	2.5	2.5	2.5	0.833	0.833	2.5	2.5	2.5
Exposure time	hours/day	8	8	8	8	24	24	5	5	5
Particulate emission factor	m^3/kg	6.20E+08	6.20E+08	6.20E+08	6.20E+08	9.30E+08	9.30E+08	9.30E+08	9.30E+08	9.30E+08
External Exposure to Ionizing Radiation from Soil/Sediment										
EF	day/day	14/365	250/365	185/365	185/365	350/365	350/365	104/365	140/365	140/365
Gamma shielding factor	unitless	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0
Gamma exposure time factor	hr/hr	8/24	8/24	8/24	8/24	18/24	18/24	5/24	5/24	5/24
Ingestion of Groundwater										
Drinking water ingestion rate	L/day	N/A	N/A	N/A	N/A	2.5	0.78	N/A	N/A	N/A
Dermal Contact with RGA Groundwater (showering)										
Body surface area exposed	m^2	N/A	N/A	N/A	N/A	2.09	0.6378	N/A	N/A	N/A
Event time	hour/event	N/A	N/A	N/A	N/A	0.71	0.54[c]	N/A	N/A	N/A
Event frequency	events/day	N/A	N/A	N/A	N/A	1	1	N/A	N/A	N/A

Table D.6. Exposure Factors Used for Intake Calculations in BHHRA (Continued)

Pathway Variable	Units	Current Industrial Worker	Future Industrial Worker	Outdoor Worker	Excavation Worker	Adult Resident	Child Resident	Adult Recreational User	Teen Recreational User	Child Recreational User
Inhalation RGA Groundwater										
Indoor inhalation rate	m^3/hour	N/A	N/A	N/A	N/A	0.833	0.833	N/A	N/A	N/A
Exposure time in the shower	hours/day	N//A	N/A	N/A	N/A	0.71	0.54[c]	N/A	N/A	N/A
Time of shower	hour	N/A	N/A	N/A	N/A	0.1	0.1	N/A	N/A	N/A
Time after shower	hour	N/A	N/A	N/A	N/A	0.1	0.1	N/A	N/A	N/A
Fraction volatilized while showering	unitless	N/A	N/A	N/A	N/A	0.75	0.75	N/A	N/A	N/A
Water flow rate	L/h	N/A	N/A	N/A	N/A	890	890	N/A	N/A	N/A
Bathroom volume	m^3	N/A	N/A	N/A	N/A	11	11	N/A	N/A	N/A
AT—cancer	hours	N/A	N/A	N/A	N/A	24 × 70 × 365	24 × 70 × 365	N/A	N/A	N/A
AT—noncancer	hours	N/A	N/A	N/A	N/A	24 × 365 × 20	24 × 365 × 6	N/A	N/A	N/A
Exposure time household use	hours/day	N/A	N/A	N/A	N/A	24	24	N/A	N/A	N/A
Exchange rate	changes/day	N/A	N/A	N/A	N/A	10	10	N/A	N/A	N/A
Mixing coefficient	unitless	N/A	N/A	N/A	N/A	0.5	0.5	N/A	N/A	N/A
Fraction volatilized household use	unitless	N/A	N/A	N/A	N/A	0.5	0.5	N/A	N/A	N/A
Water flow rate	L/day	N/A	N/A	N/A	N/A	890	890	N/A	N/A	N/A
House volume	m^3	N/A	N/A	N/A	N/A	450	450	N/A	N/A	N/A

Notes:
[a] Information taken from DOE 2015a.
[b] Best professional judgements similar to value used for DOE 2008.
[c] Updated based on Paducah Risk Assessment Working group follow-up e-mail, October 20, 2015.
[d] Updated based on Paducah Risk Assessment Working Group Meeting Minutes, September 16, 2015.
N/A = Not available or not applicable

this assessment only for the teen, which is the more conservative of the two, and is consistent with planning and scoping for the OU. Consumption of wild game was not included in this evaluation.

Future Hypothetical Rural Resident. The future residential scenario is evaluated using both an adult and a child potentially exposed to site surface soils for SWMU 229, which is within the limited area. Although this land use is unlikely, this evaluation provides information on potential for adverse impacts if no land use restrictions were in place. Future residents are assumed to be exposed to RGA groundwater for SWMU 229 where potential impacts to groundwater are identified from the soils. Appendix C describes the groundwater modeling. Similarly, potential exposure to soil volatile organic compound (VOCs) that have migrated to indoor air through vapor intrusion have been considered only for the sites with releases of VOCs from the soils and potential presence in the shallow groundwater.

Future Outdoor Worker and Excavation Worker. For evaluation of potential future direct contact issues with subsurface soil, two scenarios were considered: excavation worker and outdoor worker. Each assumes contact with both surface and subsurface soils, but differ in that the excavation addresses contact during the excavation/construction process, so for each SWMU 229 EU, ED was limited to 5 years. Additional detail is provided below. For the outdoor worker, it is assumed that surface and subsurface soils are mixed (brought to the surface) where EDs may be extended.

According to the Risk Methods Document (DOE 2015a), 185 days per year and 25 years are recommended for the EF and the ED, respectively, for the outdoor worker. However, the Risk Methods Document provides flexibility in this assumption when applying to an excavation worker. According to the Risk Methods Document (DOE 2015a), "…the exposure duration of 25 years for the outdoor worker may be replaced with a shorter duration of 1 to 5 years that is more likely to reflect the potential exposures at the site. The shorter exposure duration and possibly a revised exposure frequency combined with the other default parameters for the outdoor worker scenario also may be used to produce an excavation worker scenario." When used for the excavation worker scenario, the ED has been reduced to 5 years (DOE 2015a). Further, from a practical standpoint, defaulting to outdoor worker exposure assumptions for an excavation scenario will exceed the reasonable assumptions for SWMU 229 because the excavation scenario typically represents a soil removal action associated with construction of a foundation or excavation of contaminated soil. For nearly all waste sites or foundation construction sites, this is a one-time event of short duration.

D.3.4.2 Delineation of Exposure Point/Exposure Routes

As discussed, human health risks are assessed by determining points of exposure (POEs) and exposure routes. POEs are locations where human receptors can contact contaminated media. Exposure routes are the processes by which human receptors contact contaminated media. The exposure routes considered during the exposure assessment for all BHHRAs per the Risk Methods Document (DOE 2015a) are listed in the following paragraphs. This material also presents reasons for selecting or not selecting each exposure route for each of the potentially exposed populations in this BHHRA. The exposure routes evaluated and those that were assessed quantitatively in this BHHRA are described below.

Surface Water. SWMU 229 is not located near a drainageway, therefore significant surface water contamination is not expected as a result of this SWMU (UK 2007). Further, due to the physical cover at SWMU 229 that limits the potential for particulate transport through sheet flow and based upon the modeling performed as part of the SI report for the outfalls and their associated internal ditches, no contaminants are migrating in surface water (dissolved or through sediment) from ditches to surrounding creeks at concentrations that may impact human health adversely (DOE 2008). As a result, human health risks associated with exposure to surface water were not assessed in this BHHRA.

Groundwater. Residential and industrial use of RGA groundwater is common in western Kentucky. There is no current complete pathway for domestic use of RGA groundwater downgradient of the facility; however, a conservative assumption for evaluating impacts to the RGA is based on hypothetical future use of RGA groundwater by a resident. This SWMU was identified with soil concentrations that could yield potentially unacceptable concentrations in groundwater associated with migration from the areas. The potential POE as completed in the modeling is the SWMU boundary, which is the most stringent assumption. This modeled concentration is used for risk estimates.

For domestic use of groundwater by a hypothetical future resident, the following routes of exposure are evaluated:

- Groundwater ingestion (potable use of RGA groundwater),
- Inhalation of volatile constituents emitted while using groundwater (all household uses), and
- Dermal contact with groundwater while showering.

Vapor Intrusion. Transport of vapors in subsurface soils and shallow groundwater into buildings is considered a potential future exposure pathway. The POE—location where this is complete—is focused at the source areas where volatile compounds were release. These are the primary locations where VOCs may be in the soils or upper groundwater layer where a building may be constructed in the future. Although future residential use is not considered likely, this exposure route was considered in this BHHRA for rural residential scenario. No additional contribution via inhalation of vapors that may be transported into basements is expected.

Soil. A primary consideration for risks associated with contamination in soils is direct contact with these at SWMU 229; therefore, these are the POEs either under current conditions where exposure may be to contaminants in the 0 ft–1 ft depth or possible future contact with contaminants in the subsurface. To estimate risks for the receptors described in the previous section, the following routes of exposure are quantified:

- Incidental ingestion of contaminated soil,
- Dermal contact with contaminated soil,
- Inhalation of particulates emitted from contaminated soil,
- Inhalation of volatile constituents emitted from contaminated soil, and
- External exposure to ionizing radiation emitted from contaminated soil.

D.3.5 QUANTIFICATION OF EXPOSURE

D.3.5.1 Calculation of EPCs of COPCs

The EPCs were determined as described in Section D.2.3.2.

Soil—Direct Contact Exposure. In determining the EPC for soil, the data are segregated into depth intervals relevant to receptors. For all scenarios, except the excavation worker and the outdoor worker (exposed to surface and subsurface soil), data from samples collected from 0 to 1 ft bgs are used to estimate the EPC. For the excavation worker and the outdoor worker (exposed to surface and subsurface soil), data collected from 0 to 16 ft bgs are used to estimate the EPC.

Groundwater—Residential Use. The groundwater COPC concentrations in the RGA groundwater at the SWMU boundary are based on the results of the modeling as presented in the fate and transport discussion.

D.3.5.2 Chronic Daily Intakes

The EPC for each COPC was used to calculate potential chemical intakes. The equations to be used to combine the EPCs and exposure factors to estimate chemical intake followed the general format presented in RAGS, Part A (EPA 1989) as follows:

$$\text{Chemical Intake}\,[\text{mg/(kg} \times \text{day}] = \frac{C_s \times CF \times EF \times FI \times ED \times IR}{BW \times AT}$$

Where:

Chemical Intake = the dose
C_s = average concentration contacted over the exposure period
CF = contact rate or amount of contaminated medium contacted per unit time or event
EF = exposure frequency
FI = frequency of ingestion
ED = exposure duration
IR = ingestion rate
BW = average body weight of the receptor over the term of exposure
AT = averaging time or period over which exposure is averaged

and

$$\text{Radionuclide Intake}\,(\text{pCi}) = A_s \times CF_{rad} \times EF \times FI \times ED \times IR$$

Where:

Radionuclide Intake = the dose
A_s = average activity contacted over the exposure period
CF_{rad} = conversion factor.
EF = exposure frequency
FI = fraction ingested
ED = exposure duration
IR = ingestion rate
EC = exposure concentration

Calculation of intake, both noncancerous and cancerous, is presented in Tables D.7 through D.24.

Table D.7. Noncancerous CDIs for the Current Industrial Worker Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	3.61E-06		3.10E-09
1	Cadmium	mg/kg	2.12E+01	5.08E-07	3.58E-08	4.37E-10
1	Uranium	mg/kg	1.56E+02	3.74E-06		3.21E-09
2	Antimony	mg/kg	1.08E+02	2.59E-06		2.23E-09
2	Arsenic	mg/kg	2.12E+01	5.08E-07	1.08E-06	4.37E-10
2	Cadmium	mg/kg	2.01E+01	4.83E-07	3.40E-08	4.15E-10
2	Chromium	mg/kg	2.91E+01	6.99E-07		6.01E-10
2	Uranium	mg/kg	7.45E+01	1.79E-06		1.54E-09

Table D.8. Cancerous CDIs for the Current Industrial Worker Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	1.50E+02	1.29E-06		1.11E-06	
1	Cadmium	mg/kg	2.12E+01	1.81E-07	1.28E-08	1.56E-07	
1	Uranium	mg/kg	1.56E+02	1.33E-06		1.15E-06	
1	PAH, Total	mg/kg	1.57E-01	1.34E-09	1.23E-08	1.15E-09	
1	Neptunium-237	pCi/g	1.69E+00	2.96E+01		7.63E-03	4.32E-01
1	Uranium-234	pCi/g	1.61E+03	2.82E+04		7.27E+00	4.12E+02
1	Uranium-235	pCi/g	1.03E+02	1.80E+03		4.65E-01	2.63E+01
1	Uranium-238	pCi/g	1.71E+03	2.99E+04		7.72E+00	4.37E+02
2	Antimony	mg/kg	1.08E+02	9.26E-07		7.97E-07	
2	Arsenic	mg/kg	2.12E+01	1.82E-07	3.84E-07	1.56E-07	
2	Cadmium	mg/kg	2.01E+01	1.72E-07	1.22E-08	1.48E-07	
2	Chromium	mg/kg	2.91E+01	2.49E-07		2.15E-07	
2	Uranium	mg/kg	7.45E+01	6.38E-07		5.49E-07	
2	PAH, Total	mg/kg	1.69E+00	1.45E-08	1.33E-07	1.25E-08	
2	Neptunium-237	pCi/g	2.87E-01	5.02E+00		1.30E-03	7.34E-02
2	Uranium-234	pCi/g	1.22E+01	2.13E+02		5.51E-02	3.12E+00
2	Uranium-235	pCi/g	8.40E-01	1.47E+01		3.79E-03	2.15E-01
2	Uranium-238	pCi/g	2.49E+01	4.36E+02		1.12E-01	6.37E+00

Table D.9. Noncancerous CDIs for the Future Industrial Worker Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	6.44E-05		5.54E-08
1	Cadmium	mg/kg	2.12E+01	9.07E-06	6.40E-07	7.80E-09
1	Uranium	mg/kg	1.56E+02	6.67E-05		5.74E-08
2	Antimony	mg/kg	1.08E+02	4.63E-05		3.98E-08
2	Arsenic	mg/kg	2.12E+01	9.08E-06	1.92E-05	7.81E-09
2	Cadmium	mg/kg	2.01E+01	8.62E-06	6.08E-07	7.41E-09
2	Chromium	mg/kg	2.91E+01	1.25E-05		1.07E-08
2	Uranium	mg/kg	7.45E+01	3.19E-05		2.74E-08

Table D.10. Cancerous CDIs for the Future Industrial Worker Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	1.50E+02	2.30E-05		1.98E-05	
1	Cadmium	mg/kg	2.12E+01	3.24E-06	2.28E-07	2.79E-06	
1	Uranium	mg/kg	1.56E+02	2.38E-05		2.05E-05	
1	PAH, Total	mg/kg	1.57E-01	2.40E-08	2.20E-07	2.06E-08	
1	Neptunium-237	pCi/g	1.69E+00	5.28E+02		1.36E-01	7.72E+00
1	Uranium-234	pCi/g	1.61E+03	5.03E+05		1.30E+02	7.35E+03
1	Uranium-235	pCi/g	1.03E+02	3.22E+04		8.31E+00	4.70E+02
1	Uranium-238	pCi/g	1.71E+03	5.34E+05		1.38E+02	7.81E+03
2	Antimony	mg/kg	1.08E+02	1.65E-05		1.42E-05	
2	Arsenic	mg/kg	2.12E+01	3.24E-06	6.86E-06	2.79E-06	
2	Cadmium	mg/kg	2.01E+01	3.08E-06	2.17E-07	2.65E-06	
2	Chromium	mg/kg	2.91E+01	4.46E-06		3.83E-06	
2	Uranium	mg/kg	7.45E+01	1.14E-05		9.80E-06	
2	PAH, Total	mg/kg	1.69E+00	2.59E-07	2.38E-06	2.23E-07	
2	Neptunium-237	pCi/g	2.87E-01	8.97E+01		2.31E-02	1.31E+00
2	Uranium-234	pCi/g	1.22E+01	3.81E+03		9.84E-01	5.57E+01
2	Uranium-235	pCi/g	8.40E-01	2.62E+02		6.77E-02	3.84E+00
2	Uranium-238	pCi/g	2.49E+01	7.78E+03		2.01E+00	1.14E+02

Table D.11. Noncancerous CDIs for the Outdoor Worker Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	4.58E-04		4.10E-08
1	Cadmium	mg/kg	2.12E+01	6.44E-05	4.73E-07	5.77E-09
1	Uranium	mg/kg	1.56E+02	4.74E-04		4.25E-08
2	Antimony	mg/kg	1.08E+02	3.29E-04		2.95E-08
2	Arsenic	mg/kg	2.12E+01	6.45E-05	1.42E-05	5.78E-09
2	Cadmium	mg/kg	2.01E+01	6.12E-05	4.50E-07	5.49E-09
2	Chromium	mg/kg	2.91E+01	8.86E-05		7.94E-09
2	Uranium	mg/kg	7.45E+01	2.27E-04		2.03E-08

Table D.12. Cancerous CDIs for the Outdoor Worker Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	1.50E+02	1.63E-04		1.46E-05	
1	Cadmium	mg/kg	2.12E+01	2.30E-05	1.69E-07	2.06E-06	
1	Uranium	mg/kg	1.56E+02	1.69E-04		1.52E-05	
1	PAH, Total	mg/kg	1.57E-01	1.70E-07	1.63E-07	1.53E-08	
1	Neptunium-237	pCi/g	1.69E+00	3.75E+03		1.01E-01	5.71E+00
1	Uranium-234	pCi/g	1.61E+03	3.57E+06		9.61E+01	5.44E+03
1	Uranium-235	pCi/g	1.03E+02	2.29E+05		6.15E+00	3.48E+02
1	Uranium-238	pCi/g	1.71E+03	3.80E+06		1.02E+02	5.78E+03
2	Antimony	mg/kg	1.08E+02	1.18E-04		1.05E-05	
2	Arsenic	mg/kg	2.12E+01	2.30E-05	5.08E-06	2.06E-06	
2	Cadmium	mg/kg	2.01E+01	2.19E-05	1.61E-07	1.96E-06	
2	Chromium	mg/kg	2.91E+01	3.16E-05		2.84E-06	
2	Uranium	mg/kg	7.45E+01	8.09E-05		7.25E-06	
2	PAH, Total	mg/kg	1.69E+00	1.84E-06	1.76E-06	1.65E-07	
2	Neptunium-237	pCi/g	2.87E-01	6.37E+02		1.71E-02	9.70E-01
2	Uranium-234	pCi/g	1.22E+01	2.71E+04		7.28E-01	4.12E+01
2	Uranium-235	pCi/g	8.40E-01	1.86E+03		5.01E-02	2.84E+00
2	Uranium-238	pCi/g	2.49E+01	5.53E+04		1.49E+00	8.41E+01

Table D.13. Noncancerous CDIs for the Outdoor Worker Exposed to Surface and Subsurface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	4.58E-04		4.10E-08
1	Arsenic	mg/kg	1.17E+01	3.55E-05	7.82E-06	3.18E-09
1	Cadmium	mg/kg	2.12E+01	6.44E-05	4.73E-07	5.77E-09
1	Chromium	mg/kg	4.76E+01	1.45E-04		1.30E-08
1	Mercury	mg/kg	9.27E+00	2.82E-05		2.53E-09
1	Uranium	mg/kg	1.56E+02	4.74E-04		4.25E-08
2	Antimony	mg/kg	1.08E+02	3.29E-04		2.95E-08
2	Arsenic	mg/kg	2.12E+01	6.45E-05	1.42E-05	5.78E-09
2	Cadmium	mg/kg	2.01E+01	6.12E-05	4.50E-07	5.49E-09
2	Chromium	mg/kg	4.80E+01	1.46E-04		1.31E-08
2	Mercury	mg/kg	7.30E+00	2.22E-05		1.99E-09
2	Uranium	mg/kg	7.45E+01	2.27E-04		2.03E-08

Table D.14. Cancerous CDIs for the Outdoor Worker Exposed to Surface and Subsurface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	1.50E+02	1.63E-04		1.46E-05	
1	Arsenic	mg/kg	1.17E+01	1.27E-05	2.79E-06	1.13E-06	
1	Cadmium	mg/kg	2.12E+01	2.30E-05	1.69E-07	2.06E-06	
1	Chromium	mg/kg	4.76E+01	5.17E-05		4.63E-06	
1	Mercury	mg/kg	9.27E+00	1.01E-05		9.02E-07	
1	Uranium	mg/kg	1.56E+02	1.69E-04		1.52E-05	
1	PAH, Total	mg/kg	1.57E-01	1.70E-07	1.63E-07	1.53E-08	
1	Neptunium-237	pCi/g	1.69E+00	3.75E+03		1.01E-01	5.71E+00
1	Uranium-234	pCi/g	1.61E+03	3.57E+06		9.61E+01	5.44E+03
1	Uranium-235	pCi/g	1.03E+02	2.29E+05		6.15E+00	3.48E+02
1	Uranium-238	pCi/g	1.71E+03	3.80E+06		1.02E+02	5.78E+03
2	Antimony	mg/kg	1.08E+02	1.18E-04		1.05E-05	
2	Arsenic	mg/kg	2.12E+01	2.30E-05	5.08E-06	2.06E-06	
2	Cadmium	mg/kg	2.01E+01	2.19E-05	1.61E-07	1.96E-06	
2	Chromium	mg/kg	4.80E+01	5.21E-05		4.67E-06	
2	Mercury	mg/kg	7.30E+00	7.93E-06		7.10E-07	
2	Uranium	mg/kg	7.45E+01	8.09E-05		7.25E-06	
2	PAH, Total	mg/kg	1.69E+00	1.84E-06	1.76E-06	1.65E-07	
2	Cesium-137	pCi/g	3.21E-01	5.42E+02		1.46E-02	8.25E-01
2	Neptunium-237	pCi/g	2.87E-01	6.37E+02		1.71E-02	9.70E-01
2	Uranium-234	pCi/g	1.22E+01	2.71E+04		7.28E-01	4.12E+01
2	Uranium-235	pCi/g	8.40E-01	1.86E+03		5.01E-02	2.84E+00
2	Uranium-238	pCi/g	2.49E+01	5.53E+04		1.49E+00	8.41E+01

Table D.15. Noncancerous CDIs for the Excavation Worker Exposed to Surface and Subsurface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	4.58E-04		4.10E-08
1	Arsenic	mg/kg	1.17E+01	3.55E-05	7.82E-06	3.18E-09
1	Cadmium	mg/kg	2.12E+01	6.44E-05	4.73E-07	5.77E-09
1	Chromium	mg/kg	4.76E+01	1.45E-04		1.30E-08
1	Mercury	mg/kg	9.27E+00	2.82E-05		2.53E-09
1	Uranium	mg/kg	1.56E+02	4.74E-04		4.25E-08
2	Antimony	mg/kg	1.08E+02	3.29E-04		2.95E-08
2	Arsenic	mg/kg	2.12E+01	6.45E-05	1.42E-05	5.78E-09
2	Cadmium	mg/kg	2.01E+01	6.12E-05	4.50E-07	5.49E-09
2	Chromium	mg/kg	4.80E+01	1.46E-04		1.31E-08
2	Mercury	mg/kg	7.30E+00	2.22E-05		1.99E-09
2	Uranium	mg/kg	7.45E+01	2.27E-04		2.03E-08

Table D.16. Cancerous CDIs for the Excavation Worker Exposed to Surface and Subsurface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	1.50E+02	3.27E-05		2.93E-06	
1	Arsenic	mg/kg	1.17E+01	2.53E-06	5.58E-07	2.27E-07	
1	Cadmium	mg/kg	2.12E+01	4.60E-06	3.38E-08	4.12E-07	
1	Chromium	mg/kg	4.76E+01	1.03E-05		9.27E-07	
1	Mercury	mg/kg	9.27E+00	2.01E-06		1.80E-07	
1	Uranium	mg/kg	1.56E+02	3.38E-05		3.03E-06	
1	PAH, Total	mg/kg	1.57E-01	3.41E-08	3.25E-08	3.05E-09	
1	Neptunium-237	pCi/g	1.69E+00	7.50E+02		2.02E-02	1.14E+00
1	Uranium-234	pCi/g	1.61E+03	7.15E+05		1.92E+01	1.09E+03
1	Uranium-235	pCi/g	1.03E+02	4.57E+04		1.23E+00	6.96E+01
1	Uranium-238	pCi/g	1.71E+03	7.59E+05		2.04E+01	1.16E+03
2	Antimony	mg/kg	1.08E+02	2.35E-05		2.11E-06	
2	Arsenic	mg/kg	2.12E+01	4.61E-06	1.02E-06	4.13E-07	
2	Cadmium	mg/kg	2.01E+01	4.37E-06	3.21E-08	3.92E-07	
2	Chromium	mg/kg	4.80E+01	1.04E-05		9.34E-07	
2	Mercury	mg/kg	7.30E+00	1.59E-06		1.42E-07	
2	Uranium	mg/kg	7.45E+01	1.62E-05		1.45E-06	
2	PAH, Total	mg/kg	1.69E+00	3.68E-07	3.52E-07	3.30E-08	
2	Cesium-137	pCi/g	3.21E-01	1.35E+02		3.62E-03	2.05E-01
2	Neptunium-237	pCi/g	2.87E-01	1.27E+02		3.43E-03	1.94E-01
2	Uranium-234	pCi/g	1.22E+01	5.42E+03		1.46E-01	8.24E+00
2	Uranium-235	pCi/g	8.40E-01	3.73E+02		1.00E-02	5.68E-01
2	Uranium-238	pCi/g	2.49E+01	1.11E+04		2.97E-01	1.68E+01

Table D.17. Noncancerous CDIs for the Adult Resident Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	1.80E-04		1.16E-07
1	Cadmium	mg/kg	2.12E+01	2.54E-05	1.53E-06	1.64E-08
1	Uranium	mg/kg	1.56E+02	1.87E-04		1.20E-07
2	Antimony	mg/kg	1.08E+02	1.30E-04		8.37E-08
2	Arsenic	mg/kg	2.12E+01	2.54E-05	4.60E-05	1.64E-08
2	Cadmium	mg/kg	2.01E+01	2.41E-05	1.46E-06	1.56E-08
2	Chromium	mg/kg	2.91E+01	3.49E-05		2.25E-08
2	Uranium	mg/kg	7.45E+01	8.93E-05		5.76E-08

Table D.18. Noncancerous CDIs for the Child Resident Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	1.92E-03		1.16E-07
1	Cadmium	mg/kg	2.12E+01	2.71E-04	3.21E-06	1.64E-08
1	Uranium	mg/kg	1.56E+02	1.99E-03		1.20E-07
2	Antimony	mg/kg	1.08E+02	1.38E-03		8.37E-08
2	Arsenic	mg/kg	2.12E+01	2.71E-04	9.65E-05	1.64E-08
2	Cadmium	mg/kg	2.01E+01	2.57E-04	3.05E-06	1.56E-08
2	Chromium	mg/kg	2.91E+01	3.73E-04		2.25E-08
2	Uranium	mg/kg	7.45E+01	9.53E-04		5.76E-08

Table D.19. Cancerous CDIs for the Resident Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	1.50E+02	2.16E-04		4.32E-05	
1	Cadmium	mg/kg	2.12E+01	3.05E-05	7.50E-07	6.08E-06	
1	Uranium	mg/kg	1.56E+02	2.24E-04		4.48E-05	
1	PAH, Total	mg/kg	1.57E-01	2.26E-07	7.21E-07	4.50E-08	
1	Neptunium-237	pCi/g	1.69E+00	1.89E+03		2.98E-01	2.53E+01
1	Uranium-234	pCi/g	1.61E+03	1.80E+06		2.84E+02	2.41E+04
1	Uranium-235	pCi/g	1.03E+02	1.15E+05		1.81E+01	1.54E+03
1	Uranium-238	pCi/g	1.71E+03	1.92E+06		3.01E+02	2.56E+04
2	Antimony	mg/kg	1.08E+02	1.56E-04		3.11E-05	
2	Arsenic	mg/kg	2.12E+01	3.05E-05	2.25E-05	6.09E-06	
2	Cadmium	mg/kg	2.01E+01	2.90E-05	7.13E-07	5.78E-06	
2	Chromium	mg/kg	2.91E+01	4.19E-05		8.37E-06	
2	Uranium	mg/kg	7.45E+01	1.07E-04		2.14E-05	
2	PAH, Total	mg/kg	1.69E+00	2.44E-06	7.80E-06	4.87E-07	
2	Neptunium-237	pCi/g	2.87E-01	3.21E+02		5.05E-02	4.29E+00
2	Uranium-234	pCi/g	1.22E+01	1.37E+04		2.15E+00	1.82E+02
2	Uranium-235	pCi/g	8.40E-01	9.41E+02		1.48E-01	1.26E+01
2	Uranium-238	pCi/g	2.49E+01	2.79E+04		4.39E+00	3.72E+02

Table D.20. Noncancerous CDIs for the Adult Recreational User Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	5.36E-05		9.60E-09
1	Cadmium	mg/kg	2.12E+01	7.54E-06	4.55E-07	1.35E-09
1	Uranium	mg/kg	1.56E+02	5.55E-05		9.95E-09
2	Antimony	mg/kg	1.08E+02	3.85E-05		6.91E-09
2	Arsenic	mg/kg	2.12E+01	7.55E-06	1.37E-05	1.35E-09
2	Cadmium	mg/kg	2.01E+01	7.17E-06	4.32E-07	1.28E-09
2	Chromium	mg/kg	2.91E+01	1.04E-05		1.86E-09
2	Uranium	mg/kg	7.45E+01	2.65E-05		4.76E-09

Table D.21. Noncancerous CDIs for the Teen Recreational User Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	1.31E-04		1.29E-08
1	Cadmium	mg/kg	2.12E+01	1.85E-05	1.38E-06	1.82E-09
1	Uranium	mg/kg	1.56E+02	1.36E-04		1.34E-08
2	Antimony	mg/kg	1.08E+02	9.43E-05		9.30E-09
2	Arsenic	mg/kg	2.12E+01	1.85E-05	4.16E-05	1.82E-09
2	Cadmium	mg/kg	2.01E+01	1.75E-05	1.32E-06	1.73E-09
2	Chromium	mg/kg	2.91E+01	2.54E-05		2.50E-09
2	Uranium	mg/kg	7.45E+01	6.49E-05		6.40E-09

Table D.22. Noncancerous CDIs for the Child Recreational User Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	1.50E+02	7.69E-04		1.29E-08
1	Cadmium	mg/kg	2.12E+01	1.08E-04	1.29E-06	1.82E-09
1	Uranium	mg/kg	1.56E+02	7.97E-04		1.34E-08
2	Antimony	mg/kg	1.08E+02	5.53E-04		9.30E-09
2	Arsenic	mg/kg	2.12E+01	1.08E-04	3.86E-05	1.82E-09
2	Cadmium	mg/kg	2.01E+01	1.03E-04	1.22E-06	1.73E-09
2	Chromium	mg/kg	2.91E+01	1.49E-04		2.50E-09
2	Uranium	mg/kg	7.45E+01	3.81E-04		6.40E-09

Table D.23. Cancerous CDIs for the Recreational User Exposed to Surface Soil

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	1.50E+02	8.93E-05		4.33E-06	
1	Cadmium	mg/kg	2.12E+01	1.26E-05	3.47E-07	6.09E-07	
1	Uranium	mg/kg	1.56E+02	9.31E-08	3.34E-07	4.51E-09	
1	PAH, Total	mg/kg	1.57E-01	9.25E-05		4.48E-06	
1	Neptunium-237	pCi/g	1.69E+00	6.96E+02		2.98E-02	3.16E+00
1	Uranium-234	pCi/g	1.61E+03	6.63E+05		2.84E+01	3.01E+03
1	Uranium-235	pCi/g	1.03E+02	4.24E+04		1.82E+00	1.93E+02
1	Uranium-238	pCi/g	1.71E+03	7.05E+05		3.02E+01	3.20E+03
2	Antimony	mg/kg	1.08E+02	6.42E-05		3.11E-06	
2	Arsenic	mg/kg	2.12E+01	1.26E-05	1.04E-05	6.10E-07	
2	Cadmium	mg/kg	2.01E+01	1.19E-05	3.30E-07	5.79E-07	
2	Chromium	mg/kg	2.91E+01	1.73E-05		8.38E-07	
2	Uranium	mg/kg	7.45E+01	1.01E-06	3.61E-06	4.87E-08	
2	PAH, Total	mg/kg	1.69E+00	4.42E-05		2.14E-06	
2	Neptunium-237	pCi/g	2.87E-01	1.18E+02		5.06E-03	5.37E-01
2	Uranium-234	pCi/g	1.22E+01	5.03E+03		2.15E-01	2.28E+01
2	Uranium-235	pCi/g	8.40E-01	3.46E+02		1.48E-02	1.57E+00
2	Uranium-238	pCi/g	2.49E+01	1.03E+04		4.39E-01	4.66E+01

Table D.24. Cancerous CDIs for the Resident Exposed to Groundwater

COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
Technetium-99	pCi/L	3.40E+02	6.51E+06	N/A	N/A	N/A

D.3.6 SUMMARY OF EXPOSURE ASSESSMENT

Consistent with the data collected during the RI, the receptors selected for assessment are the outdoor/excavation worker, industrial worker, and rural resident.

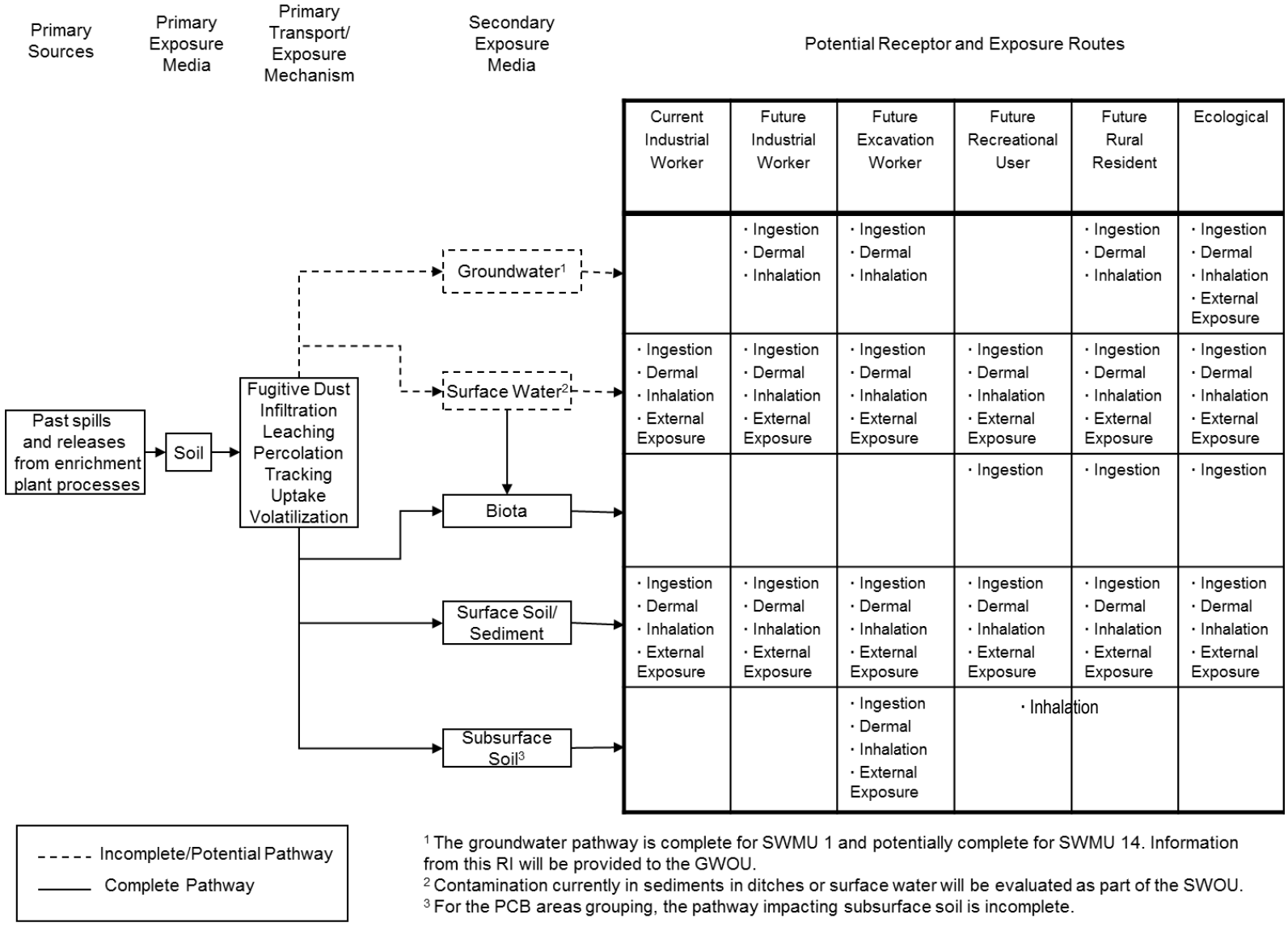
D.3.6.1 Development of Conceptual Site Models

The scope of the sampling in support of the RI discussed in Section 1 of the RI/Feasibility Study Work Plan is as follows:

> The objective of this investigation is to determine the nature and extent of contamination in the soils to a depth of 10 ft below ground surface (bgs) or up to 16 ft bgs at infrastructure (e.g., pipelines). For all source units, the initial focus of the investigation will be surface and subsurface soil contamination to a depth of 4 ft bgs. If contamination at the 4 ft bgs is found, then secondary sources from the unit located in the subsurface soil, which extend to a depth of 10 ft bgs, will be investigated. Any contamination that is found to extend past the depths specified in this investigation will be addressed under another OU.

This scope and the uncertainties in site conditions subsequently were used in the baseline risk assessment to develop a CSM that identified the sources of contamination (from both process releases and unspecified releases), release mechanisms, primary and secondary contaminated environmental media, transport mechanisms, potential receptors, and routes of exposure consistent with the RI. This CSM is presented in Figure D.3.

SWMU 229 with the stepout gridding includes 0.849 acres and 2 EUs.



[1] The groundwater pathway is complete for SWMU 1 and potentially complete for SWMU 14. Information from this RI will be provided to the GWOU.
[2] Contamination currently in sediments in ditches or surface water will be evaluated as part of the SWOU.
[3] For the PCB areas grouping, the pathway impacting subsurface soil is incomplete.

Revised from DOE 2013 (Figure D.3)

Figure D.3. CSM for SWMU 229

D.4. TOXICITY ASSESSMENT

This section summarizes the potential toxicological effects of the COPCs on exposed populations. Many of the toxicological summaries were obtained from the *Risk Assessment Information System* (RAIS) Web site, available at http://rais.ornl.gov/ (UT 2013). This site also lists toxicity values taken from EPA's Integrated Risk Information System (IRIS) database (EPA 2015), National Center for Environmental Assessment (NCEA), and Health Effects Assessment Summary Tables (HEAST) database (EPA 1998). This list formed the basis of the toxicity values reported in this section. For those chemicals not profiled in RAIS, a brief summary of information drawn from Agency for Toxic Substances and Disease Registry or other library research sources is included in this section. The last paragraph of each profile contains the toxicity values used in this BHHRA.

The toxicity information considered in the assessment of potential carcinogenic risks includes (1) a weight-of-evidence classification and (2) a slope factor (SF) or inhalation unit risk (IUR). The weight-of-evidence classification qualitatively describes the likelihood that an agent is a human carcinogen, based on the available data from animal and human studies. A chemical may be placed in one of three groups to indicate its potential for carcinogenic effects: Group A, a known human carcinogen; Group B, a probable human carcinogen; and Group C, a possible human carcinogen. Group B is divided into Subgroups B1 and B2. Assignment of a chemical to Subgroup B1 indicates that the judgment that the chemical is a probable human carcinogen is based on limited human data, and assignment of a chemical to Subgroup B2 indicates that the judgment that the chemical is a probable human carcinogen is based on animal data because human data are lacking or inadequate. Chemicals that cannot be classified as human carcinogens because of a lack of data are categorized in Group D, and those for which there is evidence of noncarcinogenicity in humans are categorized in Group E.

The SF for chemicals is defined as a plausible upperbound estimate of the probability of a response (i.e., development of cancer) per unit intake of a chemical over a lifetime (EPA 1989). SFs are specific for each chemical and route of exposure. Similarly, IURs may be called the inhalation slope factor. SFs and IURs currently are available for ingestion and inhalation pathways. The SFs and IURs used for oral and inhalation routes of exposure for the COPCs considered in this report are shown in Attachment D2.

Toxicity values used in risk calculations also include the chronic reference dose (RfD) and reference concentration (RfC), which is used to estimate the potential for systemic toxicity or noncarcinogenic risk. The chronic RfD is defined as an estimate of a daily exposure level for the human population, including sensitive subpopulations, that is likely to be without an appreciable risk of deleterious effects during a lifetime (EPA 1989). RfD values are specific to the route of exposure. The RfDs used for oral routes of exposure and the RfCs used for inhalation routes of exposure for the COPCs considered in this report are presented in Attachment D2.

For the dermal routes of exposure (i.e., dermal exposure to contaminated water while showering or bathing or dermal contact with contaminated soil), it is necessary to consider the absorbed dose received by a receptor. This is reflected by the addition of an absorption coefficient in the equations used to calculate the CDI for these pathways. Because the CDI is expressed as an absorbed dose, it is necessary to use RfDs and SFs that also are expressed in terms of absorbed dose. Currently, EPA has not produced lists of RfDs and SFs based on absorbed dose, but has produced guidance concerning the estimation of absorbed dose RfDs and SFs from administered dose RfDs and SFs. This guidance is found in *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)* (EPA 2004) and states, "that to convert an administered dose

slope factor to an absorbed dose slope factor, the administered dose slope factor is divided by the gastrointestinal (GI) absorption efficiency of the contaminant." Alternatively, to convert an administered dose RfD to an absorbed dose RfD, the administered dose RfD is multiplied by the GI absorption efficiency of the contaminant. The absorbed dose slope factors and RfDs and the information used in their derivation are presented in Attachment D2.

Toxicity profiles for primary contaminants of concern (COCs) identified in this assessment are included in Attachment D3.

D.4.1 CHEMICALS FOR WHICH NO EPA TOXICITY VALUES ARE AVAILABLE

Chemicals for which no EPA toxicity values are available have been evaluated as an uncertainty included in Attachment D1.

D.4.2 UNCERTAINTIES RELATED TO TOXICITY INFORMATION

Standard EPA RfDs/RfCs and SFs/IURs were used to estimate potential noncarcinogenic and carcinogenic health effects from exposure to detected chemical contaminants. Considerable uncertainty is associated with the methodology applied to derive SFs/IURs and RfDs/RfCs. EPA working groups review all relevant human and animal studies for each compound and select the studies pertinent to the derivation of the specific RfD/RfC and SF/IUR. These studies often involve data from experimental studies in animals, high exposure levels, and exposures under acute or occupational conditions. Extrapolation of these data to humans under low-dose, chronic conditions introduces uncertainties. The magnitude of these uncertainties is addressed by applying uncertainty factors to the dose response data for each applicable uncertainty. These factors are incorporated to provide a margin of safety for use in human health assessments.

D.4.2.1 Development of Dermal Toxicity Factors

Dermal RfDs and SFs are derived from the corresponding oral values, using a route-to-route extrapolation based on the absorption efficiency of the chemical though the exposure route (for example, through the gastrointestinal tract), provided that there is no evidence to suggest that dermal exposure induces exposure route-specific effects that are not appropriately modeled by oral exposure data. In the derivation of a dermal RfD, the oral RfD is multiplied by the gastrointestinal absorption factor (ABS_{GI}), expressed as a decimal fraction. The resulting dermal RfD, therefore, is based on absorbed dose. The RfD based on absorbed dose is the appropriate value with which to compare a dermal dose, because dermal doses are expressed as absorbed rather than exposure doses. The dermal SF is derived by dividing the oral SF by the ABS_{GI}. The oral SF is divided, rather than multiplied, by the ABS_{GI} because SFs are expressed as a reciprocal dose.

Dermal contact with soil has been a driving exposure route in previous BHHRAs at PGDP, with most of this risk arising from contact with metals (e.g., beryllium, vanadium). This is a direct result of using dermal absorption factors that exceed GI absorption values and may be overly conservative. In such circumstances, risk estimates from the dermal exposure route may be unrealistic and exceed the real risk posed by this route of exposure. Although chemical-specific ABS values were used when available, default ABS values were used for most chemicals because chemical-specific values are lacking. It should be noted that risk management decisions based on the dermal contact with soil exposure route should be considered carefully because of the uncertainty associated with risk from this exposure route.

In the past, it has been assumed that 5% of the inorganic materials will be absorbed through the skin as from the gastrointestinal tract. This was considered conservative because the primary function of the GI tract is to allow absorption of minerals and nutrients, where the function of the skin is to act as a barrier to entry of foreign materials. Therefore, absorption of materials from the GI tract generally is considered to occur more readily than dermal absorption. In addition, once ingested, it will remain in contact with the GI tract for approximately 24 hours or more, while materials on skin most likely will be washed off more frequently.

D.4.2.2 Lead Toxicity

Although it is known that exposure to lead can result in systemic toxic effects and possibly cancer, the approved toxicity values required to estimate potential for systemic toxicity and carcinogenesis are not available. Thus, the approach to evaluating health risks associated with exposure to lead is different from other chemicals detected at the site. To determine if exposure to lead has occurred, the amount of lead present in the blood can be measured; the level of lead in the blood is measured in micrograms per deciliter (µg/dL). Ten µg/dL is considered the national health criteria that no more than 5% of the population should exceed this level before health effects may be exhibited (EPA 2003a). Based on the target blood lead (PbB) level of 10 µg/dL, EPA has derived a residential screening level of 400 mg/kg lead in soil, which is considered protective for young children exposed routinely under a residential scenario. This residential screening value of 400 mg/kg also is adopted as the NAL for lead in soils at PGDP for identifying lead as a COPC. EPA also has derived an industrial screening level of 800 mg/kg lead in soil.

Lead is unique in that a continuous level of exposure is needed to detect an increase in PbB. According to EPA guidance on intermittent exposures to lead (EPA 2003b), the magnitude and duration of the increase in PbB will vary depending on the temporal pattern of exposure at a site. According to EPA guidance (EPA 2003a; 2003b), an increase in PbB will be greatest if exposure occurs every day in succession over an extended period of time (e.g., summer); in comparison to intermittent exposures (e.g., once every 7 days) would give rise to smaller PbB increases. Infrequent exposures (i.e., less than 1 day per week) over a minimum duration of 90 days would be expected to produce oscillations in blood lead concentrations associated with the absorption and subsequent clearance of lead from the blood between each exposure event. As a result, EPA's Technical Review Workgroup recommends that PbB models for evaluating child and adult exposure to lead be applied to exposure that exceed a minimum frequency of one day per week and a duration of 3 consecutive months (EPA 2003b).

For PGDP, the preliminary risk characterization of lead is conducted for SWMU 229 by comparing the maximum detected result to the residential screening value of 400 mg/kg. Lead is not considered a COPC at SWMU 229 because it does not exceed the screening value.

D.4.2.3 Carcinogenic PAHs

During the development of the list of COPCs, concentrations of total cancerous PAHs were derived based on the methodology in the Risk Methods Document (DOE 2015a). When deriving Total PAHs, the toxicity equivalence factors (TEFs) presented in Human Health Risk Assessment Protocol for Hazardous Waste Combustion Facilities (EPA 2005) were used. These TEFs were applied to the concentrations of detected PAHs in each sample and then the Total PAH concentration in a sample was the sum of the products of each carcinogenic PAH and its TEF. When calculating the EPC for carcinogenic PAHs, for samples in which PAHs are not detected, the value for the minimum detection limit of the PAHs with TEFs were used.

D.4.2.4 Total Dioxins/Furans

Dioxins and furans were not sampled for SWMU 229.

D.5. RISK CHARACTERIZATION

Risk characterization is the final step in the risk assessment process. In this step, the information from the exposure and toxicity assessments is integrated to quantitatively estimate both carcinogenic health risks and noncarcinogenic hazard potential. For this assessment, risk is defined as both the lifetime probability of excess cancer incidence for carcinogens and the estimate of daily intake exceeding intake that may lead to toxic effects for noncarcinogens.

D.5.1 DETERMINATION OF POTENTIAL FOR NONCANCER EFFECTS

In this BHHRA, the numeric estimate of the potential for noncancer effects posed by a single chemical within one pathway of exposure is derived as the ratio of the CDI or EC of a chemical, from a single pathway to the appropriate RfD or RfC. This ratio also is referred to as a hazard quotient (HQ). This value is calculated as shown in the following equations, as appropriate:

$$HQ_i = \frac{CDI_i[mg/(kg \times day)]}{RfD_i[mg/(kg \times day)]}$$

where:

HQ_i is the hazard quotient, an estimate of the systemic toxicity posed by a single chemical, dimensionless

CDI_i is the estimate of chronic daily intake (or absorbed dose for some exposure routes) from the exposure assessment

RfD_i is the chronic reference dose for administered or absorbed dose, as appropriate

or

$$HQ_i = \frac{EC_i\ (\mu g/m^3)}{[RfC_i\ (mg/m^3) \times 1000\ (\mu g/mg)]}$$

where:

HQ_i is the hazard quotient, an estimate of the systemic toxicity posed by a single chemical for inhalation

EC_i is the exposure concentration for chronic exposure

RfC_i is the reference concentration for chronic inhalation exposure

When performing this calculation, the proper RfD/RfC was used for each CDI/EC. For CDIs that reflect ingestion, the RfD used was that for administered dose. For CDIs that reflect absorption, as in dermal contact, the RfD used was that for absorbed dose. Finally, for ECs that reflect inhalation exposure, the

RfC used was that for inhalation. For all exposures, regardless of duration, the chronic RfD was used (DOE 2015a).

If several chemicals may reach a receptor through a common pathway, guidance (DOE 2015a) recommends adding the HQs of all chemicals reaching the receptor through the common pathway to calculate a pathway HI. This can be represented by the following equation:

$$HI_p = \sum_{i=1}^{n} HQ_i$$

where:

HI_p or the pathway HI is the sum of the individual chemical HQs, dimensionless

HQ_1 to HQ_n are the individual chemical hazard quotients relevant to the pathway, dimensionless

Similarly, guidance (DOE 2015a) recommends summing the pathway HIs for all pathways relevant to an individual receptor to develop a total HI. The total HI is not an estimate of the systemic toxicity posed by all contaminants that may reach the receptor, but can be used to estimate if a toxic effect may result if all contaminants reaching the receptor have additive effects over all pathways. This can be represented as in the following equation:

$$HI_{total} = \sum_{p=1}^{n} HI_p$$

where:

HI_{total} or total HI is the sum of all pathways relevant to a single receptor, dimensionless

HI_1 to HI_n are the individual pathway HIs

Note that the HQ, the pathway HI, and the total HI do not define a dose-response relationship. That is, the magnitude of the HQ or HI does not represent a statistical probability of incurring an adverse effect. If the HQ is less than 1, the estimated exposure to a substance may be judged to be below a level that could present a toxic effect. If the HQ is greater than 1, a toxic effect may or may not result depending on the assumptions used to develop the CDI/EC and assumptions used in deriving the RfD/RfC. Similarly, if the pathway HI is less than 1, then the estimated exposure to multiple chemicals contributing to the pathway HI should not be expected to present a toxic effect. If the pathway HI is greater than 1, then exposure may or may not result in a toxic effect depending on what assumptions were used to develop the pathway and how the chemicals included in the pathway interact. Finally, if the total HI is less than 1, then the estimated exposure to multiple chemicals over multiple pathways should not be expected to result in a toxic effect. If the total HI is greater than 1, then a toxic effect may or may not result depending on the rigor used to develop the CSM for all pathways and the interaction between pathways and individual chemicals.

D.5.2 DETERMINATION OF EXCESS LIFETIME CANCER RISK

Estimates of the potential for cancer induction are measured by calculating estimates of ELCR. Generally, ELCR can be defined as the incremental increase in the probability that a receptor may develop cancer if the receptor is exposed to chemicals or radionuclides or both. ELCRs are specific to the CSM used to define the routes and magnitude of exposure. The magnitude of the ELCRs could vary markedly if the exposure assumptions used to develop the CSM are varied.

D.5.2.1 Chemical Excess Cancer Risk

The numeric estimate of the ELCR resulting from exposure to a single chemical carcinogen is derived by multiplying the CDI or EC through a particular pathway by the SF or IUR appropriate to that pathway. The resulting value is referred to as a chemical-specific ELCR. These values are calculated as shown in the following equations:

$$ELCR_i = CDI_i[mg/(kg \times day)] \times SF_i[mg/(kg \times day)]^{-1}$$

where:

$ELCR_i$ or chemical-specific ELCR is an estimate of the excess lifetime probability of developing cancer that results because of exposure to the specific chemical, dimensionless

CDI_i is the chronic daily intake of the chemical

SF_i is the slope factor for the specific chemical

or

$$ELCR_i = EC_i\ (\mu g/m^3) \times IUR_i\ (\mu g/m^3)^{-1}$$

where:

$ELCR_i$ or chemical-specific ELCR is an estimate of the excess lifetime probability of developing cancer that results because of exposure to the specific chemical, dimensionless

EC_i is the exposure concentration for chronic exposure to the chemical

IUR_i is the unit risk for chronic inhalation exposure for the specific chemical

As with the calculation used to derive HQs, the proper SF/IUR was used for each CDI/EC when performing this calculation. For CDIs that reflect ingestion, the SF was that for an administered dose. For CDIs that reflect absorption, the SF was that for absorbed dose. Finally, for ECs that reflect inhalation exposure, the IUR was that for inhalation.

If several chemicals may reach a receptor through a common pathway, the chemical specific ELCRs of all chemicals reaching the receptor through the common pathway are summed to calculate a pathway ELCR. This can be represented by the following equation:

$$ELCR_p = \sum_{i=1}^{n} ELCR_i$$

where:

$ELCR_p$ or the pathway ELCR is the sum of the individual chemical-specific ELCRs, dimensionless

$ELCR_1$ to $ELCR_n$ are the chemical-specific ELCRs relevant to the pathway; dimensionless

Similarly, the pathway ELCRs for all pathways relevant to an individual receptor are summed to develop a total ELCR. The total ELCR is not an actuarial estimate of an individual developing cancer, but can be used to estimate the total ELCR that may result if all contaminants reaching the receptor have additive effects over all pathways. This can be represented as in the following equation:

$$\mathrm{ELCR}_{total} = \sum_{p=1}^{n} \mathrm{ELCR}_p$$

where:

ELCR_{total} or total ELCR is the sum of all pathways relevant to a single receptor, dimensionless

ELCR_1 to ELCR_n is the individual pathway ELCRs

Unlike the HQ, the pathway HI and the total HI, the chemical-specific ELCR, the pathway ELCR, and total ELCR define a dose-response relationship. That is, the ELCRs represent a statistical probability of the increased risk of developing cancer that exists in receptors exposed under the assumptions used in the calculation of the CDI/EC.

D.5.2.2 Radionuclide Excess Cancer Risk

Calculation of cancer risk due to exposure to radionuclides through ingestion or inhalation is conceptually similar to calculation of risks for chemical carcinogens. In performing this calculation, ELCR due to exposure to a particular radionuclide within a specific pathway is calculated by multiplying the intake of the radionuclide by the route-specific cancer slope factor. This can be represented by the following equations:

For ingestion:

$$\mathrm{ELCR}_i = \mathrm{CDI}_i(\mathrm{pCi}) \times \mathrm{SF}_i(\mathrm{risk/pCi})$$

where:

ELCR_i or radionuclide-specific ELCR is an estimate of the excess lifetime probability of developing cancer that results because of exposure to the specific radionuclide, dimensionless

CDI_i is the ingestion chronic daily intake of the radionuclide

SF_i is the ingestion slope factor for the specific radionuclide

For external exposure to ionizing radiation, the equation above is used, except units for CDI and SF are pCi-year/g and risk-g/pCi-year, respectively.

For inhalation:

$$\mathrm{ELCR}_i = \mathrm{EC}_i(\mathrm{pCi}) \times \mathrm{IUR}_i(\mathrm{risk/pCi})$$

where:

ELCR_i or radionuclide-specific ELCR is an estimate of the excess lifetime probability of developing cancer that results because of exposure to the specific radionuclide, dimensionless

EC_i is the exposure concentration for chronic exposure to the radionuclide

IUR_i is the unit risk for chronic inhalation exposure for the specific chemical

As with the calculation used to derive chemical-specific ELCRs, the proper SF or IUR was used for each CDI when performing this calculation. For CDIs that reflect ingestion, the SF was that for ingestion. Similarly, for ECs that reflect inhalation exposure, the IUR was that for inhalation.

Both the pathway ELCR for radionuclides and the total ELCR from exposure to multiple radionuclides within a pathway and over multiple pathways, respectively, are calculated as illustrated for chemical carcinogens in the Risk Methods Document (DOE 2015a). These equations will not be presented in this risk assessment. The uncertainties related to this method of determining ELCR from exposure to radionuclides is discussed in detail in Section D.6.

In this risk assessment, ELCRs from exposure to chemicals and radionuclides were summed within pathways and over all pathways to indicate the potential health risk to a receptor that may be exposed to radionuclides and chemicals over all pathways. The uncertainties associated with combining radionuclide and chemical ELCRs are discussed in detail in Section D.6.

D.5.3 RISK CHARACTERIZATION FOR SOIL

This subsection presents the systemic toxicity [hazard index (HI)] and ELCR for soil exposure at each source area calculated from the COPCs at each unit. Both HI and ELCR are presented. The results of the quantitative risk assessment are presented in Tables D.25 through D.41 and include (1) risks by contaminant for each pathway, (2) risks by contaminant across all pathways (shown in "Total" column), (3) total pathway risks for all contaminants (shown across "Total" row, and d) total risk for all contaminants across all pathways (bold value in "Total" row).

Table D.25. HIs for the Current Industrial Worker Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	0.01			0.01	73.2%
1	Cadmium	2.12E+01	0.00	0.00	0.00	0.00	16.1%
1	Uranium	1.56E+02	0.00		0.00	0.00	10.8%
1	**Totals**		**0.01**	**0.00**	**0.00**	**0.01**	
1	**Percent**		**87%**	**12%**	**1%**		
2	Antimony	1.08E+02	0.01			0.01	45.3%
2	Arsenic	2.12E+01	0.00	0.00	0.00	0.01	37.1%
2	Cadmium	2.01E+01	0.00	0.00	0.00	0.00	13.2%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.00		0.00	0.00	4.4%
2	**Totals**		**0.01**	**0.00**	**0.00**	**0.02**	
2	**Percent**		**65%**	**35%**	**1%**		

Table D.26. HIs for the Future Industrial Worker Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	0.16			0.16	73.2%
1	Cadmium	2.12E+01	0.01	0.03	0.00	0.04	16.1%
1	Uranium	1.56E+02	0.02		0.00	0.02	10.8%
1	**Totals**		**0.19**	**0.03**	**0.00**	**0.22**	
1	**Percent**		**87%**	**12%**	**1%**		
2	Antimony	1.08E+02	0.12			0.12	45.3%
2	Arsenic	2.12E+01	0.03	0.06	0.00	0.09	37.1%
2	Cadmium	2.01E+01	0.01	0.02	0.00	0.03	13.2%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.01		0.00	0.01	4.4%
2	**Totals**		**0.17**	**0.09**	**0.00**	**0.25**	
2	**Percent**		**65%**	**35%**	**1%**		

Table D.27. HIs for the Outdoor Worker Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	1.14			1.14	82.5%
1	Cadmium	2.12E+01	0.06	0.02	0.00	0.08	6.1%
1	Uranium	1.56E+02	0.16		0.00	0.16	11.5%
1	**Totals**		**1.37**	**0.02**	**0.00**	**1.38**	
1	**Percent**		**99%**	**1%**	**0%**		
2	Antimony	1.08E+02	0.82			0.82	66.3%
2	Arsenic	2.12E+01	0.21	0.05	0.00	0.26	21.2%
2	Cadmium	2.01E+01	0.06	0.02	0.00	0.08	6.4%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.08		0.00	0.08	6.1%
2	**Totals**		**1.17**	**0.07**	**0.00**	**1.24**	
2	**Percent**		**95%**	**5%**	**0%**		

Table D.28. HIs for the Outdoor Worker Exposed to Surface and Subsurface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	1.14			1.14	70.4%
1	Arsenic	1.17E+01	0.12	0.03	0.00	0.14	8.9%
1	Cadmium	2.12E+01	0.06	0.02	0.00	0.08	5.2%
1	Chromium	4.76E+01	0.00			0.00	0.0%
1	Mercury	9.27E+00	0.09			0.09	5.8%
1	Uranium	1.56E+02	0.16		0.00	0.16	9.8%
1	**Totals**		**1.58**	**0.04**	**0.00**	**1.61**	
1	**Percent**		**97%**	**3%**	**0%**		
2	Antimony	1.08E+02	0.82			0.82	62.5%
2	Arsenic	2.12E+01	0.21	0.05	0.00	0.26	20.0%
2	Cadmium	2.01E+01	0.06	0.02	0.00	0.08	6.1%
2	Chromium	4.80E+01	0.00			0.00	0.0%
2	Mercury	7.30E+00	0.07			0.07	5.6%
2	Uranium	7.45E+01	0.08		0.00	0.08	5.8%
2	**Totals**		**1.25**	**0.07**	**0.00**	**1.31**	
2	**Percent**		**95%**	**5%**	**0%**		

Table D.29. HIs for the Excavation Worker Exposed to Surface and Subsurface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	1.14			1.14	70.4%
1	Arsenic	1.17E+01	0.12	0.03	0.00	0.14	8.9%
1	Cadmium	2.12E+01	0.06	0.02	0.00	0.08	5.2%
1	Chromium	4.76E+01	0.00			0.00	0.0%
1	Mercury	9.27E+00	0.09			0.09	5.8%
1	Uranium	1.56E+02	0.16		0.00	0.16	9.8%
1	**Totals**		**1.58**	**0.04**	**0.00**	**1.61**	
1	**Percent**		**97%**	**3%**	**0%**		
2	Antimony	1.08E+02	0.82			0.82	62.5%
2	Arsenic	2.12E+01	0.21	0.05	0.00	0.26	20.0%
2	Cadmium	2.01E+01	0.06	0.02	0.00	0.08	6.1%
2	Chromium	4.80E+01	0.00			0.00	0.0%
2	Mercury	7.30E+00	0.07			0.07	5.6%
2	Uranium	7.45E+01	0.08		0.00	0.08	5.8%
2	**Totals**		**1.25**	**0.07**	**0.00**	**1.31**	
2	**Percent**		**95%**	**5%**	**0%**		

Table D.30. HIs for the Future Hypothetical Adult Resident Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	0.45			0.45	74.6%
1	Cadmium	2.12E+01	0.03	0.06	0.00	0.09	14.6%
1	Uranium	1.56E+02	0.06		0.00	0.07	10.8%
1	**Totals**		**0.54**	**0.06**	**0.00**	**0.61**	
1	**Percent**		**89%**	**10%**	**1%**		
2	Antimony	1.08E+02	0.32			0.32	47.8%
2	Arsenic	2.12E+01	0.08	0.15	0.00	0.24	35.2%
2	Cadmium	2.01E+01	0.02	0.06	0.00	0.08	12.4%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.03		0.00	0.03	4.6%
2	**Totals**		**0.46**	**0.21**	**0.00**	**0.67**	
2	**Percent**		**68%**	**31%**	**1%**		

Table D.31. HIs for the Future Hypothetical Child Resident Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	4.81			4.81	81.8%
1	Cadmium	2.12E+01	0.27	0.13	0.00	0.40	6.8%
1	Uranium	1.56E+02	0.66		0.00	0.67	11.4%
1	**Totals**		**5.74**	**0.13**	**0.00**	**5.88**	
1	**Percent**		**98%**	**2%**	**0%**		
2	Antimony	1.08E+02	3.46			3.46	64.2%
2	Arsenic	2.12E+01	0.90	0.32	0.00	1.23	22.8%
2	Cadmium	2.01E+01	0.26	0.12	0.00	0.38	7.1%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.32		0.00	0.32	5.9%
2	**Totals**		**4.94**	**0.44**	**0.00**	**5.39**	
2	**Percent**		**92%**	**8%**	**0%**		

Table D.32. HIs for the Adult Recreational User Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	0.13			0.13	75.0%
1	Cadmium	2.12E+01	0.01	0.02	0.00	0.03	14.5%
1	Uranium	1.56E+02	0.02		0.00	0.02	10.5%
1	**Totals**		**0.16**	**0.02**	**0.00**	**0.18**	
1	**Percent**		**90%**	**10%**	**0%**		
2	Antimony	1.08E+02	0.10			0.10	48.0%
2	Arsenic	2.12E+01	0.03	0.05	0.00	0.07	35.3%
2	Cadmium	2.01E+01	0.01	0.02	0.00	0.02	12.3%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.01		0.00	0.01	4.5%
2	**Totals**		**0.14**	**0.06**	**0.00**	**0.20**	
2	**Percent**		**69%**	**31%**	**0%**		

Table D.33. HIs for the Teen Recreational User Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	0.33			0.33	73.3%
1	Cadmium	2.12E+01	0.02	0.06	0.00	0.07	16.5%
1	Uranium	1.56E+02	0.05		0.00	0.05	10.2%
1	**Totals**		**0.39**	**0.06**	**0.00**	**0.45**	
1	**Percent**		**87.5%**	**12.4%**	**0.1%**		
2	Antimony	1.08E+02	0.24			0.24	44.6%
2	Arsenic	2.12E+01	0.06	0.14	0.00	0.20	37.9%
2	Cadmium	2.01E+01	0.02	0.05	0.00	0.07	13.3%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.02		0.00	0.02	4.1%
2	**Totals**		**0.34**	**0.19**	**0.00**	**0.53**	
2	**Percent**		**63.7%**	**36.2%**	**0.1%**		

Table D.34. HIs for the Child Recreational User Exposed to Surface Soil

EU	COPC	EPC (mg/kg)	Ingestion	Dermal	Inhalation	HI	Percent
1	Antimony	1.50E+02	1.92			1.92	81.9%
1	Cadmium	2.12E+01	0.11	0.05	0.00	0.16	6.8%
1	Uranium	1.56E+02	0.27		0.00	0.27	11.3%
1	**Totals**		**2.30**	**0.05**	**0.00**	**2.35**	
1	**Percent**		**98%**	**2%**	**0%**		
2	Antimony	1.08E+02	1.38			1.38	64.3%
2	Arsenic	2.12E+01	0.36	0.13	0.00	0.49	22.8%
2	Cadmium	2.01E+01	0.10	0.05	0.00	0.15	7.1%
2	Chromium	2.91E+01	0.00			0.00	0.0%
2	Uranium	7.45E+01	0.13		0.00	0.13	5.9%
2	**Totals**		**1.97**	**0.18**	**0.00**	**2.15**	
2	**Percent**		**92%**	**8%**	**0%**		

Table D.35. ELCRs for the Current Industrial Worker Exposed to Surface Soil

EU	COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
1	Cadmium	2.12E+01			2.81E-10		2.81E-10	0.0%
1	PAH, Total	1.57E-01	9.80E-09	8.99E-08	1.27E-12		9.97E-08	0.1%
1	Neptunium-237	1.69E+00	1.47E-09		2.19E-10	3.69E-07	3.71E-07	0.5%
1	Uranium-234	1.61E+03	1.44E-06		2.02E-07	1.04E-07	1.75E-06	2.4%
1	Uranium-235	1.03E+02	9.01E-08		1.16E-08	1.52E-05	1.53E-05	21.4%
1	Uranium-238	1.71E+03	1.68E-06		1.83E-07	5.20E-05	5.39E-05	75.5%
1	**Totals**		**3.22E-06**	**8.99E-08**	**3.97E-07**	**6.77E-05**	**7.14E-05**	
1	**Percent**		**5%**	**0%**	**1%**	**95%**		
2	Arsenic	2.12E+01	2.72E-07	5.76E-07	6.71E-10		8.48E-07	29.0%
2	Cadmium	2.01E+01			2.67E-10		2.67E-13	0.0%
2	Chromium	2.91E+01			1.80E-08		1.80E-11	0.6%
2	PAH, Total	1.69E+00	1.06E-07	9.71E-07	1.37E-11		1.08E-06	36.8%
2	Neptunium-237	2.87E-01	2.49E-10		3.72E-11	6.27E-08	6.30E-08	2.2%
2	Uranium-234	1.22E+01	1.09E-08		1.53E-09	7.89E-10	1.32E-08	0.5%
2	Uranium-235	8.40E-01	7.35E-10		9.48E-11	1.24E-07	1.25E-07	4.3%
2	Uranium-238	2.49E+01	2.45E-08		2.67E-09	7.58E-07	7.85E-07	26.8%
2	**Totals**		**4.15E-07**	**1.55E-06**	**2.33E-08**	**9.45E-07**	**2.93E-06**	
2	**Percent**		**14%**	**53%**	**1%**	**32%**		

Table D.36. ELCRs for the Future Industrial Worker Exposed to Surface Soil

EU	COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
1	Cadmium	2.12E+01			5.01E-09		5.01E-09	0.0%
1	PAH, Total	1.57E-01	1.75E-07	1.60E-06	2.27E-11		1.78E-06	0.1%
1	Neptunium-237	1.69E+00	2.62E-08		3.91E-09	6.60E-06	6.63E-06	0.5%
1	Uranium-234	1.61E+03	2.57E-05		3.61E-06	1.86E-06	3.12E-05	2.4%
1	Uranium-235	1.03E+02	1.61E-06		2.08E-07	2.71E-04	2.73E-04	21.4%
1	Uranium-238	1.71E+03	3.00E-05		3.27E-06	9.29E-04	9.62E-04	75.5%
1	**Totals**		**5.76E-05**	**1.60E-06**	**7.09E-06**	**1.21E-03**	**1.27E-03**	
1	**Percent**		**5%**	**0%**	**1%**	**95%**		
2	Arsenic	2.12E+01	4.86E-06	1.03E-05	1.20E-08		1.52E-05	29.1%
2	Cadmium	2.01E+01			4.77E-09		4.77E-09	0.0%
2	Chromium	2.91E+01			3.22E-07		3.22E-07	0.0%
2	PAH, Total	1.69E+00	1.89E-06	1.73E-05	2.45E-10		1.92E-05	37.0%
2	Neptunium-237	2.87E-01	4.45E-09		6.64E-10	1.12E-06	1.13E-06	2.2%
2	Uranium-234	1.22E+01	1.95E-07		2.74E-08	1.41E-08	2.36E-07	0.5%
2	Uranium-235	8.40E-01	1.31E-08		1.69E-09	2.21E-06	2.22E-06	4.3%
2	Uranium-238	2.49E+01	4.37E-07		4.76E-08	1.35E-05	1.40E-05	27.0%
2	**Totals**		**7.40E-06**	**2.76E-05**	**4.16E-07**	**1.69E-05**	**5.23E-05**	
2	**Percent**		**14%**	**53%**	**1%**	**32%**		

Table D.37. ELCRs for the Outdoor Worker Exposed to Surface Soil

EU	COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
1	Cadmium	2.12E+01			3.71E-09		3.71E-12	0.0%
1	PAH, Total	1.57E-01	1.24E-06	1.19E-06	1.68E-11		2.43E-06	0.2%
1	Neptunium-237	1.69E+00	1.86E-07		2.89E-09	4.88E-06	5.07E-06	0.4%
1	Uranium-234	1.61E+03	1.83E-04		2.67E-06	1.38E-06	1.87E-04	14.3%
1	Uranium-235	1.03E+02	1.14E-05		1.54E-07	2.00E-04	2.12E-04	16.2%
1	Uranium-238	1.71E+03	2.13E-04		2.42E-06	6.88E-04	9.03E-04	69.0%
1	**Totals**		**4.09E-04**	**1.19E-06**	**5.25E-06**	**8.94E-04**	**1.31E-03**	
1	**Percent**		**31%**	**0%**	**0%**	**68%**		
2	Arsenic	2.12E+01	3.45E-05	7.61E-06	8.87E-09		4.22E-05	49.1%
2	Cadmium	2.01E+01			3.53E-09		3.53E-12	0.0%
2	Chromium	2.91E+01			2.38E-07		2.38E-10	0.3%
2	PAH, Total	1.69E+00	1.34E-05	1.28E-05	1.81E-10		2.63E-05	30.6%
2	Neptunium-237	2.87E-01	3.16E-08		4.92E-10	8.29E-07	8.61E-07	1.0%
2	Uranium-234	1.22E+01	1.38E-06		2.02E-08	1.04E-08	1.41E-06	1.6%
2	Uranium-235	8.40E-01	9.32E-08		1.25E-09	1.63E-06	1.73E-06	2.0%
2	Uranium-238	2.49E+01	3.11E-06		3.52E-08	1.00E-05	1.32E-05	15.3%
2	**Totals**		**5.26E-05**	**2.05E-05**	**3.08E-07**	**1.25E-05**	**8.57E-05**	
2	**Percent**		**61%**	**24%**	**0%**	**15%**		

Table D.38. ELCRs for the Outdoor Worker Exposed to Surface and Subsurface Soil

EU	COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
1	Arsenic	1.17E+01	1.90E-05	4.19E-06	4.88E-09		2.32E-05	1.7%
1	Cadmium	2.12E+01			3.71E-09		3.71E-09	0.0%
1	Chromium	4.76E+01			3.89E-07		3.89E-07	0.0%
1	PAH, Total	1.57E-01	1.24E-06	1.19E-06	1.68E-11		2.43E-06	0.2%
1	Neptunium-237	1.69E+00	1.86E-07		2.89E-09	4.88E-06	5.07E-06	0.4%
1	Uranium-234	1.61E+03	1.83E-04		2.67E-06	1.38E-06	1.87E-04	14.0%
1	Uranium-235	1.03E+02	1.14E-05		1.54E-07	2.00E-04	2.12E-04	15.9%
1	Uranium-238	1.71E+03	2.13E-04		2.42E-06	6.88E-04	9.03E-04	67.8%
1	**Totals**		**4.28E-04**	**5.37E-06**	**5.64E-06**	**8.94E-04**	**1.33E-03**	
1	**Percent**		**32%**	**0%**	**0%**	**67%**		
2	Arsenic	2.12E+01	3.45E-05	7.61E-06	8.87E-09		4.22E-05	47.9%
2	Cadmium	2.01E+01			3.53E-09		3.53E-09	0.0%
2	Chromium	4.80E+01			3.92E-07		3.92E-07	0.4%
2	PAH, Total	1.69E+00	1.34E-05	1.28E-05	1.81E-10		2.63E-05	29.8%
2	Cesium-137	3.21E-01	1.72E-08		1.63E-12	2.09E-06	2.10E-06	2.4%
2	Neptunium-237	2.87E-01	3.16E-08		4.92E-10	8.29E-07	8.61E-07	1.0%
2	Uranium-234	1.22E+01	1.38E-06		2.02E-08	1.04E-08	1.41E-06	1.6%
2	Uranium-235	8.40E-01	9.32E-08		1.25E-09	1.63E-06	1.73E-06	2.0%
2	Uranium-238	2.49E+01	3.11E-06		3.52E-08	1.00E-05	1.32E-05	14.9%
2	**Totals**		**5.26E-05**	**2.05E-05**	**4.62E-07**	**1.46E-05**	**8.78E-05**	
2	**Percent**		**60%**	**23%**	**1%**	**17%**		

Table D.39. ELCRs for the Excavation Worker Exposed to Surface and Subsurface Soil

EU	COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
1	Arsenic	1.17E+01	3.80E-06	8.37E-07	9.76E-10		4.64E-06	1.7%
1	Cadmium	2.12E+01			7.42E-10		7.42E-10	0.0%
1	Chromium	4.76E+01			7.78E-08		7.78E-08	0.0%
1	PAH, Total	1.57E-01	2.49E-07	2.37E-07	3.36E-12		4.86E-07	0.2%
1	Neptunium-237	1.69E+00	3.72E-08		5.79E-10	9.76E-07	1.01E-06	0.4%
1	Uranium-234	1.61E+03	3.65E-05		5.34E-07	2.75E-07	3.73E-05	14.0%
1	Uranium-235	1.03E+02	2.29E-06		3.07E-08	4.01E-05	4.24E-05	15.9%
1	Uranium-238	1.71E+03	4.27E-05		4.84E-07	1.38E-04	1.81E-04	67.8%
1	**Totals**		**8.56E-05**	**1.07E-06**	**1.13E-06**	**1.79E-04**	**2.67E-04**	
1	**Percent**		**32%**	**0%**	**0%**	**67%**		
2	Arsenic	2.12E+01	6.91E-06	1.52E-06	1.77E-09		8.43E-06	47.6%
2	Cadmium	2.01E+01			7.05E-10		7.05E-10	0.0%
2	Chromium	4.80E+01			7.85E-08		7.85E-08	0.4%
2	PAH, Total	1.69E+00	2.69E-06	2.57E-06	3.63E-11		5.25E-06	29.7%
2	Cesium-137	3.21E-01	4.28E-09		4.05E-13	5.18E-07	5.23E-07	2.9%
2	Neptunium-237	2.87E-01	6.32E-09		9.83E-11	1.66E-07	1.72E-07	1.0%
2	Uranium-234	1.22E+01	2.77E-07		4.05E-09	2.09E-09	2.83E-07	1.6%
2	Uranium-235	8.40E-01	1.86E-08		2.51E-10	3.27E-07	3.46E-07	2.0%
2	Uranium-238	2.49E+01	6.21E-07		7.04E-09	2.00E-06	2.63E-06	14.8%
2	**Totals**		**1.05E-05**	**4.09E-06**	**9.24E-08**	**3.02E-06**	**1.77E-05**	
2	**Percent**		**59%**	**23%**	**1%**	**17%**		

Table D.40. ELCRs for the Resident Exposed to Surface Soil

EU	COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
1	Cadmium	2.12E+01			1.10E-08		1.10E-08	0.0%
1	PAH, Total	1.57E-01	1.65E-06	5.27E-06	4.95E-11		6.91E-06	0.1%
1	Neptunium-237	1.69E+00	2.67E-07		8.54E-09	2.16E-05	2.19E-05	0.5%
1	Uranium-234	1.61E+03	2.67E-04		7.88E-06	6.09E-06	2.81E-04	6.0%
1	Uranium-235	1.03E+02	1.78E-05		4.54E-07	8.87E-04	9.06E-04	19.5%
1	Uranium-238	1.71E+03	3.77E-04		7.14E-06	3.04E-03	3.43E-03	73.8%
1	**Totals**		**6.64E-04**	**5.27E-06**	**1.55E-05**	**3.96E-03**	**4.64E-03**	
1	**Percent**		**14%**	**0%**	**0%**	**85%**		
2	Arsenic	2.12E+01	4.57E-05	3.38E-05	2.62E-08		7.95E-05	36.4%
2	Cadmium	2.01E+01			1.04E-08		1.04E-08	0.0%
2	Chromium	2.91E+01			7.03E-07		7.03E-07	0.3%
2	PAH, Total	1.69E+00	1.78E-05	5.69E-05	5.36E-10		7.47E-05	34.2%
2	Neptunium-237	2.87E-01	4.53E-08		1.45E-09	3.67E-06	3.72E-06	1.7%
2	Uranium-234	1.22E+01	2.02E-06		5.97E-08	4.62E-08	2.13E-06	1.0%
2	Uranium-235	8.40E-01	1.45E-07		3.70E-09	7.24E-06	7.39E-06	3.4%
2	Uranium-238	2.49E+01	5.49E-06		1.04E-07	4.43E-05	4.99E-05	22.9%
2	**Totals**		**7.12E-05**	**9.07E-05**	**9.09E-07**	**5.53E-05**	**2.18E-04**	
2	**Percent**		**33%**	**42%**	**0%**	**25%**		

Table D.41. ELCRs for the Recreational User Exposed to Surface Soil

EU	COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
1	Cadmium	2.12E+01			1.10E-09		1.10E-09	0.0%
1	PAH, Total	1.57E-01	6.79E-07	2.44E-06	4.96E-12		3.12E-06	0.4%
1	Neptunium-237	1.69E+00	9.82E-08		8.55E-10	2.71E-06	2.80E-06	0.4%
1	Uranium-234	1.61E+03	9.82E-05		7.89E-07	7.63E-07	9.97E-05	13.4%
1	Uranium-235	1.03E+02	6.54E-06		4.54E-08	1.11E-04	1.18E-04	15.8%
1	Uranium-238	1.71E+03	1.39E-04		7.15E-07	3.81E-04	5.20E-04	70.0%
1	**Totals**		**2.44E-04**	**2.44E-06**	**1.55E-06**	**4.96E-04**	**7.44E-04**	
1	**Percent**		**33%**	**0%**	**0%**	**67%**		
2	Arsenic	2.12E+01	1.89E-05	1.56E-05	2.62E-09		3.45E-05	44.2%
2	Cadmium	2.01E+01			1.04E-09		1.04E-09	0.0%
2	Chromium	2.91E+01			7.04E-08		7.04E-08	0.1%
2	PAH, Total	1.69E+00	7.34E-06	2.64E-05	5.36E-11		3.37E-05	43.2%
2	Neptunium-237	2.87E-01	1.67E-08		1.45E-10	4.59E-07	4.76E-07	0.6%
2	Uranium-234	1.22E+01	7.44E-07		5.98E-09	5.78E-09	7.56E-07	1.0%
2	Uranium-235	8.40E-01	5.33E-08		3.70E-10	9.06E-07	9.59E-07	1.2%
2	Uranium-238	2.49E+01	2.02E-06		1.04E-08	5.55E-06	7.58E-06	9.7%
2	**Totals**		**2.91E-05**	**4.20E-05**	**9.10E-08**	**6.92E-06**	**7.81E-05**	
2	**Percent**		**37%**	**54%**	**0%**	**9%**		

D.5.3.1 Systemic Toxicity (Direct Exposure to Soil)

Tables D.25 through D.34 summarize the computed HIs for soil exposure for each receptor. Total HIs greater than 1 were observed for the following scenarios by SWMU 229:

- Outdoor Worker (exposed to surface soil),
- Outdoor Worker (exposed to surface and subsurface soil),
- Excavation Worker,
- Future Hypothetical Child Residential Receptor, and
- Child Recreational User.

D.5.3.2 Excess Lifetime Cancer Risk (Direct Exposure to Soil)

Tables D.35 through D.41 summarize the computed lifetime cancer risks for soil exposure for all receptors from all COPCs (including radionuclides). ELCRs greater than 1E-06 were observed for the receptors listed below. Total ELCRs greater than 1E-04 are shown in italicized font.

- Industrial Worker (current),
- *Industrial Worker (future)*,
- *Outdoor Worker (exposed to surface soil)*,
- *Outdoor Worker (exposed to surface and subsurface soil)*,
- *Excavation Worker*,
- *Future Hypothetical Residential Receptor*, and
- *Recreational User*.

D.5.4 RISK CHARACTERIZATION FOR RESIDENTIAL USE OF GROUNDWATER DRAWN FROM THE RGA (MODELED FROM SOIL CONCENTRATIONS)

This subsection presents the risk for residential use of groundwater drawn from the RGA. Tables and discussion in this subsection provide the total HI or ELCR for the each source area and list the major exposure routes and COPCs contributing to the total HI or ELCR. Environmental data for each source area was used to model groundwater concentrations at the POEs (see Appendix C for details of the groundwater modeling). The groundwater assessment is conducted only for the residential scenario. Characterization of risks from groundwater at off-site POEs (plant boundary, property boundary, and Ohio River) are discussed in Section D.3.4.2.

D.5.4.1 Systemic Toxicity (Groundwater Use)

Technetium-99 from SWMU 229 is present in soils at concentrations that required modeling to determine if it was at concentrations that could migrate to the RGA to exceed 900 pCi/L. Results of modeling indicate technetium-99 does not exceed 900 pCi/L at the SWMU boundary. Further, the technetium-99 plume at PGDP does not indicate a contribution from SWMU 229 (LATA KY 2015). Technetium-99 does not contribute to hazard; therefore, it is not summarized here.

D.5.4.2 Excess Lifetime Cancer Risk (Groundwater Use)

Table D.42 summarizes the ELCRs for the modeled groundwater exposure above SWMU 229 for the rural resident. The EPC is taken from the modeled activity at the SWMU boundary (i.e., 340 pCi/L, see Appendix C). As shown in the table, the total ELCR (bold value in "ELCR" column) is 1.8E-05, so technetium-99 is a COC for the units.

Table D.42. ELCRs for the Resident Exposed to Groundwater (Modeled Concentrations)

COPC	EPC (pCi/L)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
Technetium-99	3.40E+02	1.79E-05				**1.8E-05**	100.0%

D.5.5 LEAD ASSESSMENT

SWMU 229 did not identify lead as a COPC because the maximum detected result for each grid was below the residential screening value of 400 mg/kg. Because lead was not identified as a COPC, lead is not considered a COC.

D.5.6 DOSE ASSESSMENT

A dose assessment was performed for radionuclides (separate from the ELCR evaluation) selected as COPCs within each SWMU/EU (Section D.2). Calculation of dose was performed using the following equation and screening values provided in the Risk Methods Document (DOE 2015a):

$$\mathbf{Dose} = \frac{\mathbf{EPC}}{\mathbf{SSL}} \times \mathbf{Target\,Dose}$$

where:

EPC = exposure point concentration
SSL = soil screening level provided in the Risk Methods Document (DOE 2015a, Table A.8)
Target Dose = The target dose upon which the SSL was based (1 mrem)

Tables D.43 and D.44 provide the results of the dose assessment.

Dose greater than 12 mrem were observed for the following pathways for SWMU 229:

- Industrial Worker (future),
- Outdoor Worker (exposed to surface soil),
- Outdoor Worker (exposed to surface and subsurface soil),
- Excavation Worker,
- Future Hypothetical Adult Residential Receptor,
- Future Hypothetical Child Residential Receptor,
- Adult Recreational User,
- Teen Recreational User, and
- Child Recreational User.

D.5.7 IDENTIFICATION OF LAND USE SCENARIOS, PATHWAYS, MEDIA, AND COCS

This subsection outlines those chemicals, land use scenarios, exposure pathways, and media for each source area. Section D.8 presents the RGOs for each location and land use scenario.

D.5.7.1 Land Use Scenarios of Concern

To make a determination whether land use scenarios are of concern, quantitative risk and hazard results were compared to risk and hazard benchmarks for each land use scenario. The benchmarks used for this comparison were HI $\geq$ 1 and/or ELCR $\geq$ 1E-06. Land use scenarios with total HIs exceeding the benchmark of 1 are deemed land use scenarios of concern for noncancer hazard. Land use scenarios with a total ELCR exceeding the benchmark of 1E-06 are deemed land use scenarios of concern for cancer risk. The following are land uses of concern for SWMU 229.

- Industrial Worker (current) (ELCR),
- Industrial Worker (future) (ELCR),
- Outdoor Worker (exposed to surface soil) (HI and ELCR),
- Outdoor Worker (exposed to surface and subsurface soil) (HI and ELCR),
- Excavation Worker (HI and ELCR),
- Future Hypothetical Residential Receptor (for HI, the child resident exposure assumptions are shown; for ELCR, the dose method incorporates age-adjusted values for the 30-year exposure duration), and
- Child Recreational User (HI and for ELCR, the dose method incorporates age-adjusted values for the 30-year exposure duration).

Table D.43. Surface Soil Dose Assessment for SWMU 229

			Dose (mrem/yr)						
EU	**COPC**	**EPC (pCi/g)**	**Future Industrial Worker**	**Outdoor Worker (Exposed to Surface Soil)**	**Adult Resident**	**Child Resident**	**Adult Recreator**	**Teen Recreator**	**Child Recreator**
1	Neptunium-237	1.69E+00	0.3	0.3	1.0	1.0	0.1	0.1	0.1
1	Uranium-234	1.61E+03	4.2	26.3	10.8	37.7	0.7	1.4	3.3
1	Uranium-235	1.03E+02	13.3	11.3	41.7	43.3	4.3	5.8	5.9
1	Uranium-238	1.71E+03	41.7	55.5	129.5	159.8	13.0	17.8	20.1
1	**Totals**		**59.5**	**93.4**	**183.1**	**241.8**	**18.1**	**25.2**	**29.4**
2	Neptunium-237	2.87E-01	0.1	0.0	0.2	0.2	0.0	0.0	0.0
2	Uranium-234	1.22E+01	0.0	0.2	0.1	0.3	0.0	0.0	0.0
2	Uranium-235	8.40E-01	0.1	0.1	0.3	0.4	0.0	0.0	0.0
2	Uranium-238	2.49E+01	0.6	0.8	1.9	2.3	0.2	0.3	0.3
2	**Totals**		**0.8**	**1.1**	**2.5**	**3.1**	**0.2**	**0.3**	**0.4**

Table D.44. Subsurface Soil Dose Assessment for SWMU 229

EU	COPC	EPC (pCi/g)	Dose (mrem/yr)	
			Outdoor Worker (Exposed to Surface and Subsurface Soil)	Excavation Worker
1	Neptunium-237	1.69E+00	0.3	0.3
1	Uranium-234	1.61E+03	26.3	26.3
1	Uranium-235	1.03E+02	11.3	11.3
1	Uranium-238	1.71E+03	55.5	55.5
1	**Totals**		**93.4**	**93.4**
2	Cesium-137	3.21E-01	0.1	0.1
2	Neptunium-237	2.87E-01	0.0	0.0
2	Uranium-234	1.22E+01	0.2	0.2
2	Uranium-235	8.40E-01	0.1	0.1
2	Uranium-238	2.49E+01	0.8	0.8
2	**Totals**		**1.3**	**1.3**

D.5.7.2 Contaminants of Concern

To make a determination about whether contaminants are of concern, quantitative risk and hazard results over all pathways were compared to risk and hazard benchmarks for land use scenarios of concern. The benchmarks used for this comparison were HI ≥ 0.1 and/or ELCR ≥ 1E-06. COCs based on the toxicity factors listed in Attachment D2 are shown in summary tables in Section D.5.7.6.

Contaminants with chemical-specific HIs or ELCRs exceeding these benchmarks were deemed COCs. Priority COCs are contaminants where chemical-specific HI is greater than 1 or where ELCR is greater than 1E-04 for one or more scenarios. These priority COCs can be found in the summary tables in Section D.5.7.6.

D.5.7.3 Contaminants of Concern (Groundwater—Modeled from Soil)

Similarly, no priority COCs were identified (i.e., contaminants whose chemical-specific HI is greater than 1 or whose ELCR is greater than 1E-04) for domestic use of groundwater for a hypothetical future residential use of the SWMU.

D.5.7.4 Pathways of Concern

To determine whether pathways are of concern, the quantitative risks and hazards for each exposure route are summed over all contaminants and compared to benchmarks for land use scenarios of concern. The benchmarks used for this comparison were HI ≥ 0.1 and/or ELCR ≥ 1E-06. Exposure routes with HIs and ELCRs exceeding these benchmarks are considered pathways of concern (POCs). Each of the pathways included in the BHHRA is a POC for at least one SWMU.

D.5.7.5 Media of Concern

Media of concern are those media that appear in at least one POC. Because they contribute to at least one POC, soil is a medium of concern for SWMU 229.

Though not quantified in this evaluation, UCRS groundwater could pose as a medium of concern under certain exposure scenarios; however, these risks were not quantified due to the high improbability of the UCRS at SWMU 229 being used as a drinking water aquifer [see Section 3.3.4.3 of the Risk Methods Document (DOE 2015a)].

D.5.7.6 Summary of Risk Characterization

Tables D.45 and D.46 present summaries of the risk characterization by location considered in the BHHRA. They present land use scenarios of concern, COCs, and POCs. In addition, each table lists the following:

- Receptor risks for each land use scenario of concern;
- Percent contribution by pathway to the total risk; and
- Percent contribution each COC contributes to the total risk.

Table D.45. Summary of Risk Characterization for SWMU 229, EU 1

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Current Industrial Worker (surface soil)	**7.14E-05**	Uranium-234 Uranium-235 Uranium-238	2% 21% 76%	Ingestion Dermal Inhalation External exposure	5% < 1% 95%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Industrial Worker (surface soil)	**1.27E-03**	PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	0% 1% 2% 21% 76%	Ingestion Dermal Inhalation External exposure	5% 0% < 1% 95%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Outdoor Worker (surface soil)	**1.31E-03**	PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	0% 0% 14% 16% 69%	Ingestion Dermal Inhalation External exposure	31% 0% 0% 68%	**1.38**	Antimony Uranium	82% 11%	Ingestion Dermal Inhalation	99% 1% 0%
Outdoor Worker (surface and subsurface soil)	**1.33E-03**	Arsenic PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	2% 0% 0% 14% 16% 68%	Ingestion Dermal Inhalation External exposure	32% 0% 0% 67%	**1.61**	Antimony Arsenic Uranium	70% 9% 10%	Ingestion Dermal Inhalation	97% 3% 0%
Excavation Worker (surface and subsurface soil)	**2.67E-04**	Arsenic Neptunium-237 Uranium-234 Uranium-235 Uranium-238	2% 0% 14% 16% 68%	Ingestion Dermal Inhalation External exposure	32% 0% 0% 67%	**1.61**	Antimony Arsenic Uranium	70% 9% 10%	Ingestion Dermal Inhalation	97% 3% 0%
Future Adult Resident (surface soil)	**4.64E-03**	PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	0% 0% 6% 20% 74%	Ingestion Dermal Inhalation External exposure	14% 0% 0% 85%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Child Resident (surface soil)	See Future Adult Resident					**5.88**	Antimony Cadmium Uranium	82% 7% 11%	Ingestion Dermal Inhalation	98% 2% 0%

Table D.45. Summary of Risk Characterization for SWMU 229, EU 1 (Continued)

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Future Adult Recreational User (surface soil)	**7.44E-04**	PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	0% 0% 13% 16% 70%	Ingestion Dermal Inhalation External exposure	33% 0% 0% 67%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Teen Recreational User (surface soil)	See Future Adult Recreational User					**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Child Recreational User (surface soil)	See Future Adult Recreational User					**2.35**	Antimony Cadmium Uranium	82% 7% 11%	Ingestion Dermal Inhalation	98% 2% 0%

Total ELCR and total HI represent total risk or hazard summed across all routes of exposure for all COPCs.
*No COCs = There are no COCs.
ELCR for Future Adult Resident and Future Child Resident are the combined lifetime scenario.
ELCR for Future Adult Recreational User, Future Teen Recreational User, and Future Child Recreational User are the combined lifetime scenario.

Table D.46. Summary of Risk Characterization for SWMU 229, EU 2

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Current Industrial Worker (surface soil)	**2.93E-06**	PAH, Total	37%	Ingestion Dermal Inhalation External exposure	14% 53% 1% 32%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Industrial Worker (surface soil)	**5.23E-05**	Arsenic PAH, Total Neptunium-237 Uranium-235 Uranium-238	29% 37% 2% 4% 27%	Ingestion Dermal Inhalation External exposure	14% 53% 1% 32%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Outdoor Worker (surface soil)	**8.57E-05**	Arsenic PAH, Total Uranium-234 Uranium-235 Uranium-238	49% 31% 2% 2% 15%	Ingestion Dermal Inhalation External exposure	61% 24% 0% 15%	**1.24**	Antimony Arsenic	66% 21%	Ingestion Dermal Inhalation	95% 5% 0%
Outdoor Worker (surface and subsurface soil)	**8.78E-05**	Arsenic PAH, Total Cesium-137 Uranium-234 Uranium-235 Uranium-238	48% 30% 2% 2% 2% 15%	Ingestion Dermal Inhalation External exposure	60% 23% 1% 17%	**1.31**	Antimony Arsenic	63% 20%	Ingestion Dermal Inhalation	95% 5% 0%
Excavation Worker (surface and subsurface soil)	**1.77E-05**	Arsenic PAH, Total Uranium-238	48% 30% 15%	Ingestion Dermal Inhalation External exposure	59% 23% 1% 17%	**1.31**	Antimony Arsenic	63% 20%	Ingestion Dermal Inhalation	95% 5% 0%
Future Adult Resident (surface soil)	**2.18E-04**	Arsenic PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	37% 34% 2% 1% 3% 23%	Ingestion Dermal Inhalation External exposure	33% 42% 0% 25%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Child Resident (surface soil)	See Future Adult Resident					**5.39**	Antimony Arsenic Cadmium Uranium	64% 23% 7% 6%	Ingestion Dermal Inhalation	92% 8% 0%

Table D.46. Summary of Risk Characterization for SWMU 229, EU 2 (Continued)

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Future Adult Recreational User (surface soil)	**7.81E-05**	Arsenic PAH, Total Uranium-238	44% 43% 10%	Ingestion Dermal Inhalation External exposure	37% 54% 0% 9%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Teen Recreational User (surface soil)	See Future Adult Recreational User					**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Child Recreational User (surface soil)	See Future Adult Recreational User					**2.15**	Antimony Arsenic Cadmium Uranium	64% 23% 7% 6%	Ingestion Dermal Inhalation	92% 8% 0%

Total ELCR and total HI represent total risk or hazard summed across all routes of exposure for all COPCs.
*No COCs = There are no COCs.
ELCR for Future Adult Resident and Future Child Resident are the combined lifetime scenario.
ELCR for Future Adult Recreational User, Future Teen Recreational User, and Future Child Recreational User are the combined lifetime scenario.

D.6. UNCERTAINTY IN THE RISK ASSESSMENT

Uncertainties are associated with each step of the risk assessment process. The potential effect of the uncertainties on the final risk characterization must be considered when interpreting the results of the risk characterization because a number of assumptions are made during the risk assessment. Types of uncertainties to consider are divided into four broad categories: (1) those associated with data, (2) exposure assessment, (3) toxicity assessment, and (4) risk characterization.

Specific uncertainties in each of these categories are discussed in the following sections. Magnitude of the effect of the uncertainty on the risk characterization is categorized as small, moderate, or large. Uncertainties categorized as small are assumed to not affect the risk estimates by more than one order of magnitude; those categorized as moderate are assumed to affect the risk estimates by between one and two orders of magnitude, and uncertainties categorized as large are assumed to affect the risk estimate by more than two orders of magnitude.

In evaluating these uncertainties and their estimated effect on the risk estimates, it should be remembered that the following uncertainties are neither independent nor mutually exclusive; therefore, the total effect of all uncertainties on the risk estimates (i.e., total ELCRs and HIs) is not necessarily the sum of the estimated effects.

D.6.1 UNCERTAINTIES ASSOCIATED WITH DATA AND DATA EVALUATION

The purpose of data evaluation is to determine which constituents, if any, are present at concentrations requiring evaluation in the risk assessment. Uncertainty with respect to data evaluation can arise from many sources, such as the quality of data used to characterize the site and the process used to select data and COPCs used in the risk assessment.

Since many of the detection limits for XRF data are above background concentrations (see Appendix B) and possibly NALs, the COPCs identified using these data are expected to overstate the presence of these metals. The potential uncertainty associated with this issue is small.

COPCs were selected for each EU for those analytes that were detected above background and where maximum detected value is greater than the no action level [Risk Methods Document (DOE 2015a) for the child residential scenario]. For those analytes that never were detected within an EU, even if the detection limit is greater than the no action level, the analyte was not considered a COPC. Uncertainties are associated with this assumption. To assist in evaluating this uncertainty, the maximum detection limit was used as an EPC and hazard and ELCR calculated for the nondetected analyses. Attachment D4 presents the results of these calculations. The potential uncertainty associated with this assumption is small.

The use of historical data in addition to data collected during the RI is an uncertainty. As noted earlier, these data were added to the data set to augment the information collected during the RI. Use of these data is consistent with current EPA guidelines (EPA 1989). No statistical determination was performed to see if historical data and data collected during the remedial investigation were comparable; however, the estimated effect of this uncertainty on this risk assessment is assumed to be small.

The full range of background was not considered beyond the initial screening against site-specific background. Further, surface soil background levels were used for all but the outdoor worker (exposed to

surface and subsurface soil) and the excavation worker, where subsurface soil background levels were used for screening to determine COPCs. If sample data used in determining COPCs for the outdoor worker (exposed to surface and subsurface soil) and the excavation worker actually were collected from the surface, the inappropriate background value was used for comparison. The potential uncertainty associated with this assumption is small.

Some SQLs for the data are above screening levels. Since nondetect results were used at their SQL in determining EPCs, the potential uncertainty for the high SQL is small.

D.6.2 UNCERTAINTIES ASSOCIATED WITH EXPOSURE ASSESSMENT

Uncertainties associated with dermal absorption have been included in Section 6.5.

Significant uncertainty exists in the exposure assumptions used to calculate chemical intakes from exposure to various media (e.g., rate of soil ingestion, frequency and duration of exposure, absorption through the skin). Conservative (i.e., health protective) exposure factors are used when information available is limited in the form of using RME exposure assumptions as per the draft update of the Risk Methods Document (DOE 2015a). This may result in an overestimation of potential ELCRs and HIs; this potential uncertainty is moderate.

D.6.3 UNCERTAINTIES ASSOCIATED WITH TOXICITY ASSESSMENT

Uncertainty is involved in characterizing EPCs for environmental media under future conditions in this BHHRA. In calculating the EPCs at SWMU 229, the concentrations of COPCs are kept constant throughout the exposure period. That is, the risk assessment does not consider that concentrations of some COCs may be lower or higher in the future because of processes such as degradation and attenuation. Because the COCs driving risk at SWMU 229 is not expected to degrade significantly throughout a lifetime, the effect of this uncertainty is estimated to be small.

A second uncertainty is the potential risk that may develop as COPCs in media at SWMU 229 migrate to groundwater below the SWMU and are transported off-site. To address this uncertainty, results from a fate and transport model were used to estimate potential contributions from SWMU 229 to a POE for groundwater exposure away at the source boundary (see Appendix C). While the modeling estimated contaminant transport though groundwater based on contaminant concentrations in the surrounding soil, uncertainty still exists in the POE at which exposure may occur in the future and the contaminant mass that is present in the source areas contributing to the future groundwater concentrations of contaminants. These uncertainties are discussed in Appendix C. Generally, the estimated effect for most of the modeling uncertainties is moderate to small, indicating that the ELCR and HI estimates generated using the modeled concentrations can be expected to vary by less than an order of magnitude.

Additional information regarding uncertainties associated with toxicity assessment can be found in Section D.4.2.

D.6.4 UNCERTAINTIES ASSOCIATED WITH RISK CHARACTERIZATION

The potential risk of adverse health effects is characterized based on potential exposures to COPCs and potential dose-response relationships for the COPCs. Two important additional sources of uncertainty are introduced in this phase of the BHHRA: (1) the evaluation of potential simultaneous exposure to multiple

chemicals and (2) the combination of upper-bound exposure estimates with upper-bound toxicity estimates.

As prescribed by the Risk Methods Document (DOE 2015a), after potential exposures and potential risks from each COPC are calculated, the total potential upper-bound risk and HI associated with each receptor scenario are calculated by combining the estimated potential health risk from each COPC for each scenario. For virtually all combinations of chemicals, little if any evidence of interaction is available, and synergistic/antagonistic effects and magnitude of effects cannot be addressed; therefore, additivity is assumed. For noncarcinogenic effects, this is equivalent to the assumption of simple similar action. Whether assuming additivity can lead to an underestimation or overestimation of risk is unknown. The general consensus is that the effect of this uncertainty is small to moderate.

Additionally, some uncertainty is associated with adding risks from chemical exposure to those from exposure to radionuclides. Because SWMU 229 has multiple chemicals and radionuclides driving risk and these COCs have differing endpoints, the effect of this uncertainty could be moderate.

Though not quantified in this evaluation, UCRS groundwater could pose as a medium of concern under certain exposure scenarios; however, these risks were not quantified due to the high improbability of the UCRS at SWMU 229 being used as a drinking water aquifer (DOE 2015a).

D.6.5 UNCERTAINTIES ASSOCIATED WITH DERMAL ABSORPTION

Due to the circumstances presented in Section D.4.2.1, Development of Dermal Toxicity Factors, Attachment D5 has been developed. Attachment D5 presents summaries of the risk characterization by location considered for metals in the BHHRA, as an analysis using an alternative approach to that described in the Risk Methods Document to incorporate recent guidance. The alternative approach considers dermal absorption for all metals because RAGS Part E lists ABS values for all metals except arsenic and cadmium as zero. The summaries presented in Attachment D5 are similar to those presented in Tables D.44 and D.45. They present land use scenarios of concern, COCs, and POCs. In addition, each table lists the following:

- Receptor risks for each land use scenario of concern;
- Percent contribution by pathway to the total risk; and
- Percent contribution each COC contributes to the total risk.

Because the effects of this uncertainty are large, they have been considered further in selection of COCs. This COCs selection is provided in Section D.7.4.2.

D.6.6 SUMMARY OF UNCERTAINTIES

The large number of assumptions used in the risk assessment could introduce a great deal of uncertainty. While it is theoretically possible that this leads to underestimates of potential risk, the use of numerous upper-bound assumptions most likely results in conservative estimates of potential risks. Any individual's potential exposure and subsequent potential risk are influenced by their individual exposure and toxicity parameters and will vary on a case-by-case basis. Despite inevitable uncertainties associated with the steps used to derive potential risks, the use of numerous health-protective assumptions most likely will result in a protective estimate of potential health risks for receptors that could be exposed to site contaminants at EUs evaluated in this Soils OU RI 2 Addendum.

D.7. CONCLUSIONS

This section summarizes the results of the BHHRA and draws conclusions from the results. The primary purpose of this section is to provide a concise summary of each of the BHHRA steps without the use of tables, extensive explanations, or justifications. This section also includes a series of observations in which the results of the BHHRA are combined with the uncertainties in the risk assessment.

D.7.1 CHEMICALS OF POTENTIAL CONCERN

COPCs were selected from soil data collected in the Soils OU RI 2 and historical data from the OREIS database. This data set was screened to produce final COPCs lists aggregated by location.

Through a series of screening steps, which follow the Risk Methods Document (DOE 2015a) and other regulatory agency approved procedures, the data sets were reduced to lists of COPCs for SWMU 229.

D.7.2 EXPOSURE ASSESSMENT

Historical information and newly collected data were used to develop a CSM. After consideration of the available data and scope of the SI, the potential receptor population under current conditions at the source units is industrial workers, and the potential receptor populations under future conditions are industrial workers, excavation workers, and residents.

Industrial Worker

Incidental ingestion of surface soil
Dermal contact with surface soil
Inhalation of vapors emitted by surface soil
External exposure to ionizing radiation in surface soil

Outdoor Worker Exposed to Surface Soil

Incidental ingestion of surface soil
Dermal contact with surface soil
Inhalation of vapors emitted by surface soil
External exposure to ionizing radiation in surface soil

Outdoor Worker and Excavation Worker Exposed to Surface and Subsurface Soil

Incidental ingestion of surface and subsurface soil
Dermal contact with surface and subsurface soil
Inhalation of vapors emitted by surface and subsurface soil
External exposure to ionizing radiation in surface and subsurface soil

Future Rural Resident

Incidental ingestion of surface soil
Dermal contact with surface soil
Inhalation of vapors emitted by surface soil

External exposure to ionizing radiation in surface soil
Ingestion of groundwater
Dermal contact with groundwater while showering
Inhalation of vapors emitted by groundwater during household use/showering and
Inhalation of vapors indoors from transport from subsurface VOCs

Recreational User

Incidental ingestion of surface soil
Dermal contact with surface soil
Inhalation of vapors emitted by surface soil
External exposure to ionizing radiation in surface soil

After selection of the exposure routes, CDIs were calculated using standard exposure models. Most parameters used in models were default values.

D.7.3 TOXICITY ASSESSMENT

The toxicity values used in the risk assessment were taken from the draft update of the Risk Methods Document (DOE 2015a), except as noted within this BHHRA. After compiling toxicity information, the determination was made that the majority of the COPCs had a toxicity value available for one or more routes of exposure (see Section D.3.5.2).

D.7.4 RISK CHARACTERIZATION

Quantitative risks were computed by integrating the CDIs tabulated from the exposure assessment and toxicity values calculated from the toxicity assessment. The quantitative risks indicate elevated risks associated with exposure to subsurface soil, surface soil, and groundwater exposure. Significant findings are summarized below.

D.7.4.1 Land Use Scenarios of Concern

A list of land uses of concern for SWMU 229 is shown in Section D.5.7.1. The list shows that each land use is a concern.

D.7.4.2 Contaminants of Concern for Soil

To determine use scenarios of concern, risk characterization results for cumulative systemic toxicity (HI) and cumulative risk (ELCR) are compared to benchmarks of 1.0 and 1E-06, respectively. Use scenarios with cumulative HI or cumulative ELCR exceeding either of these benchmarks is deemed use scenarios of concern. To make a determination about whether contaminants are of concern, quantitative risk and hazard results over all pathways were compared to risk and hazard benchmarks for land use scenarios of concern, with the alternative evaluation approach described in Section D.6.5 considered. The benchmarks used for this comparison were (a) 0.1 for a chemical-specific HQ and (b) 1E-06 for a chemical-specific ELCR.

In the subsections that follow, all COPCs are listed that meet the benchmarks above in the HI and ELCR calculations (Tables D.24–D.33 and D.34–D.40, respectively). After considering this list, including an evaluation of additional potential COCs based on dermal absorption assumptions (see Section D.6.5 and

Attachment D5), contaminants with chemical-specific HQs or ELCRs exceeding these benchmarks were deemed COCs.

Priority COCs are identified to highlight those COCs contributing most to cumulative HI and ELCR for each SWMU 229 EU. Priority COCs are contaminants deemed COCs where chemical-specific HQ is greater than 1 or where chemical-specific ELCR is greater than 1E-04 for one or more scenarios. The priority COCs found in soil at SWMU 229 are summarized in the subsections that follow.

The chemical-specific benchmark for ELCR is set at 1E-06; however, many of the COPCs listed in Appendix D, Tables D.34 through D.40, correspond to individual risks less than 1E-06 for the particular receptor evaluated. Nevertheless, these individual risk values are summed to get the cumulative risk values shown in these tables, as well as in Tables D.44 and D.45 and Attachment D5.

As calculated and shown in Tables D.44 and D.45, COCs for all exposure scenarios for SWMU 229 include those listed below. Uncertainty calculations, shown in Attachment D5, did not support addition of any COCs to the SWMU.

In SWMU 229 surface soil, COCs for systemic toxicity are the metals antimony, arsenic, cadmium, and uranium; COCs for ELCR include Total PAHs, arsenic, neptunium-237, uranium-234, uranium-235, and uranium-238. In subsurface soil, COCs are Total PAHs, antimony, arsenic, uranium, cesium-137, neptunium-237, uranium-234, uranium-235, uranium-238. The entire list of COCs is provided with the RGOs in Section D.8.

Priority COCs are located in both EUs. These include the following:

- *Future Industrial Worker:* uranium-235, uranium-238;
- *Outdoor Worker (exposed to surface soil):* antimony, uranium-234, uranium-235, uranium-238;
- *Outdoor Worker (exposed to surface and subsurface soil):* antimony, uranium-234, uranium-235, uranium-238;
- *Excavation Worker:* antimony, uranium-234, uranium-238;
- *Future Hypothetical Residential Receptor:* antimony, arsenic, uranium-234, uranium-235, uranium-238; and
- *Recreational User:* antimony, uranium-235, uranium-238.

D.7.4.3 Contaminants of Concern for Soils Potentially Contributing to Groundwater Contamination

Similarly for soil potentially contributing to groundwater contamination, to determine whether modeled concentrations of contaminants are of concern, quantitative risk and hazard results over all pathways were compared to risk and hazard benchmarks for land use scenarios of concern. The benchmarks used for this comparison were HI $\geq$ 0.1 and/or ELCR $\geq$ 1E-06 for ELCR.

“Priority COCs” are identified in this section as an aid to risk managers during decision making.

There were no priority COCs identified above in this risk assessment are based on the modeled groundwater concentrations at all POEs.

D.7.4.4 Pathways of Concern

Each of the pathways included in the BHHRA is a POC.

D.7.4.5 Media of Concern

Media of concern are those media that appear in at least one POC. Because they contribute to at least one POC, soil is a media of concern at SWMU 229.

D.7.5 OBSERVATIONS

Consistent with regulatory guidance and agreements contained in the Risk Methods Document (DOE 2015a), this BHHRA presents ELCRs and HIs for land use scenarios representing current use, as well as for several hypothetical future uses. Risk evaluation of surface soil was conducted for SWMU 229 as part of the evaluation of the scenarios specified in the work plan. The scenarios described in the BHHRA are as follows:

- Current industrial use (e.g., site maintenance)—direct contact with surface soil (soil 0 to 1 ft bgs).
- Future on-site industrial use—direct contact with surface soil (soil 0 to 1 ft bgs).
- On-site outdoor use—direct contact with surface soil (soil 0 to 1 ft bgs).
- Off-site outdoor use—direct contact with surface and subsurface soil (soil 0 to 16 ft bgs).
- On-site excavation worker—direct contact with surface and subsurface soil (soil 0 to 16 ft bgs).
- Future hypothetical on-site rural resident—direct contact with surface soil (soil 0 to 1 ft bgs) and use of groundwater drawn from the RGA at source areas.
- Recreational use—direct contact with surface soil (soil 0 to 1 ft bgs).

Specific observations for this BHHRA are presented in Tables D.47 and D.48.

Table D.47. Summary of Direct Contact Risks for SWMU 229

			Direct Contact*	
EU	Scenario	Total HI	Total ELCR	Total Dose (mrem/yr)
1	Future Industrial Worker	< 1	***1.3E-03***	59.5
2	Future Industrial Worker	< 1	**5.2E-05**	0.8

Bold indicates total HI > 1 or total ELCR > 1E-06; ***bold italics*** indicates total HI > 3 or total ELCR > 1E-04.
*For direct contact, future industrial worker is presented because SWMU 229 is inside the limited area. Total HI and Total ELCR represent the cumulative value across all exposure routes assessed within this BHHRA (i.e., incidental ingestion, dermal contact, inhalation, and external exposure to ionizing radiation).
Only total dose above 0.1 mrem/year is summarized.

Table D.48. Summary of RGA Groundwater Risks for SWMU 229

SWMU	Scenario	RGA Groundwater Exposure* Total HI	Total ELCR
229	Resident	N/A	**1.79E-05**

For the SWMU, the ELCR for the modeled groundwater concentrations from above the SWMU is presented.
Bold indicates ELCR > 1E-06; ***bold italics*** indicates ELCR > 1E-04.
N/A = no risks/hazards are applicable for the SWMU.
*For RGA groundwater exposure to radionuclides, ingestion is included. The combined lifetime exposure is presented for the resident.

D.8. REMEDIAL GOAL OPTIONS

This section presents RGOs for the COCs identified in this BHHRA and the methods used to calculate the RGOs. These RGOs should not be interpreted as being clean-up goals, but as risk-based values that may be used to guide the development of clean-up goals by risk managers. Cleanup goals will be determined in later decision documents.

RGOs were calculated for each COC based on targets presented in the Risk Methods Document (DOE 2015a) and consistent with EPA guidance (EPA 2014). Target risks for the RGOs were 1E-04, 1E-05, and 1E-06. Target hazards were 0.1, 1, and 3. Additionally for dose, RGOs were calculated for 1, 12, and 25 mrem/yr, based on benchmarks presented in the Risk Methods Document (DOE 2015a). When calculating the HI-based RGOs, the more conservative child-based values are reported.

D.8.1 CALCULATION OF RGOS

EPA guidance directs that RGOs are to be calculated for all COCs identified in a BHHRA (EPA 1991). The COCs identified in this risk assessment and their RGOs are presented in Tables D.48 and D.49. These COCs were calculated using the following equation:

$$\frac{\textbf{Concentration}}{\textbf{Risk}} = \frac{\textbf{RGO}}{\textbf{Target Risk}}$$

where:

Concentration is the exposure concentration for the medium.
Risk is the risk posed by exposure to the contaminated medium.
RGO is the RGO.
Target Risk is one of the values listed in Tables D.48 and D.49.

D.8.2 PRESENTATION OF RGOS

The equation developed in the previous subsection was applied for each soil COC. The RGOs developed for all COCs using this equation are presented in Table D.49. Grayed cells in Table D.49 indicate the EPC value is higher than the RGO value, or an RGO value is not applicable. RGOs for dose are presented in Table D.50.

Table D.49. RGOs for SWMU 229

EU	COC	EPC	Units	ELCR	RGO at ELCR=1E-6	RGO at ELCR=1E-5	RGO at ELCR=1E-4	HI	RGO at HI=0.1	RGO at HI=1	RGO at HI=3
Industrial Worker Soil Exposure											
1	PAH, Total	1.57E-01	mg/kg	1.8E-06	8.81E-02	8.81E-01	8.81E+00	N/A	N/A	N/A	N/A
1	Neptunium-237	1.69E+00	pCi/g	6.6E-06	2.55E-01	2.55E+00	2.55E+01	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	3.1E-05	5.16E+01	5.16E+02	5.16E+03	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	2.7E-04	3.78E-01	3.78E+00	3.78E+01	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	9.6E-04	1.78E+00	1.78E+01	1.78E+02	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	1.9E-05	8.81E-02	8.81E-01	8.81E+00	N/A	N/A	N/A	N/A
2	Arsenic	2.12E+01	mg/kg	1.5E-05	1.40E+00	1.40E+01	1.40E+02	< 0.1	N/A	N/A	N/A
2	Neptunium-237	2.87E-01	pCi/g	1.1E-06	2.55E-01	2.55E+00	2.55E+01	N/A	N/A	N/A	N/A
2	Uranium-235	8.40E-01	pCi/g	2.2E-06	3.78E-01	3.78E+00	3.78E+01	N/A	N/A	N/A	N/A
2	Uranium-238	2.49E+01	pCi/g	1.4E-05	1.78E+00	1.78E+01	1.78E+02	N/A	N/A	N/A	N/A
Outdoor Worker Surface Soil Exposure											
1	PAH, Total	1.57E-01	mg/kg	2.4E-06	6.45E-02	6.45E-01	6.45E+00	N/A	N/A	N/A	N/A
1	Antimony	1.50E+02	mg/kg	N/A	N/A	N/A	N/A	1.1	1.32E+01	1.32E+02	3.95E+02
1	Uranium	1.56E+02	mg/kg	N/A	N/A	N/A	N/A	0.2	9.80E+01	9.80E+02	2.94E+03
1	Neptunium-237	1.69E+00	pCi/g	5.1E-06	3.33E-01	3.33E+00	3.33E+01	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	1.9E-04	8.62E+00	8.62E+01	8.62E+02	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	2.1E-04	4.86E-01	4.86E+00	4.86E+01	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	9.0E-04	1.89E+00	1.89E+01	1.89E+02	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	2.6E-05	6.45E-02	6.45E-01	6.45E+00	N/A	N/A	N/A	N/A
2	Antimony	1.08E+02	mg/kg	N/A	N/A	N/A	N/A	0.8	1.32E+01	1.32E+02	3.95E+02
2	Arsenic	2.12E+01	mg/kg	4.2E-05	5.03E-01	5.03E+00	5.03E+01	0.3	8.07E+00	8.07E+01	2.42E+02
2	Uranium-234	1.22E+01	pCi/g	1.4E-06	8.62E+00	8.62E+01	8.62E+02	N/A	N/A	N/A	N/A
2	Uranium-235	8.40E-01	pCi/g	1.7E-06	4.86E-01	4.86E+00	4.86E+01	N/A	N/A	N/A	N/A
2	Uranium-238	2.49E+01	pCi/g	1.3E-05	1.89E+00	1.89E+01	1.89E+02	N/A	N/A	N/A	N/A

Table D.49. RGOs for SWMU 229 (Continued)

EU	COC	EPC	Units	ELCR	RGO at ELCR=1E-6	RGO at ELCR=1E-5	RGO at ELCR=1E-4	HI	RGO at HI=0.1	RGO at HI=1	RGO at HI=3
Excavation Worker Surface and Subsurface Soil Exposure											
1	Antimony	1.50E+02	mg/kg	N/A	N/A	N/A	N/A	1.1	1.32E+01	1.32E+02	3.95E+02
1	Arsenic	1.17E+01	mg/kg	4.6E-06	2.51E+00	2.51E+01	2.51E+02	0.1	8.07E+00	8.07E+01	2.42E+02
1	Uranium	1.56E+02	mg/kg	N/A	N/A	N/A	N/A	0.2	9.80E+01	9.80E+02	2.94E+03
1	Neptunium-237	1.69E+00	pCi/g	1.0E-06	1.67E+00	1.67E+01	1.67E+02	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	3.7E-05	4.31E+01	4.31E+02	4.31E+03	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	4.2E-05	2.43E+00	2.43E+01	2.43E+02	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	1.8E-04	9.46E+00	9.46E+01	9.46E+02	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	5.3E-06	3.23E-01	3.23E+00	3.23E+01	N/A	N/A	N/A	N/A
2	Antimony	1.08E+02	mg/kg	N/A	N/A	N/A	N/A	0.8	1.32E+01	1.32E+02	3.95E+02
2	Arsenic	2.12E+01	mg/kg	8.4E-06	2.51E+00	2.51E+01	2.51E+02	0.3	8.07E+00	8.07E+01	2.42E+02
2	Uranium-238	2.49E+01	pCi/g	2.6E-06	9.46E+00	9.46E+01	9.46E+02	N/A	N/A	N/A	N/A
Outdoor Worker Surface and Subsurface Soil Exposure											
1	PAH, Total	1.57E-01	mg/kg	2.4E-06	6.45E-02	6.45E-01	6.45E+00	N/A	N/A	N/A	N/A
1	Antimony	1.50E+02	mg/kg	N/A	N/A	N/A	N/A	1.1	1.32E+01	1.32E+02	3.95E+02
1	Arsenic	1.17E+01	mg/kg	2.3E-05	5.03E-01	5.03E+00	5.03E+01	0.1	8.07E+00	8.07E+01	2.42E+02
1	Uranium	1.56E+02	mg/kg	N/A	N/A	N/A	N/A	0.2	9.80E+01	9.80E+02	2.94E+03
1	Neptunium-237	1.69E+00	pCi/g	5.1E-06	3.33E-01	3.33E+00	3.33E+01	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	1.9E-04	8.62E+00	8.62E+01	8.62E+02	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	2.1E-04	4.86E-01	4.86E+00	4.86E+01	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	9.0E-04	1.89E+00	1.89E+01	1.89E+02	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	2.6E-05	6.45E-02	6.45E-01	6.45E+00	N/A	N/A	N/A	N/A
2	Antimony	1.08E+02	mg/kg	N/A	N/A	N/A	N/A	0.8	1.32E+01	1.32E+02	3.95E+02
2	Arsenic	2.12E+01	mg/kg	4.2E-05	5.03E-01	5.03E+00	5.03E+01	0.3	8.07E+00	8.07E+01	2.42E+02
2	Cesium-137	3.21E-01	pCi/g	2.1E-06	1.53E-01	1.53E+00	1.53E+01	N/A	N/A	N/A	N/A
2	Uranium-234	1.22E+01	pCi/g	1.4E-06	8.62E+00	8.62E+01	8.62E+02	N/A	N/A	N/A	N/A
2	Uranium-235	8.40E-01	pCi/g	1.7E-06	4.86E-01	4.86E+00	4.86E+01	N/A	N/A	N/A	N/A
2	Uranium-238	2.49E+01	pCi/g	1.3E-05	1.89E+00	1.89E+01	1.89E+02	N/A	N/A	N/A	N/A

Table D.49. RGOs for SWMU 229 (Continued)

EU	COC	EPC	Units	ELCR	RGO at ELCR=1E-6	RGO at ELCR=1E-5	RGO at ELCR=1E-4	HI	RGO at HI=0.1	RGO at HI=1	RGO at HI=3
Child Recreational User Soil Exposure											
1	PAH, Total	1.57E-01	mg/kg	3.1E-06	5.03E-02	5.03E-01	5.03E+00	N/A	N/A	N/A	N/A
1	Antimony	1.50E+02	mg/kg	N/A	N/A	N/A	N/A	1.9	7.82E+00	7.82E+01	2.35E+02
1	Cadmium	2.12E+01	mg/kg	N/A	N/A	N/A	N/A	0.2	1.32E+01	1.32E+02	3.97E+02
1	Uranium	1.56E+02	mg/kg	N/A	N/A	N/A	N/A	0.3	5.86E+01	5.86E+02	1.76E+03
1	Neptunium-237	1.69E+00	pCi/g	2.8E-06	6.03E-01	6.03E+00	6.03E+01	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	1.0E-04	1.61E+01	1.61E+02	1.61E+03	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	1.2E-04	8.75E-01	8.75E+00	8.75E+01	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	5.2E-04	3.29E+00	3.29E+01	3.29E+02	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	3.4E-05	5.03E-02	5.03E-01	5.03E+00	N/A	N/A	N/A	N/A
2	Antimony	1.08E+02	mg/kg	N/A	N/A	N/A	N/A	1.4	7.82E+00	7.82E+01	2.35E+02
2	Arsenic	2.12E+01	mg/kg	3.5E-05	6.14E-01	6.14E+00	6.14E+01	0.5	4.33E+00	4.33E+01	1.30E+02
2	Cadmium	2.01E+01	mg/kg	N/A	N/A	N/A	N/A	0.2	1.32E+01	1.32E+02	3.97E+02
2	Uranium	7.45E+01	mg/kg	N/A	N/A	N/A	N/A	0.1	5.86E+01	5.86E+02	1.76E+03
2	Uranium-238	2.49E+01	pCi/g	7.6E-06	3.29E+00	3.29E+01	3.29E+02	N/A	N/A	N/A	N/A
Hypothetical Child Residential User Soil Exposure											
1	PAH, Total	1.57E-01	mg/kg	6.9E-06	2.27E-02	2.27E-01	2.27E+00	N/A	N/A	N/A	N/A
1	Antimony	1.50E+02	mg/kg	N/A	N/A	N/A	N/A	4.8	3.13E+00	3.13E+01	9.39E+01
1	Cadmium	2.12E+01	mg/kg	N/A	N/A	N/A	N/A	0.4	5.28E+00	5.28E+01	1.58E+02
1	Uranium	1.56E+02	mg/kg	N/A	N/A	N/A	N/A	0.7	2.34E+01	2.34E+02	7.01E+02
1	Neptunium-237	1.69E+00	pCi/g	2.2E-05	7.72E-02	7.72E-01	7.72E+00	N/A	N/A	N/A	N/A
1	Uranium-234	1.61E+03	pCi/g	2.8E-04	5.73E+00	5.73E+01	5.73E+02	N/A	N/A	N/A	N/A
1	Uranium-235	1.03E+02	pCi/g	9.1E-04	1.14E-01	1.14E+00	1.14E+01	N/A	N/A	N/A	N/A
1	Uranium-238	1.71E+03	pCi/g	3.4E-03	4.99E-01	4.99E+00	4.99E+01	N/A	N/A	N/A	N/A
2	PAH, Total	1.69E+00	mg/kg	7.5E-05	2.27E-02	2.27E-01	2.27E+00	N/A	N/A	N/A	N/A
2	Antimony	1.08E+02	mg/kg	N/A	N/A	N/A	N/A	3.5	3.13E+00	3.13E+01	9.39E+01
2	Arsenic	2.12E+01	mg/kg	8.0E-05	2.67E-01	2.67E+00	2.67E+01	1.2	1.73E+00	1.73E+01	5.19E+01
2	Cadmium	2.01E+01	mg/kg	N/A	N/A	N/A	N/A	0.4	5.28E+00	5.28E+01	1.58E+02
2	Uranium	7.45E+01	mg/kg	N/A	N/A	N/A	N/A	0.3	2.34E+01	2.34E+02	7.01E+02
2	Neptunium-237	2.87E-01	pCi/g	3.7E-06	7.72E-02	7.72E-01	7.72E+00	N/A	N/A	N/A	N/A
2	Uranium-234	1.22E+01	pCi/g	2.1E-06	5.73E+00	5.73E+01	5.73E+02	N/A	N/A	N/A	N/A
2	Uranium-235	8.40E-01	pCi/g	7.4E-06	1.14E-01	1.14E+00	1.14E+01	N/A	N/A	N/A	N/A
2	Uranium-238	2.49E+01	pCi/g	5.0E-05	4.99E-01	4.99E+00	4.99E+01	N/A	N/A	N/A	N/A

Grayed cells indicate EPC value is lower than RGO value or an RGO value is not applicable.
N/A = Not applicable because the COC was not applicable (i.e., the COC was of concern for HI but not ELCR or it was of concern for ELCR but not HI).

Table D.50. Dose RGOs for SWMU 229

EU	COC	EPC	RGO at 1 mrem/yr	RGO at 12 mrem/yr	RGO at 25 mrem/yr	Units
Industrial Worker Exposure to Surface Soil						
1	Uranium-234	1.61E+03	3.84E+02	N/A	N/A	pCi/g
1	Uranium-235	1.03E+02	7.76E+00	9.31E+01	N/A	pCi/g
1	Uranium-238	1.71E+03	4.10E+01	4.92E+02	1.03E+03	pCi/g
Outdoor Worker Exposure to Surface Soil						
1	Uranium-234	1.61E+03	6.12E+01	7.34E+02	1.53E+03	pCi/g
1	Uranium-235	1.03E+02	9.15E+00	N/A	N/A	pCi/g
1	Uranium-238	1.71E+03	3.08E+01	3.70E+02	7.70E+02	pCi/g
Outdoor Worker Exposure to Surface and Subsurface Soil						
1	Uranium-234	1.61E+03	6.12E+01	7.34E+02	1.53E+03	pCi/g
1	Uranium-235	1.03E+02	9.15E+00	N/A	N/A	pCi/g
1	Uranium-238	1.71E+03	3.08E+01	3.70E+02	7.70E+02	pCi/g
Excavation Worker Exposure to Surface and Subsurface Soil						
1	Uranium-234	1.61E+03	6.12E+01	7.34E+02	1.53E+03	pCi/g
1	Uranium-235	1.03E+02	9.15E+00	N/A	N/A	pCi/g
1	Uranium-238	1.71E+03	3.08E+01	3.70E+02	7.70E+02	pCi/g
Adult Recreational User Exposure to Surface Soil						
1	Uranium-235	1.03E+02	2.41E+01	N/A	N/A	pCi/g
1	Uranium-238	1.71E+03	1.32E+02	1.58E+03	N/A	pCi/g
Teen Recreational User Exposure to Surface Soil						
1	Uranium-234	1.61E+03	1.12E+03	N/A	N/A	pCi/g
1	Uranium-235	1.03E+02	1.78E+01	N/A	N/A	pCi/g
1	Uranium-238	1.71E+03	9.59E+01	1.15E+03	N/A	pCi/g
Child Recreational User Exposure to Surface Soil						
1	Uranium-234	1.61E+03	4.85E+02	N/A	N/A	pCi/g
1	Uranium-235	1.03E+02	1.75E+01	N/A	N/A	pCi/g
1	Uranium-238	1.71E+03	8.52E+01	1.02E+03	N/A	pCi/g
Adult Resident Exposure to Surface Soil						
1	Neptunium-237	1.69E+00	1.68E+00	N/A	N/A	pCi/g
1	Uranium-234	1.61E+03	1.49E+02	N/A	N/A	pCi/g
1	Uranium-235	1.03E+02	2.47E+00	2.96E+01	6.18E+01	pCi/g
1	Uranium-238	1.71E+03	1.32E+01	1.58E+02	3.30E+02	pCi/g
2	Uranium-238	2.49E+01	1.32E+01	N/A	N/A	pCi/g
Child Resident Exposure to Surface Soil						
1	Neptunium-237	1.69E+00	1.61E+00	N/A	N/A	pCi/g
1	Uranium-234	1.61E+03	4.27E+01	5.12E+02	1.07E+03	pCi/g
1	Uranium-235	1.03E+02	2.38E+00	2.86E+01	5.95E+01	pCi/g
1	Uranium-238	1.71E+03	1.07E+01	1.28E+02	2.68E+02	pCi/g
2	Uranium-238	2.49E+01	1.07E+01	N/A	N/A	pCi/g

N/A = not applicable because the EPC value is lower than the RGO value.

D.9. REFERENCES

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ATTACHMENT D1

NO ACTION LEVEL SCREENING VALUES

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D1. NO ACTION LEVEL SCREENING VALUES

The Risk Methods Document (RMD) identifies those constituents considered potential chemicals (and radionuclides) of potential concern (COPCs) at the Paducah Gaseous Diffusion Plant (PGDP) and tabulates their no action levels (NALs) (see Table A.4 of the RMD) (DOE 2015). Additionally, three constituents [benzo(ghi)perylene, 2-methylnaphthalene, and dibenzofuran] were detected in samples evaluated for Solid Waste Management Unit (SWMU) 229 for which there previously were no tabulated child residential NAL or background value.

Because the residential NAL is used in the risk assessment for identification of potential COPCs, it was necessary to develop child resident NALs consistent with the approach documented in the RMD to identify COPCs in the risk assessment. The noncancer NAL is based on the child resident (hazard index of 0.1) and the NAL for carcinogens is based on the aggregate resident (26-year exposure) (excess lifetime cancer risk of 1E-06).

The constituent benzo(ghi)perylene was detected in SWMU 229 soils, but has no toxicity values for which to determine screening values. Benzo(ghi)perylene is a noncarcinogenic polycyclic aromatic hydrocarbon (PAH). It has no toxicity criteria. Similar to anthracene and pyrene, noncarcinogenic PAHs are not classifiable as to their carcinogenicity to humans. Although no specific reference doses have been provided by the U.S. Environmental Protection Agency for these, frequently they are screened based on values derived for pyrene or other noncarcinogenic PAHs.

These NALs are presented below. Screened against these values, these three PAH constituents would not be COPCs.

Table D1.1. Additional No Action Level Screening Values

Chemical Abstract Number	Analyte	Units	Hazard	Residential (Child) Cancer	NAL
91576	2-Methylnaphthalene	mg/kg	1.14E+01		1.14E+01
132649	Dibenzofuran	mg/kg	5.57E+00		5.57E+00
129000	Benzo(ghi)perylene*	mg/kg	8.54E+01		8.54E+01

*NALs for pyrene are used as a surrogate for benzo(ghi)perylene.

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ATTACHMENT D2

TOXICITY VALUE AND INFORMATION USED IN SWMU 229 RISK ANALYSIS

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Table D2.1. Toxicity Values and Information Used in SWMU 229 Risk Analysis

AnaType	Analyte	GI Absorption Factor	RfDo	RfDd	RfC	RfDi	SFo	SFow	SFos (Res)	SFos (Ind)	SFd	IUR	SFe	PEF Res	PEF Ind	VF Res	VF Ind	EPA_ABS	KY_ABS	Kp	Lambda
I	Antimony	1.50E-01	4.00E-04	6.00E-05										9.30E+08	6.20E+08				5.00E-02	1.00E-03	
I	Arsenic	1.00E+00	3.00E-04	3.00E-04	1.50E-05		1.50E+00				1.50E+00	4.30E-03		9.30E+08	6.20E+08			3.00E-02	3.00E-02	1.00E-03	
I	Cadmium	2.50E-02	1.00E-03	2.50E-05	1.00E-05							1.80E-03		9.30E+08	6.20E+08			1.00E-03	1.00E-03	1.00E-03	
I	Chromium	1.30E-02	1.50E+00	1.95E-02								8.40E-02		9.30E+08	6.20E+08				1.30E-02	1.00E-03	
I	Mercury	7.00E-02	3.00E-04	2.10E-05										9.30E+08	6.20E+08				5.00E-02	1.00E-03	
I	Uranium	1.00E+00	3.00E-03	3.00E-03	4.00E-05									9.30E+08	6.20E+08				5.00E-02	1.00E-03	
O	PAH, Total	1.00E+00					7.30E+00				7.30E+00	1.10E-03		9.30E+08	6.20E+08			1.30E-01	1.30E-01	7.13E-01	
R	Cesium-137+D	1.00E+00						3.05E-11	4.26E-11	3.18E-11		1.12E-10	2.53E-06	9.30E+08	6.20E+08						2.30E-02
R	Neptunium-237+D	5.00E-04						6.85E-11	1.41E-10	4.96E-11		2.87E-08	8.55E-07	9.30E+08	6.20E+08						3.23E-07
R	Uranium-234	2.00E-02						7.07E-11	1.48E-10	5.11E-11		2.78E-08	2.53E-10	9.30E+08	6.20E+08						2.82E-06
R	Uranium-235+D	2.00E-02						7.18E-11	1.54E-10	5.00E-11		2.50E-08	5.76E-07	9.30E+08	6.20E+08						9.84E-10
R	Uranium-238+D	2.00E-02						8.70E-11	1.97E-10	5.62E-11		2.37E-08	1.19E-07	9.30E+08	6.20E+08						1.55E-10

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ATTACHMENT D3

TOXICITY PROFILES

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D3.1 INORGANIC COMPOUNDS

D3.1.1 ANTIMONY (CAS 007440-36-0) (RAIS)

Antimony is a naturally occurring silvery-white metal that is found in the earth's crust. Antimony ores are mined and then mixed with other metals to form antimony alloys or combined with oxygen to form antimony oxide. Little antimony is currently mined in the United States. It is brought into this country from other countries for processing; however, there are companies in the United States that produce antimony as a by-product of smelting lead and other metals. Antimony is used in lead storage batteries, solder, sheet and pipe metal, bearings, castings, and pewter. Antimony oxide is added to textiles and plastics to prevent them from catching fire. It also is used in paints, ceramics, and fireworks, and as enamels for plastics, metal, and glass.

Metallic antimony and a few trivalent antimony compounds are the most significant regarding exposure potential and toxicity. Antimony is a common urban air pollutant, occurring at an average concentration of 0.001 $\mu g/m^3$. Exposure to antimony may occur via inhalation and by ingestion of contaminated food.

Acute oral and inhalation exposure of humans and animals to high doses of antimony or antimony-containing compounds (antimonials) may cause gastrointestinal disorders (vomiting, diarrhea), respiratory difficulties, and death at extremely high doses. Subchronic and chronic oral exposure may affect hematologic parameters. Long-term oral exposure to high doses of antimony or antimonials has been shown to adversely affect longevity in animals. Long-term occupational exposure of humans has resulted in electrocardiac disorders, respiratory disorders, and possibly increased mortality. Antimony levels for these occupational exposure evaluations ranged from 2.2 to 11.98 mg Sb/m^3. Based on limited data, occupational exposure of women to metallic antimony and several antimonials has been reported to have caused alterations in the menstrual cycle and an increased incidence of spontaneous abortions.

The Department of Health and Human Services (DHHS), the International Agency for Research on Cancer (IARC), and the U.S. Environmental Protection Agency (EPA) have not classified antimony as to its human carcinogenicity.

Chronic RfDs for antimony also are available in RAIS. The oral RfD used in the BHHRA is 4.00E-04 (mg/kg-day). The GI absorption factor is 0.15 and the corresponding absorbed dose RfD is 6.00E-05 (mg/kg-day).

D3.1.2 ARSENIC (CAS 007440-38-2) (RAIS)

Arsenic is a naturally occurring element widely distributed in the earth's crust. In the environment, arsenic is combined with oxygen, chlorine, and sulfur to form inorganic arsenic compounds. Arsenic in animals and plants combines with carbon and hydrogen to form organic arsenic compounds. Inorganic arsenic compounds are used mainly to preserve wood. Organic arsenic compounds are used as pesticides, primarily on cotton plants. Arsenic cannot be destroyed in the environment. It can change its form, only. Arsenic in air either will settle to the ground or will be washed out of the air by rain. Many arsenic compounds can dissolve in water. Fish and shellfish can accumulate arsenic, but the arsenic in fish is mostly in a form that is not harmful. The toxicity of inorganic arsenic depends on its valence state and also on the physical and chemical properties of the compound in which it occurs.

Water soluble inorganic arsenic compounds are absorbed through the GI tract and lungs; distributed primarily to the liver, kidney, lung, spleen, aorta, and skin; and excreted mainly in the urine at rates as high as 80%. Symptoms of acute inorganic arsenic poisoning in humans are nausea, anorexia, vomiting, epigastric and abdominal pain, and diarrhea. Dermatitis (exfoliative erythroderma), muscle cramps, cardiac abnormalities, hepatotoxicity, bone marrow suppression and hematologic abnormalities (anemia), vascular lesions, and peripheral neuropathy (motor dysfunction, paresthesia) also have been reported. Oral doses as low as 20–60 μg/kg/day have been reported to cause toxic effects in some individuals. Severe exposures can result in acute encephalopathy, congestive heart failure, stupor, convulsions, paralysis, coma, and death. The acute lethal dose to humans has been estimated to be about 0.6 mg/kg/day.

General symptoms of chronic arsenic poisoning in humans are weakness, general debility and lassitude, loss of appetite and energy, loss of hair, hoarseness of voice, loss of weight, and mental disorders. Primary target organs are the skin (hyperpigmentation and hyperkeratosis), nervous system (peripheral neuropathy), and vascular system. Anemia, leukopenia, hepatomegaly, and portal hypertension also have been reported. In addition, possible reproductive effects include a high male to female birth ratio.

Epidemiological studies have revealed an association between arsenic concentrations in drinking water and increased incidences of skin cancers, as well as cancers of the liver, bladder, respiratory, and GI tracts. Occupational exposure studies have shown a clear correlation between exposure to arsenic and lung cancer mortality. Several studies have shown that inorganic arsenic can increase the risk of lung cancer, skin cancer, bladder cancer, liver cancer, kidney cancer, and prostate cancer. The World Health Organization, the DHHS, and the EPA have determined that inorganic arsenic is a human carcinogen and is classified A, human carcinogen.

Cancer slope factors for arsenic are available from EPA's IRIS. The values used in the BHHRA are 1.50E+00, 1.51E+01, and 1.50 E+00 $[mg/(kg \times day)]^{-1}$ for the oral, inhalation, and dermal exposure routes, respectively. The slope factor for the dermal exposure route was calculated by assuming a GI absorption factor of 1.0.

Chronic RfDs for arsenic also are available in RAIS. The oral and dermal values used in the BHHRA were 3.00E-04 mg/(kg × day) for both. The dermal RfD was calculated by assuming a GI absorption factor of 1.0.

D3.1.3 CADMIUM (CAS 007440-43-9) (RAIS)

Cadmium is a naturally occurring metal that is used in various chemical forms in metallurgical and other industrial processes, and in the production of pigments. Environmental exposure can occur via the diet and drinking water (ATSDR 1989).

Cadmium is absorbed more efficiently by the lungs (30 to 60%) than by the gastrointestinal tract, the latter being a saturable process (Nordberg et al., 1985). Cadmium is transported in the blood and widely distributed in the body but accumulates primarily in the liver and kidneys (Goyer 1991). Cadmium burden (especially in the kidneys and liver) tends to increase in a linear fashion up to about 50 or 60 years of age after which the body burden remains somewhat constant. Metabolic transformations of cadmium are limited to its binding to protein and nonprotein sulfhydryl groups, and various macromolecules, such as metallothionein, which is especially important in the kidneys and liver (ATSDR 1989). Cadmium is excreted primarily in the urine.

Acute oral exposure to 20–30 g has caused fatalities in humans. Exposure to lower amounts may cause gastrointestinal irritation, vomiting, abdominal pain, and diarrhea (ATSDR 1989). An asymptomatic period of one-half to one hour may precede the onset of clinical signs. Oral LD_{50} values in animals range from 63 to 1125 mg/kg, depending on the cadmium compound (USAF 1990). Longer term exposure to cadmium primarily affects the kidneys, resulting in tubular proteinosis although other conditions such as "itai-itai" disease may involve the skeletal system. Cadmium involvement in hypertension is not fully understood (Goyer 1991).

Inhalation exposure to cadmium and cadmium compounds may result in effects including headache, chest pains, muscular weakness, pulmonary edema, and death (USAF 1990). The 1-minute and 10-minute lethal concentration of cadmium for humans has been estimated to be about 2,500 and 250 mg/m^3, respectively (Barrett et al. 1947; Beton et al. 1966). An 8-hour TWA (time-weighted-average) exposure level of 5 mg/m^3 has been estimated for lethal effects of inhalation exposure to cadmium, and exposure to 1 mg/m^3 is considered to be immediately dangerous to human health (Friberg 1950). Renal toxicity (tubular proteinosis) also may result from inhalation exposure to cadmium (Goyer 1991).

Chronic oral RfDs of 5E-4 and 1E-3 mg/kg/day have been established for cadmium exposure via drinking water and food, respectively (EPA 1991). Both values reflect incorporation of an uncertainty factor of 10. The RfDs are based on an extensive database regarding toxicokinetics and toxicity in both humans and animals, the critical effect being renal tubular proteinuria. Confidence in the RfD and data base is high.

Inhalation RfC values currently are not available.

The target organ for cadmium toxicity via oral exposure is the kidney (Goyer 1991). For inhalation exposure, both the lungs and kidneys are target organs for cadmium-induced toxicity (ATSDR 1989; Goyer 1991).

There is limited evidence from epidemiologic studies for cadmium-related respiratory tract cancer (ATSDR 1989). An inhalation unit risk of 1.8E-3 $(\mu g/m^3)^{-1}$ and an inhalation slope factor of 6.1E+0 $(mg/kg/day)^{-1}$ are based on respiratory tract cancer associated with occupational exposure (EPA 1985). Based on limited evidence from multiple occupational exposure studies and adequate animal data, cadmium is placed in weight-of-evidence group B1, probable human carcinogen.

D3.1.4 CHROMIUM (CAS 007440-47-3) (RAIS)

Elemental chromium does not occur in nature, but it is present in ores, primarily chromite. Chromium can be found in rocks, animals, plants, soil, and in volcanic dust and gases. Chromium is present in the environment in several different forms (oxidation states). The most common forms are chromium (0), chromium (III), and chromium (VI). No taste or odor is associated with chromium compounds. Chromium (III) occurs naturally in the environment and is an essential nutrient that helps the body use sugar, protein, and fat. Chromium (VI) and chromium (0) are generally produced by industrial processes. The metal chromium, chromium (0), is used for making steel. Chromium (VI) and chromium (III) are used for chrome plating, dyes and pigments, leather tanning, and wood preserving. Chromium enters the body through the lungs, digestive tract and, to a lesser extent, the skin. Inhalation is the most important route for occupational exposure. Nonoccupational exposure occurs via ingestion of chromium-containing food and water. Breathing high levels of chromium (VI) can cause irritation to the nose, such as runny nose, nosebleeds, and ulcers and holes in the nasal septum. Ingesting large amounts of chromium (VI) can cause stomach upsets and ulcers, convulsions, kidney and liver damage, and even death. Skin contact with certain chromium (VI) compounds can cause skin ulcers. Some people are extremely sensitive to chromium (VI) or chromium (III). Allergic reactions consisting of severe redness and swelling of the skin

have been noted. Several studies have shown that chromium (VI) compounds can increase the risk of lung cancer when inhaled. Animal studies have also shown an increased risk of cancer. There is also evidence for an increased risk of developing nasal, pharyngeal, and gastrointestinal carcinomas. Chromium (III) carcinogenicity is unknown. However, the classification of chromium (VI) as a known human carcinogen raises a concern for the carcinogenic potential of trivalent chromium.

The cancer inhalation unit risk for chromium (VI) from RAIS was used in the BHHRA. The value used was 8.40E-5 mg/m^3 for the inhalation route of exposure. Slope factors for the oral and dermal routes of exposure are not available.

Consistent with the Risk Methods Document, the chronic RfDs from RAIS associated with Chromium (III) were used in the BHHRA. The values used were 1.50E+00 and 1.95E-02 mg/(kg × day) for the oral and dermal routes, respectively. The dermal RfD was calculated by assuming a GI absorption factor of 1.30E-02.

D3.1.5 MERCURY (CAS 007439-97-6) (RAIS)

Mercury is a naturally occurring metal which has several forms. The metallic mercury is a shiny, silver-white, odorless liquid; if heated, it is a colorless, odorless gas. Mercury combines with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or "salts," which are usually white powders or crystals. Mercury also combines with carbon to make organic mercury compounds; methylmercury is the most common organic mercury compound and is produced mainly by microscopic organisms in the water and soil. More mercury in the environment can increase the amounts of methylmercury that these small organisms make. Metallic mercury is used to produce chlorine gas and caustic soda and is also used in thermometers, dental fillings, electrical switches, and batteries. Mercury salts are sometimes used in skin lightening creams and as antiseptic creams and ointments.

The nervous system is very sensitive to all forms of mercury. Methylmercury and metallic mercury vapors are more harmful than other forms, because more mercury reaches the brain in these forms. Exposure to high levels of metallic, inorganic, or organic mercury can permanently damage the brain, kidneys, and developing fetus. Effects on brain functioning may result in irritability, shyness, tremors, changes in vision or hearing, and memory problems. Short-term exposure to high levels of metallic mercury vapors may cause lung damage, nausea, vomiting, diarrhea, increases in blood pressure or heart rate, skin rashes, and eye irritation.

No data were available regarding the carcinogenicity of mercury in humans or animals. EPA has placed inorganic mercury in weight-of-evidence classification D, not classifiable as to human carcinogenicity. Other forms of mercury are possible human carcinogens.

A chronic RfD for the oral route of exposure from RAIS was used in the BHHRA. The values used in the BHHRA are 3.00E-04 and 2.10E-05 (mg/kg-day) for the oral and dermal routes, respectively. The dermal RfD was calculated assuming a GI absorption factor of 7.0E-02.

D3.1.6 URANIUM (METAL AND SOLUBLE SALTS) (CAS 007440-61-1)

Uranium is a hard, silvery white amphoteric metal and is a radioactive element. In its natural state it consists of three isotopes: uranium-234 (U-234), uranium-235 (U-235), and uranium-238 (U-238). More than 100 uranium minerals exist; those of commercial importance are the oxides and oxygenous salts. The processing of uranium ore generally involves extraction then leaching either by an acid or a carbonate

method. In addition, the metal may be obtained from its halides by fused salt electrolysis. The primary use of natural uranium is in nuclear energy as a fuel for nuclear reactors, in plutonium production, and as feeds for gaseous diffusion plants; it is also a source of radium salts. Uranium compounds are used in staining glass, glazing ceramics, and enameling; in photographic processes; for alloying steels; and as a catalyst for chemical reactions, radiation shielding, and aircraft counterweights (Sittig 1985).

The primary route of exposure to uranium metals and salts is through dermal contact. Uranium soluble compounds act as a poison to cause kidney damage under acute exposure and pneumoconiosis or pronounced blood changes under chronic exposure conditions. Furthermore, it is difficult to separate the toxic chemical effects of uranium and its compounds from their radiation effects. The chronic radiation effects are similar to those produced by ionizing radiation. Reports now confirm that carcinogenicity is related to dose and exposure time. Cancer of the lung, osteosarcoma, and lymphoma have all been reported (Sittig 1985). An EPA weight-of-evidence classification for uranium metal was not located in the available literature. Slope factors for uranium metal also were not available for use in the BHHRA.

Chronic RfDs from RAIS were available for uranium metal (listed as uranium soluble salts). The oral and dermal RfD used in the BHHRA was 3.00E-03 mg/(kg × day), for both. A GI absorption factor of 1.00E+00 was used to derive the dermal RfD.

D3.2 ORGANIC COMPOUNDS

D3.2.1 TOTAL PAHS

Total PAHs are evaluated in this BRA by weighting the concentration of each PAH to convert it to benzo(a) pyrene equivalents as described in the 2001 Risk Methods Document and then evaluating the sum of the concentrations based on the toxicity of benzo(a)pyrene. The PAHs included in this calculation for the PAH class are benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene.

Benzo[a]pyrene is one of many chemicals known as PAHs. It exists as yellowish plates and needles. Benzo[a]pyrene is practically insoluble in water but is soluble in benzene, toluene, xylene and sparingly soluble in alcohol and methanol. No current commercial production or use of benzo[a]pyrene is known. It occurs ubiquitously in products of incomplete combustion and in fossil fuels. It has been identified in surface water, tap water, rain water, groundwater, waste water, and sewage sludge. Benzo[a]pyrene is primarily released to the air and removed from the atmosphere by photochemical oxidation and dry deposition to land or water. Biodegradation is the most important transformation process in soil or sediment.

No data are available on the systemic (noncarcinogenic) effects of benzo[a]pyrene in humans. Benzo[a]pyrene is readily absorbed following inhalation, oral, and dermal routes of administration. Following inhalation exposure, benzo[a]pyrene is rapidly distributed to several tissues in rats. The metabolism of benzo[a]pyrene is complex and includes the formation of a proposed ultimate carcinogen, benzo[a]pyrene 7,8 diol-9,10-epoxide. Dietary administration of doses as low as 10 mg/kg during gestation caused reduced fertility and reproductive capacity in mice offspring, and treatment by gavage with 120 mg/kg/day during gestation caused stillbirths, resorptions, and malformations.

Numerous epidemiologic studies have shown a clear association between exposure to various mixtures of PAHs containing benzo[a]pyrene (e.g., coke oven emissions, roofing tar emissions, and cigarette smoke) and increased risk of lung cancer and other tumors. Each of the mixtures also contained other potentially

carcinogenic PAHs; therefore, it is not possible to evaluate the contribution of benzo[a]pyrene to the carcinogenicity of these mixtures. Based on EPA guidelines, benzo[a]pyrene was assigned to weight-of-evidence group B2, probable human carcinogen.

Cancer slope factors for benzo[a]pyrene are available from RAIS, and are described in the section on that chemical, as are other constants used for specific PAHs.

D3.2.2 RADIONUCLIDES

Radionuclides are unstable atoms of chemical elements that will emit charged particles or energy or both to achieve a more stable state. These charged particles are termed "alpha and beta radiation"; energy is termed "neutral gamma rays." Interaction of these charged particles (and gamma rays) with matter will produce ionization events, or radiation, which may cause living cell tissue damage. Because the deposition of energy by ionizing radiation is a random process, sufficient energy may be deposited (in a critical volume) within a cell and result in cell modification or death. In addition, ionizing radiation has sufficient energy that interactions with matter will produce an ejected electron and a positively charged ion (known as free radicals) that are highly reactive and may combine with other elements, or compounds within a cell, to produce toxins or otherwise disrupt the overall chemical balance of the cell. These free radicals also can react with deoxyribonucleic acid (DNA), causing genetic damage, cancer induction, or even cell death.

Radionuclides are characterized by the type and energy level of the radiation emitted. Radiation emissions fall into two major categories: particulate (electrons, alpha particles, beta particles, and protons) or electromagnetic radiation (gamma and X-rays). Therefore, all radionuclides are classified by the EPA as Group A carcinogens based on their property of emitting ionizing radiation and on the extensive weight-of-evidence provided by epidemiological studies of humans with cancers induced by high doses of radiation. Alpha particles are emitted at a characteristic energy level for differing radionuclides. The alpha particle has a charge of +2 and a comparably large size. Alpha particles have the ability to react (and/or ionize) with other molecules, but they have very little penetrating power and lack the ability to pass through a piece of paper or human skin. However, alpha-emitting radionuclides are of concern when there is a potential for inhalation or ingestion of the radionuclide. Alpha particles are directly ionizing and deposit their energy in dense concentrations [termed high linear energy transfer (LET)], resulting in short paths of highly localized ionization reactions. The probability of cell damage increases as a result of the increase in ionization events occurring in smaller areas; this also may be the reason for increased cancer incidence caused by inhalation of radon gas. In addition, the cancer incidence in smokers may be directly attributed to the naturally occurring alpha emitter, polonium-210, in common tobacco products.

Beta emissions generally refer to beta negative particle emissions. Radionuclides with an excess of neutrons achieve stability by beta decay. Beta radiation, like alpha radiation, is directly ionizing but, unlike alpha activity, beta particles deposit their energy along a longer track length (low LET), resulting in more space between ionization events. Beta-emitting radionuclides can cause injury to the skin and superficial body tissue, but are most destructive when inhaled or ingested. Many beta emitters are similar chemically to naturally occurring essential nutrients and will, therefore, tend to accumulate in certain specific tissues. For example, strontium-90 is chemically similar to calcium and, as a result, accumulates in the bones, where it causes continuous exposure. The health effects of beta particle emissions depend upon the target organ. Those seeking the bones would cause a prolonged exposure to the bone marrow and affect blood cell formation, possibly resulting in leukemia, other blood disorders, or bone cancers. Those seeking the liver would result in liver diseases or cancer, while those seeking the thyroid would cause thyroid and metabolic disorders. In addition, beta radiation may lead to damage of genetic material (DNA), causing hereditary defects.

Gamma emissions are the energy that has been released from transformations of the atomic nucleus. Gamma emitters and x-rays behave similarly, but differ in their origin: gamma emissions originate in nuclear transformations, and x-rays result from changes in the orbiting electron structure. Radionuclides that emit gamma radiation can induce internal and external effects. Gamma rays have high penetrating ability in living tissue and are capable of reaching all internal body organs. Without such sufficient shielding as lead, concrete, or steel, gamma radiation can penetrate the body from the outside and does not require ingestion or inhalation to penetrate sensitive organs. Gamma rays are characterized as low-LET radiation, as is beta radiation; however, the behavior of beta radiation differs from that of gamma radiation in that beta particles deposit most of their energy in the medium through which they pass, while gamma rays often escape the medium because of higher energies, thereby creating difficulties in determining actual internal exposure. For this reason, direct whole-body measurements are necessary to detect gamma radiation, while urine/fecal analyses are usually effective in detecting beta radiation.

People receive gamma radiation continuously from naturally occurring radioactive decay processes going on in the earth's surface, from radiation naturally occurring inside their bodies, from the atmosphere as fallout from nuclear testing or explosions, and from space or cosmic sources. Cesium-137 (Cs-137) (from nuclear fallout) decays to barium-137, the highest contributor to fallout-induced gamma radiation. Beta radiation from the soil is a less penetrating form of radiation, but has many contributing sources. Potassium-40, Cs-137, lead-214, and bismuth-214 are among the most common environmental beta emitters. Tritium is also a beta emitter but contributes little to the soil beta radiation because of the low energy of its emission and its low concentration in the atmosphere. Alpha radiation also is emitted by the soil, but is not measurable more than a few centimeters from the ground surface. The majority of alpha emissions are attributable to radon-222 and radon-220 and their decay products. This contributes to what is called background exposure to radiation.

The general health effects of radiation can be divided into stochastic (related to dose) and nonstochastic (not related to dose) effects. The risk of development of cancer from exposure to radiation is a stochastic effect. Examples of nonstochastic effects include acute radiation syndrome and cataract formation, which occur only at high levels of exposures.

Radiation can damage cells in different ways. It can cause damage to DNA within the cell, and the cell either may not be able to recover from this type of damage or may survive but function abnormally. If an abnormally functioning cell divides and reproduces, a tumor or mutation in the tissue may develop. The rapidly dividing cells that line the intestines and stomach and the blood cells in bone marrow are extremely sensitive to this damage. Organ damage results from the damage caused to the individual cells. This type of damage has been reported with doses of 10 to 500 rads (0.1 to 5.0 gray, in SI units). Acute radiation sickness is seen only after doses of > 50 rads 0.5 gray), which is a dose rate usually achieved only in a nuclear accident.

When the radiation-damaged cells are reproductive cells, genetic damage can occur in the offspring of the person exposed. The developing fetus is especially sensitive to radiation. The type of malformation that may occur is related to the stage of fetal development and the cells that are differentiating at the time of exposure. Radiation damage to children exposed in the womb is related to the dose the pregnant mother receives. Mental retardation is a possible effect of fetal radiation exposure.

The most widely studied population that has had known exposure to radiation is the atomic bomb survivors of Hiroshima and Nagasaki, Japan. Data indicate an increase in the rate of leukemia and cancers in this population. However, the rate at which cancer incidence is significantly affected by low radiation exposures, such as results of exposure to natural background and industrially contaminated sites, is still undergoing study and is uncertain. In studies conducted to determine the rate of cancer and leukemia increase, as well as genetic defects, several radionuclides must be considered.

D3.2.2.1 Cesium-137 (EPA)

Radioactive Cs-137 is produced when uranium and plutonium absorb neutrons and undergo fission. Examples of the uses of this process are nuclear reactors and nuclear weapons. The splitting of uranium and plutonium in fission creates numerous fission products. Cs-137 is one of the more well-known fission products. Cesium, as well as Cs-137, is a soft, malleable, silvery white metal. Cesium is one of only three metals that is a liquid near room temperature (83°F). The half-life of Cs-137 is 30 years.

People may also be exposed from contaminated sites: Walking on Cs-137 contaminated soil could result in external exposure to gamma radiation. Leaving the contaminated area would prevent additional exposure. Coming in contact with waste materials at contaminated sites could also result in external exposure to gamma radiation. Leaving the area would also end the exposure. If Cs-137 contaminated soil becomes air-borne as dust, breathing the dust would result in internal exposure. Because the radiation emitting material is then in the body, leaving the site would not end the exposure. Drinking Cs-137 contaminated water, also would place the Cs-137 inside the body, where it would expose living tissue to gamma and beta radiation.

People may ingest Cs-137 with food and water, or may inhale it as dust. If Cs-137 enters the body, it is distributed fairly uniformly throughout the body's soft tissues, resulting in exposure of those tissues. Slightly higher concentrations of the metal are found in muscle, while slightly lower concentrations are found in bone and fat. Compared to some other radionuclides, Cs-137 remains in the body for a relatively short time. It is eliminated through the urine. Exposure to Cs-137 also may be external (that is, exposure to its gamma radiation from outside the body).

Like all radionuclides, exposure to radiation from Cs-137 results in increased risk of cancer. Everyone is exposed to very small amounts of Cs-137 in soil and water as a result of atmospheric fallout. Exposure to waste materials, from contaminated sites, or from nuclear accidents can result in cancer risks much higher than typical environmental exposures.

If exposures are very high, serious burns, and even death, can result. Instances of such exposure are very rare. One example of a high-exposure situation would be the mishandling a strong industrial Cs-137 source. The magnitude of the health risk depends on exposure conditions. These include such factors as strength of the source, length of exposure, distance from the source, and whether there was shielding between you and the source (such as metal plating).

Inhalation and external exposure cancer slope factors used in the BHHRA for Cs-137 are 1.12E-10 risk/pCi and 2.53E-06 risk/yr per pCi/g soil, respectively. Oral cancer slope factors used in the BHHRA were 4.26E-11 risk/pCi for the residential and recreational scenarios and 3.18E-11 risk/pCi for the industrial, excavation, and outdoor worker scenarios. A dermal cancer slope factor was not calculated because this route of exposure is not evaluated in the BHHRA. Oral and inhalation RfDs are available in EPA's IRIS.

D3.2.2.2 Neptunium-237 (CAS 013994-20-2)

Specific literary information for Np-237 is limited. However, available literature states that during neutron bombardment, Np-237 breaks down to Pu-238, which produces small masses of high capacity energy that is useful for satellites and spacecraft (Moskalev et al. 1979).

The most common route of Np-237 exposure is inhalation of aerosols. According to studies conducted on rats, acute effects include injury to the liver and kidney and circulation disorders. Long-term effects

include osteosarcomas and lung cancer. Extremely high doses cause immediate or premature death by destruction of the lungs (Moskalev et al. 1979).

Inhalation and external exposure cancer slope factors used in the BHHRA for Np-237 are 2.87E-08 risk/pCi and 8.55E-07 risk/yr per pCi/g soil, respectively. Oral cancer slope factors used in the BHHRA were 1.41E-10 risk/pCi for the residential and recreational scenarios and 4.96E-11 risk/pCi for the industrial, excavation, and outdoor worker scenarios. A dermal cancer slope factor was not calculated because this route of exposure is not evaluated in the BHHRA. Oral, dermal, and inhalation RfDs are not available for this element; therefore, systemic toxicity due to exposure to Np-237 is not quantified in the BHHRA.

D3.2.2.3 Uranium (CAS 007440-62-2 for metal, CAS 013966-29-5 for Uranium-234, CAS 015117-96-1 for Uranium-235, and CAS 007440-61-1 for Uranium-238) (ATSDR)

Uranium is a mildly radioactive element that occurs widely in the earth's crust. It is found in all soils, most rocks, and, in lesser concentrations, in water, vegetation, and animals, including humans. Uranium emits a low level of alpha particles and a much lower level of gamma rays. Alpha particles are unable to penetrate skin, but can travel short distances in the body if ingested or inhaled. Consequently, uranium represents a significant carcinogenic hazard only when taken into the body, where alpha particle energy is absorbed by small volumes of tissue. Although the penetrating (gamma) radiation of uranium is not considered to be significant (ATSDR 1989), one of its daughter radionuclides is a strong gamma emitter; therefore, gamma radiation may be a concern in areas containing uranium.

Natural uranium contains the uranium isotopes U-238 (which averages 99.27% of total uranium mass), U-235 (0.725), and U-234 (0.0056%), each of which undergoes radioactive decay. Natural uranium, therefore, contains the radionuclide daughter products from the decay of U-238 and U-235 (Bowen 1979; ATSDR 1989). The half-lives of the isotopes are 200,000, 700 million, and 5 billion years for U-234, U-235, and U-238, respectively.

Uranium is a radioactive element, but it also is a metallic element. Toxicological effects from the ingestion of uranium are the result of the action of uranium as a metal and its radioactive properties. The primary toxic chemical effect of uranium is seen in kidney damage. Studies in rabbits, mice, and dogs showed effects on the kidney to be dose-related. Fetal skeletal abnormalities and fetal death were found in pregnant mice exposed to 6 mg/kg or uranyl acetate dihydrate.

The primary human exposure studies to uranium have been studies of uranium miners or uranium factory workers. These studies have shown an increase in lung cancer deaths among these workers, which may be attributable to the decay of uranium into radon and its daughters. These workers are exposed to high levels of uranium dust and fumes and other radioactive elements in confined conditions (ATSDR 1989).

Cancer slope factors used in the BHHRA for U-234, U-235, and U-238 are as follows:

- Ingestion (residential and recreational scenarios) (risk/pCi)—U-234=1.48E-10, U-235=1.54E-10, U-238=1.97E-10;
- Ingestion (industrial, excavation, and outdoor worker scenarios) (risk/pCi)—U-234= 5.11E-11, U-235= 5.00E-11, U-238= 5.62E-11;
- Inhalation (risk/pCi)—U-234= 2.78E-08, U-235= 2.50E-08, U-238= 2.37E-08;
- External exposure (risk/yr per pCi)—U-234= 2.53E-10, U-235= 5.76E-07, U-238= 1.19E-07;

The slope factors for U-238 include ingrowth of short-lived degradation products. A dermal cancer slope factor was not calculated for the uranium isotopes because this route of exposure is not considered significant for radionuclides and is not evaluated in the BHHRA. Oral, dermal, and inhalation RfDs are available for uranium and are listed earlier in this section.

D3.3 REFERENCES

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ATTACHMENT D4

NONDETECT UNCERTAINTY EVALUATION

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D4. NONDETECT UNCERTAINTY EVALUATION

Chemicals or radionuclides of potential concern (COPCs) were selected for each exposure unit (EU) in Solid Waste Management Unit 229 for those analytes that were detected above background and where maximum detected value is greater than the no action level (for the child residential scenario) (DOE 2015). For those analytes that never were detected within an EU, even if the detection limit is greater than the no action level, the analyte was not considered a COPC. Uncertainties are associated with this assumption. To assist in evaluating this uncertainty, the maximum detection limit was used as an exposure point concentration, and hazard index (HI) and excess lifetime cancer risk (ELCR) were calculated for the nondetected analyses. This attachment presents the results of these calculations.

Constituents with detection limits greater than the no action limit (NAL) and background concentrations were screened as COPCs as previously discussed in this baseline human health risk assessment. The results of the screening are presented in Table D4.1.

Chronic daily intakes (CDIs) for noncarcenogens and carcinogens are shown in Tables D4.2 and D4.3. HI and ELCR are calculated in Tables D4.4 and D4.5, respectively. These calculations showed no hazard greater than 0.1. ELCR was as high as 1.3E-06, which is at the lower end of the EPA risk range (EPA 1991), for the current industrial worker. There were no constituents that would have been deemed a contaminant of concern.

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Table D4.1. Surface Soil COPCs for Nondetected Analyses

EU	Chemical	Maximum Nondetect Reporting Limit	Units	Surface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
1	Antimony	30	mg/kg	0.21	3.13	Yes
1	Arsenic	11	mg/kg	12	0.267	NoB
1	Cadmium	12	mg/kg	0.21	5.07	Yes
1	Chromium	85	mg/kg	16	0.301	Yes
1	Copper	35	mg/kg	19	313	NoA
1	Lead	13	mg/kg	36	400	NoAB
1	Mercury	10	mg/kg	0.2	2.35	Yes
1	Molybdenum	15	mg/kg		39.1	NoA
1	Nickel	65	mg/kg	21	155	NoA
1	Selenium	20	mg/kg	0.8	39.1	NoA
1	Silver	10	mg/kg	2.3	39.1	NoA
1	Thallium	0.44	mg/kg	0.21	0.0782	Yes
1	Uranium	20	mg/kg	4.9	23.4	NoA
1	Vanadium	70	mg/kg	38	39.3	Yes
1	PCB, Total	5	mg/kg		0.0782	Yes
1	Americium-241	0.00873	pCi/g		3.03	NoA
1	Cesium-137	0.0373	pCi/g	0.49	0.116	NoAB
1	Plutonium-238	0.2	pCi/g	0.073	4.42	NoA
1	Plutonium-239/240	0.0327	pCi/g	0.025	3.87	NoA
1	1,2,4-Trichlorobenzene	0.36	mg/kg			NoC
1	1,2-Dichlorobenzene	0.36	mg/kg			NoC
1	1,3-Dichlorobenzene	0.36	mg/kg			NoC
1	1,4-Dichlorobenzene	0.36	mg/kg			NoC
1	2,4,5-Trichlorophenol	0.36	mg/kg			NoC
1	2,4,6-Trichlorophenol	0.36	mg/kg			NoC
1	2,4-Dichlorophenol	0.36	mg/kg			NoC
1	2,4-Dimethylphenol	0.36	mg/kg			NoC
1	2,4-Dinitrophenol	1.8	mg/kg			NoC
1	2,4-Dinitrotoluene	0.36	mg/kg			NoC
1	2,6-Dinitrotoluene	0.36	mg/kg			NoC
1	2-Chloronaphthalene	0.36	mg/kg			NoC
1	2-Chlorophenol	0.36	mg/kg			NoC
1	2-Methyl-4,6-dinitrophenol	1.8	mg/kg			NoC
1	2-Methylnaphthalene	0.36	mg/kg			NoC
1	2-Methylphenol	0.36	mg/kg			NoC
1	2-Nitrobenzenamine	1.8	mg/kg		33.2	NoA
1	2-Nitrophenol	0.36	mg/kg			NoC
1	3,3'-Dichlorobenzidine	1.8	mg/kg			NoC
1	3-Nitrobenzenamine	1.8	mg/kg			NoC
1	4-Bromophenyl phenyl ether	0.36	mg/kg			NoC
1	4-Chloro-3-methylphenol	0.36	mg/kg			NoC
1	4-Chlorobenzenamine	0.36	mg/kg			NoC
1	4-Chlorophenyl phenyl ether	0.36	mg/kg			NoC

Table D4.1. Surface Soil COPCs for Nondetected Analyses (Continued)

EU	Chemical	Maximum Nondetect Reporting Limit	Units	Surface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
1	4-Nitrophenol	1.8	mg/kg			NoC
1	Acenaphthene	0.36	mg/kg		171	NoA
1	Acenaphthylene	0.36	mg/kg		171	NoA
1	Anthracene	0.36	mg/kg		854	NoA
1	Benzenemethanol	0.36	mg/kg			NoC
1	Benzoic acid	1.8	mg/kg			NoC
1	Bis(2-chloroethoxy)methane	0.36	mg/kg			NoC
1	Bis(2-chloroethyl) ether	0.0073	mg/kg			NoC
1	Bis(2-chloroisopropyl) ether	0.36	mg/kg			NoC
1	Bis(2-ethylhexyl)phthalate	0.36	mg/kg		14.3	NoA
1	Butyl benzyl phthalate	0.36	mg/kg			NoC
1	Dibenzofuran	0.36	mg/kg			NoC
1	Diethyl phthalate	0.36	mg/kg			NoC
1	Dimethyl phthalate	0.36	mg/kg			NoC
1	Di-n-butyl phthalate	0.36	mg/kg			NoC
1	Di-n-octylphthalate	0.36	mg/kg			NoC
1	Fluorene	0.36	mg/kg		114	NoA
1	Hexachlorobenzene	0.36	mg/kg		0.126	Yes
1	Hexachlorobutadiene	0.36	mg/kg			NoC
1	Hexachlorocyclopentadiene	1.8	mg/kg			NoC
1	Hexachloroethane	0.36	mg/kg			NoC
1	Isophorone	0.36	mg/kg			NoC
1	m,p-Cresol	0.73	mg/kg			NoC
1	Naphthalene	0.36	mg/kg		3.83	NoA
1	Nitrobenzene	1.8	mg/kg			NoC
1	N-Nitroso-di-n-propylamine	0.0073	mg/kg		0.0287	NoA
1	N-Nitrosodiphenylamine	0.36	mg/kg			NoC
1	Pentachlorophenol	1.8	mg/kg		0.243	Yes
1	Phenol	0.36	mg/kg			NoC
1	p-Nitroaniline	1.8	mg/kg			NoC
1	Pyridine	0.73	mg/kg			NoC
2	Antimony	0.34	mg/kg	0.21	3.13	NoA
2	Arsenic	11	mg/kg	12	0.267	NoB
2	Cadmium	12	mg/kg	0.21	5.07	Yes
2	Chromium	85	mg/kg	16	0.301	Yes
2	Copper	35	mg/kg	19	313	NoA
2	Mercury	10	mg/kg	0.2	2.35	Yes
2	Molybdenum	15	mg/kg		39.1	NoA
2	Nickel	65	mg/kg	21	155	NoA
2	Selenium	20	mg/kg	0.8	39.1	NoA
2	Silver	10	mg/kg	2.3	39.1	NoA
2	Thallium	0.096	mg/kg	0.21	0.0782	NoB
2	Uranium	20	mg/kg	4.9	23.4	NoA

Table D4.1. Surface Soil COPCs for Nondetected Analyses (Continued)

EU	Chemical	Maximum Nondetect Reporting Limit	Units	Surface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
2	Vanadium	70	mg/kg	38	39.3	Yes
2	PCB, Total	5	mg/kg		0.0782	Yes
2	Americium-241	0.013	pCi/g		3.03	NoA
2	Neptunium-237	0.04	pCi/g	0.1	0.239	NoAB
2	Plutonium-238	0.02	pCi/g	0.073	4.42	NoAB
2	1,2,4-Trichlorobenzene	0.35	mg/kg			NoC
2	1,2-Dichlorobenzene	0.35	mg/kg			NoC
2	1,3-Dichlorobenzene	0.35	mg/kg			NoC
2	1,4-Dichlorobenzene	0.35	mg/kg			NoC
2	2,4,5-Trichlorophenol	0.35	mg/kg			NoC
2	2,4,6-Trichlorophenol	0.35	mg/kg			NoC
2	2,4-Dichlorophenol	0.35	mg/kg			NoC
2	2,4-Dimethylphenol	0.35	mg/kg			NoC
2	2,4-Dinitrophenol	1.7	mg/kg			NoC
2	2,4-Dinitrotoluene	0.35	mg/kg			NoC
2	2,6-Dinitrotoluene	0.35	mg/kg			NoC
2	2-Chloronaphthalene	0.35	mg/kg			NoC
2	2-Chlorophenol	0.35	mg/kg			NoC
2	2-Methyl-4,6-dinitrophenol	1.7	mg/kg			NoC
2	2-Methylphenol	0.35	mg/kg			NoC
2	2-Nitrobenzenamine	1.7	mg/kg		33.2	NoA
2	2-Nitrophenol	0.35	mg/kg			NoC
2	3,3'-Dichlorobenzidine	1.7	mg/kg			NoC
2	3-Nitrobenzenamine	1.7	mg/kg			NoC
2	4-Bromophenyl phenyl ether	0.35	mg/kg			NoC
2	4-Chloro-3-methylphenol	0.35	mg/kg			NoC
2	4-Chlorobenzenamine	0.35	mg/kg			NoC
2	4-Chlorophenyl phenyl ether	0.35	mg/kg			NoC
2	4-Nitrophenol	1.7	mg/kg			NoC
2	Acenaphthylene	0.35	mg/kg		171	NoA
2	Benzenemethanol	0.35	mg/kg			NoC
2	Benzoic acid	1.7	mg/kg			NoC
2	Bis(2-chloroethoxy)methane	0.35	mg/kg			NoC
2	Bis(2-chloroethyl) ether	0.007	mg/kg			NoC
2	Bis(2-chloroisopropyl) ether	0.35	mg/kg			NoC
2	Bis(2-ethylhexyl)phthalate	0.35	mg/kg		14.3	NoA
2	Butyl benzyl phthalate	0.35	mg/kg			NoC
2	Diethyl phthalate	0.35	mg/kg			NoC
2	Dimethyl phthalate	0.35	mg/kg			NoC
2	Di-n-butyl phthalate	0.35	mg/kg			NoC
2	Di-n-octylphthalate	0.35	mg/kg			NoC
2	Hexachlorobenzene	0.35	mg/kg		0.126	Yes
2	Hexachlorobutadiene	0.35	mg/kg			NoC

Table D4.1. Surface Soil COPCs for Nondetected Analyses (Continued)

EU	Chemical	Maximum Nondetect Reporting Limit	Units	Surface Background Concentration[a]	Child Resident NAL[b]	COPC?[c]
2	Hexachlorocyclopentadiene	1.7	mg/kg			NoC
2	Hexachloroethane	0.35	mg/kg			NoC
2	Isophorone	0.35	mg/kg			NoC
2	m,p-Cresol	0.7	mg/kg			NoC
2	Nitrobenzene	1.7	mg/kg			NoC
2	N-Nitroso-di-n-propylamine	0.007	mg/kg		0.0287	NoA
2	N-Nitrosodiphenylamine	0.35	mg/kg			NoC
2	Pentachlorophenol	1.7	mg/kg		0.243	Yes
2	Phenol	0.35	mg/kg			NoC
2	p-Nitroaniline	1.7	mg/kg			NoC
2	Pyridine	0.7	mg/kg			NoC

[a] See Table D.3.
[b] Risk-based screening values are from DOE 2015. The screening values are the lesser of the HI and ELCR NALs used for the child resident of 0.1 and 1E-06, respectively (DOE 2015).
[c] Explanations for chemicals not being COPCs are listed below.
A – Maximum result is less than child resident NAL.
B – Maximum result is less than background value.
C – No toxicity information is available for screening.

Table D4.2. Noncarcinogenic CDIs for the Current Industrial Worker Exposed to Surface Soil for Nondetect Uncertainty Evaluation

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation
1	Antimony	mg/kg	3.00E+01	7.19E-07		6.19E-10
1	Cadmium	mg/kg	1.20E+01	2.88E-07	2.03E-08	2.47E-10
1	Chromium	mg/kg	8.50E+01	2.04E-06		1.75E-09
1	Mercury	mg/kg	1.00E+01	2.40E-07		2.06E-10
1	Thallium	mg/kg	4.40E-01	1.05E-08		9.07E-12
1	Vanadium	mg/kg	7.00E+01	1.68E-06		1.44E-09
1	Hexachlorobenzene	mg/kg	3.60E-01	8.63E-09		6.77E-08
1	PCB, Total	mg/kg	5.00E+00	1.20E-07	1.18E-06	1.03E-10
1	Pentachlorophenol	mg/kg	1.80E+00	4.32E-08	7.61E-07	3.71E-11
2	Cadmium	mg/kg	1.20E+01	2.88E-07	2.03E-08	2.47E-10
2	Chromium	mg/kg	8.50E+01	2.04E-06		1.75E-09
2	Mercury	mg/kg	1.00E+01	2.40E-07		2.06E-10
2	Vanadium	mg/kg	7.00E+01	1.68E-06		1.44E-09
2	Hexachlorobenzene	mg/kg	3.50E-01	8.39E-09		6.58E-08
2	PCB, Total	mg/kg	5.00E+00	1.20E-07	1.18E-06	1.03E-10
2	Pentachlorophenol	mg/kg	1.70E+00	4.08E-08	7.19E-07	3.51E-11

Table D4.3. Carcinogenic CDIs for the Current Industrial Worker Exposed to Surface Soil for Nondetect Uncertainty Evaluation

EU	COPC	Units	EPC	Ingestion	Dermal	Inhalation	External Exposure
1	Antimony	mg/kg	3.00E+01	2.57E-07		2.21E-07	
1	Cadmium	mg/kg	1.20E+01	1.03E-07	7.25E-09	8.84E-08	
1	Chromium	mg/kg	8.50E+01	7.28E-07		6.26E-07	
1	Mercury	mg/kg	1.00E+01	8.56E-08		7.36E-08	
1	Thallium	mg/kg	4.40E-01	3.77E-09		3.24E-09	
1	Vanadium	mg/kg	7.00E+01	5.99E-07		5.16E-07	
1	Hexachlorobenzene	mg/kg	3.60E-01	3.08E-09		2.42E-05	
1	PCB, Total	mg/kg	5.00E+00	4.28E-08	4.23E-07	3.68E-08	
1	Pentachlorophenol	mg/kg	1.80E+00	1.54E-08	2.72E-07	1.33E-08	
2	Cadmium	mg/kg	1.20E+01	1.03E-07	7.25E-09	8.84E-08	
2	Chromium	mg/kg	8.50E+01	7.28E-07		6.26E-07	
2	Mercury	mg/kg	1.00E+01	8.56E-08		7.36E-08	
2	Vanadium	mg/kg	7.00E+01	5.99E-07		5.16E-07	
2	Hexachlorobenzene	mg/kg	3.50E-01	3.00E-09		2.35E-05	
2	PCB, Total	mg/kg	5.00E+00	4.28E-08	4.23E-07	3.68E-08	
2	Pentachlorophenol	mg/kg	1.70E+00	1.46E-08	2.57E-07	1.25E-08	

Table D4.4. HIs for the Current Industrial Worker for Nondetect Uncertainty Evaluation

COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	HI	Percent
EU 1						
Cadmium	1.20E+01	2.88E-04	8.12E-04	2.47E-05	0.00	0%
Chromium	8.50E+01	1.36E-06			0.00	0%
Mercury	1.00E+01	7.99E-04			0.00	0%
Thallium	4.40E-01	1.05E-03			0.00	0%
Vanadium	7.00E+01	3.33E-04		1.44E-05	0.00	0%
Antimony	3.00E+01	1.80E-03			0.00	0%
Pentachlorophenol	1.80E+00	8.63E-06	1.52E-04		0.00	0%
Hexachlorobenzene	3.60E-01	1.08E-05			0.00	0%
Totals		**4.29E-03**	**9.64E-04**	**3.92E-05**	**0**	
Percent		**81%**	**18%**	**1%**		
EU 2						
Chromium	8.50E+01	1.36E-06			0.00	0%
Mercury	1.00E+01	7.99E-04			0.00	0%
Vanadium	7.00E+01	3.33E-04		1.44E-05	0.00	0%
Cadmium	1.20E+01	2.88E-04	8.12E-04	2.47E-05	0.00	0%
Hexachlorobenzene	3.50E-01	1.05E-05			0.00	0%
Pentachlorophenol	1.70E+00	8.15E-06	1.44E-04		0.00	0%
Totals		**1.44E-03**	**9.55E-04**	**3.92E-05**	**0**	
Percent		**59%**	**39%**	**2%**		

Table D4.5. ELCR for the Current Industrial Worker for Nondetect Uncertainty Evaluation

COPC	EPC (mg/kg or pCi/g)	Ingestion	Dermal	Inhalation	External Exposure	ELCR	Percent
EU 1							
Chromium	8.50E+01			5.26E-08		5.26E-08	3.9%
Cadmium	1.20E+01			1.59E-10		1.59E-10	0.0%
Pentachlorophenol	1.80E+00	6.16E-09	1.09E-07	2.37E-07		3.52E-07	26.0%
PCB, Total	5.00E+00	8.56E-08	8.46E-07	2.10E-11		9.31E-07	68.9%
Hexachlorobenzene	3.60E-01	4.93E-09		1.11E-08		1.61E-08	1.2%
Totals		**9.67E-08**	**9.54E-07**	**3.01E-07**		**1.35E-06**	
Percent		**7%**	**71%**	**22%**			
EU 2							
Chromium	8.50E+01			5.26E-08		5.26E-08	4.0%
Cadmium	1.20E+01			1.59E-10		1.59E-10	0.0%
Pentachlorophenol	1.70E+00	5.82E-09	1.03E-07	2.23E-07		3.32E-07	24.9%
PCB, Total	5.00E+00	8.56E-08	8.46E-07	2.10E-11		9.31E-07	69.9%
Hexachlorobenzene	3.50E-01	4.79E-09		1.08E-08		1.56E-08	1.2%
Totals		**9.62E-08**	**9.48E-07**	**2.87E-07**		**1.33E-06**	
Percent		**7%**	**71%**	**22%**			

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ATTACHMENT D5

SUMMARY OF SWMU 229 RISK CHARACTERIZATION USING KENTUCKY ABS VALUES

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Table D5.1. Alternate Summary of Risk Characterization using KY ABS Values for SWMU 229, EU 1

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Current Industrial Worker (surface soil)	**7.1E-05**	Uranium-234 Uranium-235 Uranium-238	2% 21% 76%	Ingestion Dermal Inhalation External exposure	5% 0% 1% 95%	**< 1**	*No COCs		Ingestion Dermal Inhalation	
Future Industrial Worker (surface soil)	**1.3E-03**	PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	0% 1% 2% 21% 76%	Ingestion Dermal Inhalation External exposure	5% 0% 1% 95%	**4.3**	Antimony Nickel Uranium	92% 3% 2%	Ingestion Dermal Inhalation	5% 95% 0%
Outdoor Worker (surface soil)	**1.3E-03**	PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	0% 0% 14% 16% 69%	Ingestion Dermal Inhalation External exposure	31% 0% 0% 68%	**4.4**	Antimony Nickel Uranium	89% 3% 5%	Ingestion Dermal Inhalation	31% 69% 0%
Outdoor Worker (surface and subsurface soil)	**1.3E-03**	Arsenic PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	2% 0% 0% 14% 16% 68%	Ingestion Dermal Inhalation External exposure	32% 0% 0% 67%	**5.2**	Antimony Arsenic Mercury Nickel Uranium	77% 3% 11% 2% 4%	Ingestion Dermal Inhalation	31% 69% 0%
Excavation Worker (surface and subsurface soil)	**2.7E-04**	Arsenic Neptunium-237 Uranium-234 Uranium-235 Uranium-238	2% 0% 14% 16% 68%	Ingestion Dermal Inhalation External exposure	32% 0% 0% 67%	**5.2**	Antimony Arsenic Mercury Nickel Uranium	77% 3% 11% 2% 4%	Ingestion Dermal Inhalation	31% 69% 0%
Future Adult Resident (surface soil)	**4.6E-03**	PAH, Total Neptunium-237 Uranium-234 Uranium-235 Uranium-238	0% 0% 6% 20% 74%	Ingestion Dermal Inhalation External exposure	14% 0% 0% 85%	**10.4**	Antimony Barium Nickel Uranium	92% 2% 3% 2%	Ingestion Dermal Inhalation	5% 95% 0%
Future Child Resident (surface soil)	See Future Adult Resident					**26.4**	Antimony Barium Cadmium Nickel Uranium	90% 1% 2% 3% 4%	Ingestion Dermal Inhalation	22% 78% 0%

Table D5.1. Alternate Summary of Risk Characterization using KY ABS Values for SWMU 229, EU 1 (Continued)

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Future Adult Recreational User (surface soil)	**7.4E-04**	PAH, Total	0%	Ingestion	33%	**3.1**	Antimony	92%	Ingestion	5%
		Neptunium-237	0%	Dermal	0%				Dermal	95%
		Uranium-234	13%	Inhalation	0%				Inhalation	0%
		Uranium-235	16%	External exposure	67%					
		Uranium-238	70%							
Future Teen Recreational User (surface soil)	See Future Adult Recreational User					**9.3**	Antimony	92%	Ingestion	4%
							Barium	2%	Dermal	96%
							Nickel	3%	Inhalation	0%
							Uranium	2%		
Future Child Recreational User (surface soil)	See Future Adult Recreational User					**10.6**	Antimony	90%	Ingestion	22%
							Barium	1%	Dermal	78%
							Cadmium	2%	Inhalation	0%
							Nickel	3%		
							Uranium	4%		

Total ELCR and total HI represent total risk or hazard summed across all routes of exposure for all COPCs.

*No COCs = There are no COCs.

ELCR for Future Adult Resident and Future Child Resident are the combined lifetime scenario.

ELCR for Future Adult Recreational User, Future Teen Recreational User and Future Child Recreational User are the combined lifetime scenario.

Table D5.2. Alternate Summary of Risk Characterization Using Kentucky ABS Values for SWMU 229, EU 2

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Current Industrial Worker (surface soil)	**2.9E-06**	PAH, Total	37%	Ingestion	14%	**< 1**	*No COCs		Ingestion	
				Dermal	53%				Dermal	
				Inhalation	1%				Inhalation	
				External exposure	32%					
Future Industrial Worker (surface soil)	**5.2E-05**	Arsenic	29%	Ingestion	14%	**3.2**	Antimony	88%	Ingestion	5%
		PAH, Total	37%	Dermal	53%		Nickel	5%	Dermal	95%
		Neptunium-237	2%	Inhalation	1%				Inhalation	0%
		Uranium-235	4%	External exposure	32%					
		Uranium-238	27%							
Outdoor Worker (surface soil)	**8.6E-05**	Arsenic	49%	Ingestion	61%	**3.5**	Antimony	82%	Ingestion	35%
		PAH, Total	31%	Dermal	24%		Arsenic	8%	Dermal	65%
		Uranium-234	2%	Inhalation	0%		Nickel	4%	Inhalation	0%
		Uranium-235	2%	External exposure	15%		Uranium	3%		
		Uranium-238	15%							
Outdoor Worker (surface and subsurface soil)	**8.8E-05**	Arsenic	48%	Ingestion	60%	**3.9**	Antimony	72%	Ingestion	32%
		PAH, Total	30%	Dermal	23%		Arsenic	7%	Dermal	68%
		Cesium-137	2%	Inhalation	1%		Mercury	12%	Inhalation	0%
		Uranium-234	2%	External exposure	17%		Nickel	3%		
		Uranium-235	2%				Uranium	3%		
		Uranium-238	15%							
Excavation Worker (surface and subsurface soil)	**1.7E-05**	Arsenic	48%	Ingestion	59%	**3.9**	Antimony	72%	Ingestion	32%
		PAH, Total	30%	Dermal	23%		Arsenic	7%	Dermal	68%
		Uranium-238	15%	Inhalation	1%		Mercury	12%	Inhalation	0%
				External exposure	17%		Nickel	3%		
							Uranium	3%		
Future Adult Resident (surface soil)	**2.2E-04**	Arsenic	36%	Ingestion	33%	**7.8**	Antimony	88%	Ingestion	6%
		PAH, Total	34%	Dermal	42%		Arsenic	3%	Dermal	94%
		Neptunium-237	2%	Inhalation	0%		Barium	2%	Inhalation	0%
		Uranium-234	1%	External exposure	25%		Nickel	5%		
		Uranium-235	3%				Uranium	2%		
		Uranium-238	23%							

Table D5.2. Alternate Summary of Risk Characterization Using Kentucky ABS Values for SWMU 229, EU 2 (Continued)

Receptor	Total ELCR	COCs	% Total ELCR	Routes of Exposure	% Total ELCR	Total HI	COCs	% Total HI	Routes of Exposure	% Total HI
Future Child Resident (surface soil)	See Future Adult Resident					**20.4**	Antimony	84%	Ingestion	25%
							Arsenic	6%	Dermal	75%
							Barium	1%	Inhalation	0%
							Cadmium	2%		
							Nickel	4%		
							Uranium	2%		
Future Adult Recreational User (surface soil)	**7.8E-05**	Arsenic	44%	Ingestion	37%	**2.3**	Antimony	88%	Ingestion	6%
		PAH, Total	43%	Dermal	54%		Nickel	5%	Dermal	94%
		Uranium-238	10%	Inhalation	0%				Inhalation	0%
				External exposure	9%					
Future Teen Recreational User (surface soil)	See Future Adult Recreational User					**7.0**	Antimony	88%	Ingestion	5%
							Arsenic	3%	Dermal	95%
							Barium	2%	Inhalation	0%
							Nickel	5%		
							Uranium	1%		
Future Child Recreational User (surface soil)	See Future Adult Recreational User					**8.1**	Antimony	84%	Ingestion	25%
							Arsenic	6%	Dermal	75%
							Barium	1%	Inhalation	0%
							Cadmium	2%		
							Nickel	4%		
							Uranium	2%		

Total ELCR and total HI represent total risk or hazard summed across all routes of exposure for all COPCs.

*No COCs = There are no COCs.

ELCR for Future Adult Resident and Future Child Resident are the combined lifetime scenario.

ELCR for Future Adult Recreational User, Future Teen Recreational User and Future Child Recreational User are the combined lifetime scenario.

APPENDIX E

SCREENING ECOLOGICAL RISK ASSESSMENT

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CONTENTS

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FIGURES

TABLES

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ACRONYMS

AOC	area of concern
COPEC	chemical of potential ecological concern
CSM	conceptual site model
DMSA	DOE Material Storage Area
DOE	U.S. Department of Energy
EPC	exposure point concentration
ESV	ecological screening value
HI	hazard index
HQ	hazard quotient
NFA	no further action
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PGDP	Paducah Gaseous Diffusion Plant
RI	remedial investigation
SERA	screening ecological risk assessment
SVOC	semivolatile organic compound
SWMU	solid waste management unit
UCL	upper confidence limit
VOC	volatile organic compound
WKWMA	West Kentucky Wildlife Management Area

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E.1. INTRODUCTION

E.1.1 SITE LOCATION

This appendix provides the results of the screening ecological risk assessments (SERAs) completed for Soils Operable Unit (OU) Remedial Investigation (RI) 2 Solid Waste Management Unit (SWMU) 229 at the Paducah Gaseous Diffusion Plant (PGDP) (Figure E.1). Some of the area surrounding the PGDP facility is a recreational wildlife area, the West Kentucky Wildlife Management Area (WKWMA), with residential areas lying beyond the WKWMA. Private land in rural residential and agricultural areas also borders the PGDP facility.

E.1.2 SITE HISTORY

SWMU 229 is described in-depth in Chapter 5 of this RI Report.

E.2. PROBLEM FORMULATION

The first step in a SERA includes the problem formulation. This step encompasses development of the preliminary conceptual site model (CSM), determination of potentially complete exposure pathways and potentially contaminated media, selection of exposure endpoints, and selection of screening levels protective of the endpoints and potentially exposed receptors at the site.

E.2.1 PRELIMINARY CONCEPTUAL SITE MODEL

The preliminary CSM includes a description of the environmental setting, known site contaminants, and a figure (Figure E.2) representing the potential exposure pathways. The figure shows several pathways as incomplete because groundwater recharge to surface water is not expected as a potential release mechanism at SWMU 229. This preliminary CSM is used as the basis for selection of benchmark values used to screen the site for potential ecological risk. The primary ecological receptors (i.e., the exposure endpoints) shown in the preliminary CSM are terrestrial animals and terrestrial plants. Specific groups included in terrestrial animals and plants which are the exposure endpoints shown in the preliminary CSM include reptiles and amphibians, birds, and mammals (see Section E.2.1.1). Screening values are protective of these endpoints and are discussed in Section E.3.

E.2.1.1 Site Environmental Setting and Habitat Descriptions

SWMU 229 is located inside the Limited Area. Although there is potential for contamination below the surface to migrate laterally toward surface water, the direction of shallow groundwater flow is primarily downward and represents limited risks to terrestrial receptors near these sites. This section presents a brief summary of the ecosystem relevant to defining the CSM and exposure pathways. Table E.1 and the text below describe ground cover and proximity to surface water/drainageways for SWMU 229. Figure E.3 displays a photograph of SWMU 229.

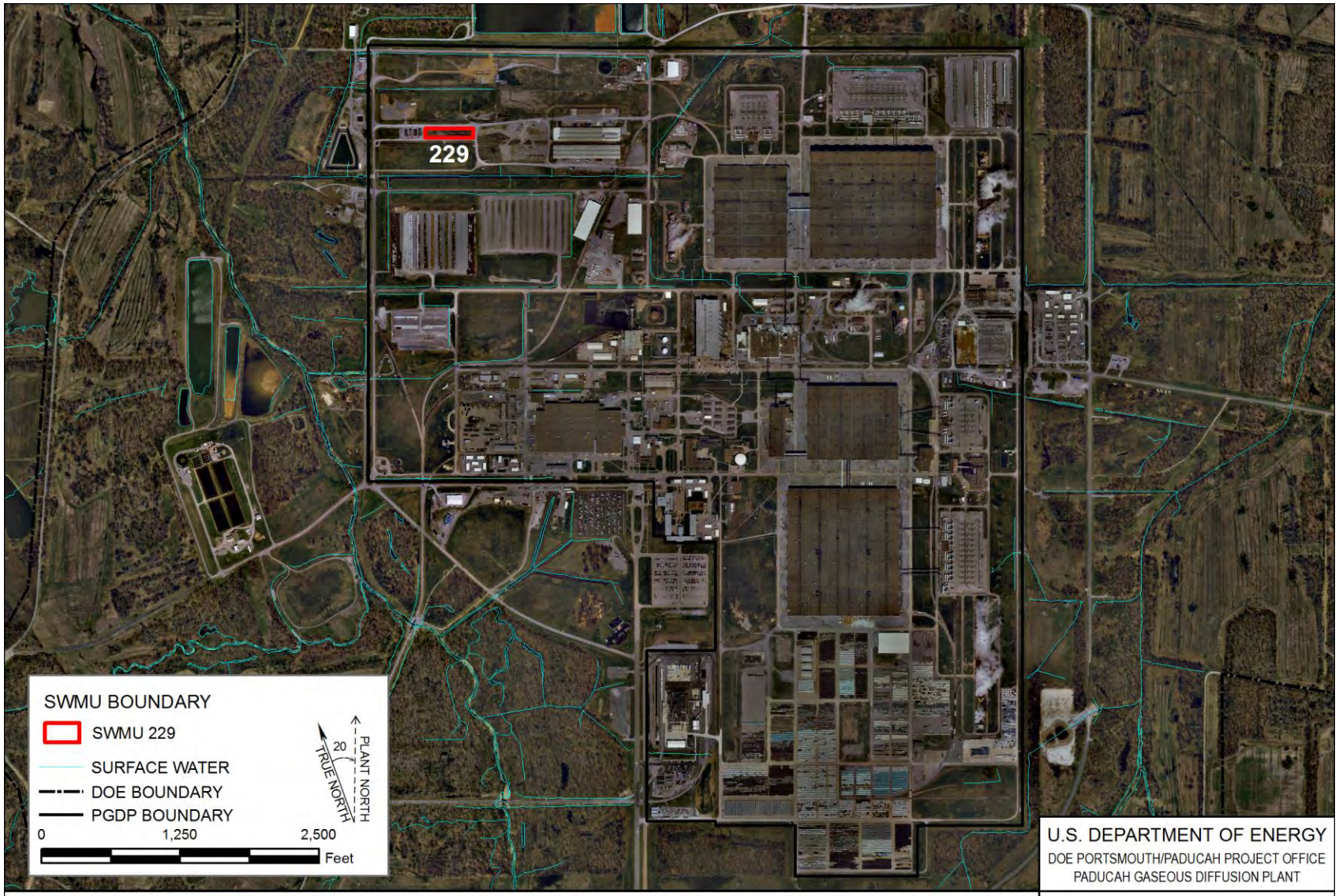

Figure E.1. Location of the Soils OU RI 2 SWMU 229

11/9/2015 G:\GIS\ARCVIEWS\PROJECTS\SoilsOU\RI Report\RI2 D1\229_E1 SWMU location.mxd

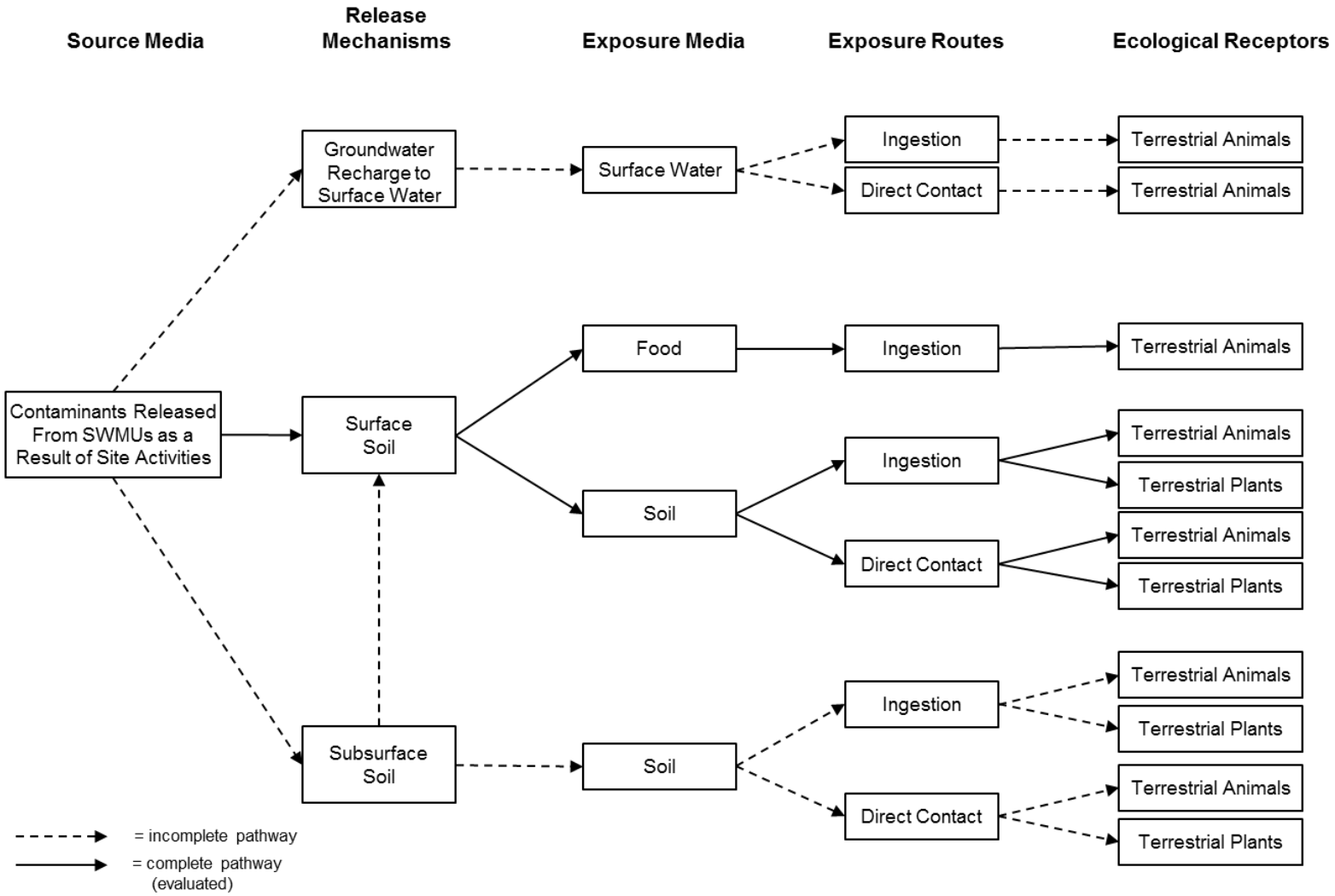

Figure E.2. Preliminary Conceptual Site Model for SWMU 229

Table E.1. Ecological Screening

Description	SWMU	Area Acres	Ground Cover	Near a Surface Water Body?	Total HI[a]	Priority COPECs	Background (mg/kg)[b]	Maximum Detection or ½ Maximum Detection Limit (mg/kg)	Soil ESV (mg/kg)	EPC (mg/kg)	HQ[a]
DMSA OS-18	229	0.849	soil/gravel mix	No	741.6	Aluminum	13000	6210	50	6210	124.2
						Antimony	0.21	150.45	0.27	104.8	388.1
						Cadmium	0.21	21.18	0.36	15.67	43.5
						Iron	28000	27400	200	14399	72.0
						Mercury	0.2	5	0.1	5	50.0
						Selenium	0.8	10	0.52	10	19.2
						Uranium	4.9	155.81	5	71.61	14.3

[a] The total Hazard Index (HI) includes contributions from all of the COPECs (listed in Table E3.1); only priority COPECs [i.e., the COPECs with HQs greater than 10, using the EPCs (Section E.3)] are shown in this table.

[b] Background values are for surface soil taken from DOE 2015a; ecological screening values (ESVs) are taken from DOE 2015b and Attachment E1.

Figure E.3. Photograph of SWMU 229
(Photo east looking west)
September 26, 2003

The human health and ecological risk assessments utilized acreage for a SWMU based on Global Positioning System coordinates and mapping tools. This acreage is reflected in the figures within this document. Of note, the acreage presented in the Background section of this document may be inconsistent with acreage utilized in the risk assessments due to its being based on historical safety analysis report administrative boundaries, which typically were estimated utilizing a map/figure.

SWMU 229 is an outside U.S. Department of Energy (DOE) Material Storage Area (DMSA). The area stored empty drums. There is no surface water body near the SWMU; however, SWMU 229 is poorly drained and stays wet with ponded water most of the year.

The primary ecosystem in the area outside the industrial area around SWMU 229 is upland grassland interspersed with developed industrial areas. The vegetation over SWMU 229 is maintained with routine mowing (see Section 3.1) approximately eight times per year. SWMU 229 also is surrounded by roads and is within the PGDP fenced area. The buffer area and areas bordering the PGDP facility include forest, thickets, and agricultural land. Much of the PGDP facility is surrounded by the WKWMA, which includes managed native prairie and deciduous forest. Species documented to occur in the area include numerous small mammals, particularly shrews, mice, and voles. Numerous bird species, including doves, turkey, quail, bluebirds and other songbirds, as well as hawks and owls, are found in this area. There also are amphibians, reptiles (primarily lizards and turtles), and bats. Table E.2 lists species observed in the nonindustrial areas of the PGDP and at the adjacent WKWMA.

Table E.2. Wildlife Species Present or Potentially Present at the PGDP Site*

Common Name	Scientific Name
Fish	
Black buffalo	*Ictiobus niger*
Blackspotted topminnow	*Fundulus olivaceus*
Creek chub	*Semotilus atromaculatus*
Bluegill sunfish	*Lepomis macrochirus*
Green sunfish	*Lepomis cyanellus*
Redspotted sunfish	*Lepomis miniatus*
Largemouth bass	*Micropterus salmoides*
Longear sunfish	*Lepomis megalotis*
Stoneroller	*Campostoma sp.*
Reptiles and Amphibians	
American toad	*Bufo americanus*
Bull frog	*Rana catesbeiana*
Eastern box turtle	*Terrapene carolina*
Leopard frog	*Rana sphenocephala*
Salamanders	Various species
Snakes	Various species
Green treefrog	*Hyla cinerea*
Woodhouse toad	*Bufo woodhousei*
Northern crawfish frog	*Rana areolata circulosa*
Green frog	*Rana clamitans melanota*
Upland chorus frog	*Pseudacris triseriata feriiarum*
Birds	
American robin	*Turdus migratorius*
American woodcock	*Scolopax minor*
Bald eagle	*Haliaeetus leucocephalus*
Barred owl	*Strix varia*
Belted kingfisher	*Ceryle alcyon*
Blue jay	*Cyanocitta cristata*
Blue-winged teal	*Anas discors*
Canada goose	*Branta canadensis*
Coot	*Fulica americana*
American crow	*Corvus brachyrhynchos*
Downy woodpecker	*Picoides pubescens*
Eastern bluebird	*Sialia sialus*
Eastern kingbird	*Tyrannus tyrannus*
Eastern meadowlark	*Sturnella magna*
Eastern phoebe	*Sayornis phoebe*
Eastern wood pewee	*Contopus virens*
Gadwall duck	*Anas strepera*
Great blue heron	*Ardea herodias*
Great crested flycatcher	*Myiarchus crinitus*
Great-horned owl	*Bubo virginianus*
Hairy woodpecker	*Picoides villosus*
Hawks	Various species
Herons and egrets	Various species
Killdeer	*Charadrius vociferus*
Loggerhead shrike	*Lanius ludovicianus*
Mallard duck	*Anas platyrhynchus*
Mourning dove	*Zenaida macroura*
Northern bobwhite (aka bobwhite quail)	*Colinus virgianus*
Northern cardinal	*Cardinalis cardinalis*

Table E.2. Wildlife Species Present or Potentially Present at the PGDP Site* (Continued)

Common Name	Scientific Name
Bird (Continued)	
Northern flicker	*Colaptes auratus*
Pileated woodpecker	*Dryocopus pileatus*
Red-bellied woodpecker	*Melanerpes erythrocephalus*
Red-shouldered hawk	*Buteo lineatus*
Red-tailed hawk	*Buteo jamaicensis*
Red-winged blackbird	*Agelaius phoeniceus*
Ruby-throated hummingbird	*Archilochus colubris*
Screech owl	*Megascops asio*
Song sparrow	*Melospiza melodia*
Swallows	Various species
Vireos	Various *vireo sp.*
Tufted titmouse	*Baeolophus bicolor*
Turkey vulture	*Cathartes aura*
Warblers	*Various species*
Chuck-will's widow	*Caprimulgus carolinensis*
White-breasted nuthatch	*Sitta carolinensis*
Whip-poor-will	*Caprimulgis vocifierous*
Wild turkey	*Meleagris gallopavo*
Wood cock	*Scolopax minor*
Wood duck	*Aix sponsa*
Wrens	Various species
Yellow-billed cuckoo	*Coccyzus americanus*
Mammals	
American beaver	*Castor canadensis*
American mink (aka mink)	*Mustela vison*
Bobcat	*Lynx rufus*
Common muskrat	*Ondatra zibethicus*
Coyote	*Canis latrans*
Eastern cottontail	*Sylvilagus floridanus*
Eastern grey squirrel and fox squirrel	*Sciurus carolinensis*
Evening bat	*Nycticeceius humeralis*
Groundhog	*Marmota monax*
Indiana bat	*Myotis sodalis*
Mice	Various species
Moles	Various species
Opposum	*Didelphis virginiana*
Raccoon	*Procyon lotor*
Red fox	*Vuples vulpes*
Grey fox	*Urocyon cinereoargenteus*
Shrews	Various species
Skunk	*Mephitis mephitis*
Southeastern myotis bat	*Myotis sodalis*
Voles	Various species
White-tailed deer	*Odocoileus virginianus*

*The listed species are from the Surface Water OU Report (DOE 2008) and the WKWMA species information Web site (http://fw.ky.gov/kfwis/arcims/WmaSpecies.asp?strID=137.

A number of state and federal listed, threatened, and endangered species may be present on the buffer areas within PGDP and the surrounding WKWMA land, though they are unlikely to be found on the maintained surface within SWMU 229 (DOE 2008). These species are listed in Table E.2 of this

document. As noted in the footnote to Table E.3, none of the species listed in the table have been reported as sighted on the DOE Reservation.

Table E.3. Federally Listed, Proposed, and Candidate Species Potentially Occurring within the Paducah Site Study Area[a]

Group	Common Name	Scientific Name	Endangered Species Act Status
Mammals	Indiana Bat	*Myotis sodalis*	Endangered
	Northern Long-eared Bat	*Myotis septentrionalis*	Proposed
Mussels	Fanshell	*Cyprogenia stegaria*	Endangered
	Pink Mucket	*Lampsilis abrupta*	Endangered
	Ring Pink	*Obovaria retusa*	Endangered
	Orangefoot Pimpleback	*Plethobasus cooperianus*	Endangered
	Clubshell	*Pleurobema clava*	Endangered
	Rough Pigtoe	*Pleurobema plenum*	Endangered
	Fat Pocketbook	*Potamilus capax*	Endangered
	Spectaclecase	*Cumberlandia monodonta*	Endangered
	Sheepnose	*Plethobasus cyphyus*	Endangered
	Rabbitsfoot	*Quadrula c. cylindrical*	Threatened
Birds	Interior Least Tern	*Sterna antillarum athalassos*	Endangered

[a] All of the listed species are identified as an Endangered, Threatened, or Candidate Species known or with the potential to be located within McCracken County, Kentucky, by the U.S. Fish and Wildlife Service (November 2013).

E.2.1.2 Data

The dataset for surface soils (i.e., 0–1 ft bgs) used in the SERA is comprised of historical sampling events as well as data collected during the fall of 2015 for this RI (DOE 2014). Chapter 5 describes the data set used for SWMU 229. Chapter 4 describes the use of grids to subdivide data by location. Appendix B addresses data quality and applicability of the historical data.

For purposes of this SERA, high molecular weight polycyclic aromatic hydrocarbons (PAHs) consist of the following: benz(a)anthracene; benzo(a)pyrene; benzo(b)fluoranthene; benzo(k)fluoranthene; chrysene; dibenz(a,h)anthracene; fluoranthene; indeno(1,2,3-cd)pyrene; and pyrene. Low molecular weight PAHs consist of acenaphthene, acenaphthylene, anthracene, fluorene, naphthalene, and phenanthrene. Results of analyses for the PAHs are summed and assessed within the group (i.e., high molecular weight PAHs and low molecular weight PAHs). Individual PAHs are not assessed.

E.2.1.3 Site Contaminants

Only surface soil contaminants at SWMU 229 were considered in the SERA. Site contaminants included inorganic chemicals, organic chemicals, and radionuclides.

E.2.1.4 Fate and Transport Mechanisms

Potential migration pathways for contaminants from soil at SWMU 229 include transport of contaminated surface soil off-site by surface water, migration of contaminants to the subsurface soil, migration to groundwater, and uptake of soil contaminants through the on-site food chain. In addition, subsurface contaminants may be brought to the surface through bioturbation by burrowing animals or uptake by vegetation on the site. Migration of contaminants through these pathways is not considered significant and is not evaluated within this SERA.

The surface soils at SWMU 229 are held in place by vegetation. Transport of surface soil off-site is likely to be minimal. Migration of contaminants to subsurface soil and through subsurface soil to groundwater is

not likely to occur at SWMU 229. Contaminants in groundwater may be discharged to surface water at areas away from SWMU 229. Contaminants in surface soil are likely to be taken up into plants and soil invertebrates at these sites and would enter higher trophic level organisms through the food chain.

E.2.2 POTENTIALLY COMPLETE EXPOSURE PATHWAYS

The potential exposure pathways for ecological receptors are direct contact with and ingestion of soil and ingestion of plants or animals thereby exposed to substances in soil. Significant contaminant transport through runoff directly to surface water is unlikely because most of SWMU 229 has a vegetated surface. The pathways through which receptors could contact contaminants in surface soil include direct ingestion of soil, ingestion of plant or animals from the site as food, external exposure to ionizing radiation, and dermal contact with soil or surface water. A CSM reflective of current site conditions is shown in Figure E.2. This SERA evaluates ecological risks associated with surface soil only.

E.2.3 POTENTIALLY CONTAMINATED MEDIA

Soil is the media of concern for SWMU 229. The substances detected in surface soils [metals, radionuclides, and semivolatile organic compounds (SVOCs)] are capable of causing adverse effects on terrestrial receptors. This SERA evaluates only terrestrial receptors (see Section E.2.1) for chemicals of potential ecological concern (COPECs).

Although drainage is poor at SWMU 229, significant surface water contamination is not expected based on evaluations previously performed at other SWMUs within the site (UK 2007). As a result, ecological risks associated with exposure to surface water were not assessed in this SERA.

E.3. SCREENING-LEVEL EFFECTS EVALUATION

For SWMU 229, the maximum site concentration of the reported values of each potential contaminant was compared to a single ecological screening level selected from the Ecological Risk Methods Document. ESVs were taken from Tables A.2 and A.3 of the Ecological Risk Methods Document (DOE 2015b). These ESVs are the PGDP no further action (NFA) values for soil. For detected radiological results for which no ESV was available in the Ecological Risk Methods Document, one was calculated following similar methodology. Additionally, detected chemicals for which an ESV is not listed in Table A.2, values from other sources were used. These values are presented in Attachment E1.

The maximum site concentration for a substance reported as detected in any sample is the larger of the maximum detected concentration and one half of the maximum reported detection limit for the substance in samples reported as nondetect. Maximum detected site concentrations, frequencies of detection and detection limit ranges are provided in Chapter 5. The maximum site concentration was used to calculate a HQ, using a ratio of the maximum site concentration with the ESV, as shown below:

$$\mathbf{HQ} = \frac{\mathbf{EPC}}{\mathbf{ESV}}$$

For those chemicals with at least one detection and whose maximum HQ was greater than or equal to 1, and at least 10 results were available, an EPC was calculated as the 95% upper confidence limit (UCL)

using ProUCL. The output from this program is included as Attachment E2. COPECs were further evaluated by calculating an HQ using the EPCs.

A total HI then was calculated by summing the HQs within each SWMU/area of concern (AOC). Priority COPECs were selected from the chemicals at each SWMU/AOC showing the HQs greater than 10 calculated with the EPC. "Priority COPECs" are identified in this RI as an aid to risk managers during decision making. Table E.1 summarized these values. Background values from the Risk Methods Document (DOE 2015a) also are shown for comparison.

A summary of the results of the site data is provided in Table E.4, which lists the number of COPECs within each analytical suite [i.e., metals, radiological constituents, polychlorinated biphenyls (PCBs), SVOCs, and volatile organic compounds (VOCs)] retained for SWMU 229 for further consideration. As shown, SWMU 229 had one or more COPECs retained. The entire screening list is provided in Attachment E3.

Table E.4. Summary of Suite of COPECs Retained in Surface Soil

SWMU	Media	Number of Metals	Number of Rads	Number of PCBs	Number of SVOCs	Number of VOCs
225	Soil	20	1	---	2	---

---: no COPECs

E.4. UNCERTAINTIES

A number of uncertainties impact the potential usefulness of the results of this SERA. An uncertainty in these screening assessments is that the ecological screening levels are protective of entire suites of receptors, some of which may not be present at these disturbed sites. The grassy areas of these sites would be attractive to ecological receptors, but SWMU 229 is relatively small, and the surrounding industrial area may limit the extent to which ecological receptors use these areas. The potential risk from exposure to subsurface soil was not quantified in this SERA and is, therefore, unknown.

Because no pH data are available for SWMU 229, aluminum has been evaluated as if pH were less than 5.5. While soils in the vicinity of PGDP tend to have a low pH, ranging from 4.5 to 5.5 (DOE 1999) (see Section 3.5 of the main text), the pH of the soils for SWMU 229 is unknown. Aluminum may be subsequently evaluated further by collection of soil pH data. Because soil pH results can be variable, however, whether aluminum should be considered a COPEC at SWMU 229 is an uncertainty. Additionally, a number of chemicals were retained as COPECs for which no benchmarks were available. These chemicals, upon further evaluation may have no negative impacts on the ecological receptors.

These uncertainties, combined with the results of the SERA, indicate the need for further evaluation of SWMU 229. Risk managers may determine that the site does not need further evaluation (if exposure pathways are not complete or planned actions will eliminate the exposure pathway) or may recommend additional evaluation of the site to better define the potential ecological risk indicated by the results. Alternatively, the benchmarks used in the screenings presented here and in the NFA levels in the PGDP Ecological Risk Methods Document (DOE 2015b) may be used as the ecologically based remedial goal options.

E.5. CONCLUSIONS

SWMU 229 retained a number of COPECs including metals, SVOCs, and rads. COPECs are listed below.

Metals:

- Aluminum
- Antimony
- Arsenic
- Barium
- Cadmium
- Calcium (retained because no ESV was available)
- Chromium
- Copper
- Iron
- Lead
- Manganese
- Mercury
- Molybdenum
- Nickel
- Selenium
- Silver
- Sodium (retained because no ESV was available)
- Uranium
- Vanadium
- Zinc

SVOCs:

- 2-Methylnaphthalene (retained because no ESV was available)
- High molecular weight PAHs

Radionuclides:

- Uranium-238

Further, the following COPECs had an HQ, based on EPC, above 10: aluminum, antimony, cadmium, iron, mercury, selenium, and uranium. These COPECs are listed in Table E.1.

E.6. REFERENCES

DOE (U.S. Department of Energy) 2008. *Surface Water Operable Unit (On-Site) Site Investigation and Baseline Risk Assessment Report at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-001&D2/R1, U.S. Department of Energy, Paducah, KY, February.

DOE 2015a. *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant Paducah, Kentucky,* Volume 1*, Human Health*, DOE/LX/07-0107/D2/R6&V1, U.S. Department of Energy, Paducah, KY, July.

DOE 2015b. *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant Paducah, Kentucky,* Volume 2, *Ecological*, DOE/LX/07-0107&D2/R1/V2, U.S. Department of Energy, Paducah, KY, January.

UK (University of Kentucky) 2007. *Assessment of Radiation in Surface Water at the Paducah Gaseous Diffusion Plant*, Radiation Health Branch, Division of Public Health Protection and Safety, Department for Public Health, Cabinet for Health and Family Services, Frankfort, KY, January.

ATTACHMENT E1

ADDITIONAL ESVS

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For detected radiological results for which no ecological screening value (ESV) was available for no further action (NFA) in the Ecological Risk Methods Document, one was calculated following similar methodology (DOE 2015a). These ESVs are presented in Table E1.1.

Table E1.1. PGDP Soil NFA Screening Values for Additional Radionuclides

Radionuclide	NFA (pCi/g)
Thorium-228	5.30E+02
Thorium-232	1.52E+03

NFA = activity (pCi/g) resulting in dose of 0.1 rad/day assuming secular equilibrium of parent and daughter products.
NFA values are from RESRAD-BIOTA, Version 1.5, Report for Level 2 (default values, except dose adjusted to 0.1 rad/day) RESRAD-BIOTA software is available at http://web.ead.anl.gov/resrad/home2/biota.cfm.

Detected chemicals for which an ESV is not listed in Table A.2 of the Ecological Risk Methods Document, values from other sources were used. These values are presented in Table E1.2.

Table E1.2. PGDP Soil NFA Screening Values for Additional Chemicals

Analyte	PGDP NFA Screening Value (mg/kg)	Source for Screening Value
Magnesium	4.40E+05	KDEP[a]
Iron	2.00E+02	KDEP[a]
Dibenzofuran	1.52E+00	KDEP[b]

[a] Kentucky Ecological Screening Values are provided in Appendix F of the Ecological Risk Methods Document (DOE 2015b).
[b] Kentucky Ecological Screening Value for sediment used for screening.

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ATTACHMENT E2

PROUCL OUTPUT

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UCL Statistics for Uncensored Full Data Sets

User Selected Options	
Date/Time of Computation	11/9/2015 1:54:13 PM
From File	UCL input.xls
Full Precision	OFF
Confidence Coefficient	95%
Number of Bootstrap Operations	2000

Antimony

General Statistics

Total Number of Observations	18	Number of Distinct Observations	17
		Number of Missing Observations	0
Minimum	15	Mean	88.81
Maximum	150.5	Median	94.83
SD	38.89	Std. Error of Mean	9.166
Coefficient of Variation	0.438	Skewness	-0.413

Normal GOF Test

Shapiro Wilk Test Statistic	0.962	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.117	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	104.8	95% Adjusted-CLT UCL (Chen-1995)	102.9
		95% Modified-t UCL (Johnson-1978)	104.6

Gamma GOF Test

A-D Test Statistic	0.865	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.744	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.165	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.205	Detected data appear Gamma Distributed at 5% Significance Level

Detected data follow Appr. Gamma Distribution at 5% Significance Level

Gamma Statistics

k hat (MLE)	3.467	k star (bias corrected MLE)	2.926
Theta hat (MLE)	25.62	Theta star (bias corrected MLE)	30.35
nu hat (MLE)	124.8	nu star (bias corrected)	105.3
MLE Mean (bias corrected)	88.81	MLE Sd (bias corrected)	51.92
		Approximate Chi Square Value (0.05)	82.66
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	80.73

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	113.2	95% Adjusted Gamma UCL (use when n<50)	115.9

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.787	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.192	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data appear Lognormal at 5% Significance Level

Data appear Approximate Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	2.708	Mean of logged Data	4.335
Maximum of Logged Data	5.014	SD of logged Data	0.664

Assuming Lognormal Distribution

95% H-UCL	135.6	90% Chebyshev (MVUE) UCL	140.5
95% Chebyshev (MVUE) UCL	161.6	97.5% Chebyshev (MVUE) UCL	190.9
99% Chebyshev (MVUE) UCL	248.4		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	103.9	95% Jackknife UCL	104.8
95% Standard Bootstrap UCL	103.4	95% Bootstrap-t UCL	104
95% Hall's Bootstrap UCL	103	95% Percentile Bootstrap UCL	103.4
95% BCA Bootstrap UCL	102.6		
90% Chebyshev(Mean, Sd) UCL	116.3	95% Chebyshev(Mean, Sd) UCL	128.8
97.5% Chebyshev(Mean, Sd) UCL	146.1	99% Chebyshev(Mean, Sd) UCL	180

Suggested UCL to Use

95% Student's-t UCL	104.8

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Note: For highly negatively-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

Arsenic

General Statistics

Total Number of Observations	18	Number of Distinct Observations	11
		Number of Missing Observations	0
Minimum	5.5	Mean	7.898
Maximum	21.2	Median	6.58
SD	3.818	Std. Error of Mean	0.9
Coefficient of Variation	0.483	Skewness	2.723

Normal GOF Test

Shapiro Wilk Test Statistic	0.65	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.265	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level	

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	9.464	95% Adjusted-CLT UCL (Chen-1995)	9.996
		95% Modified-t UCL (Johnson-1978)	9.56

Gamma GOF Test

A-D Test Statistic	1.539	**Anderson-Darling Gamma GOF Test**	
5% A-D Critical Value	0.742	Data Not Gamma Distributed at 5% Significance Level	
K-S Test Statistic	0.265	**Kolmogrov-Smirnoff Gamma GOF Test**	
5% K-S Critical Value	0.204	Data Not Gamma Distributed at 5% Significance Level	

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	6.867	k star (bias corrected MLE)	5.759
Theta hat (MLE)	1.15	Theta star (bias corrected MLE)	1.371
nu hat (MLE)	247.2	nu star (bias corrected)	207.3
MLE Mean (bias corrected)	7.898	MLE Sd (bias corrected)	3.291
		Approximate Chi Square Value (0.05)	175
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	172.2

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	9.357	95% Adjusted Gamma UCL (use when n<50)	9.512

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.779	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.269	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.209	Data Not Lognormal at 5% Significance Level	

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	1.705	Mean of logged Data	1.992
Maximum of Logged Data	3.054	SD of logged Data	0.365

Assuming Lognormal Distribution

95% H-UCL	9.276	90% Chebyshev (MVUE) UCL	9.861
95% Chebyshev (MVUE) UCL	10.79	97.5% Chebyshev (MVUE) UCL	12.08
99% Chebyshev (MVUE) UCL	14.62		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	9.379	95% Jackknife UCL	9.464
95% Standard Bootstrap UCL	9.351	95% Bootstrap-t UCL	10.99
95% Hall's Bootstrap UCL	15.87	95% Percentile Bootstrap UCL	9.434
95% BCA Bootstrap UCL	10.09		
90% Chebyshev(Mean, Sd) UCL	10.6	95% Chebyshev(Mean, Sd) UCL	11.82
97.5% Chebyshev(Mean, Sd) UCL	13.52	99% Chebyshev(Mean, Sd) UCL	16.85

Suggested UCL to Use

95% Student's-t UCL	9.464	or 95% Modified-t UCL	9.56

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Barium

General Statistics

Total Number of Observations	18	Number of Distinct Observations	18
		Number of Missing Observations	0
Minimum	316	Mean	439.2
Maximum	616.2	Median	436.8
SD	82.33	Std. Error of Mean	19.41
Coefficient of Variation	0.187	Skewness	0.449

Normal GOF Test

Shapiro Wilk Test Statistic	0.96	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.0997	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	472.9	95% Adjusted-CLT UCL (Chen-1995)	473.3
		95% Modified-t UCL (Johnson-1978)	473.3

Gamma GOF Test

A-D Test Statistic	0.217	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.739	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.104	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.203	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	30.52	k star (bias corrected MLE)	25.47
Theta hat (MLE)	14.39	Theta star (bias corrected MLE)	17.24
nu hat (MLE)	1099	nu star (bias corrected)	916.8
MLE Mean (bias corrected)	439.2	MLE Sd (bias corrected)	87.03
		Approximate Chi Square Value (0.05)	847.5
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	841.1

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	475.1	95% Adjusted Gamma UCL (use when n<50)	478.7

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.968	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.117	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.209	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	5.756	Mean of logged Data	6.068
Maximum of Logged Data	6.424	SD of logged Data	0.187

Assuming Lognormal Distribution

95% H-UCL	476.6	90% Chebyshev (MVUE) UCL	497.5
95% Chebyshev (MVUE) UCL	524	97.5% Chebyshev (MVUE) UCL	560.7
99% Chebyshev (MVUE) UCL	632.7		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	471.1	95% Jackknife UCL	472.9
95% Standard Bootstrap UCL	470	95% Bootstrap-t UCL	476.7
95% Hall's Bootstrap UCL	477.1	95% Percentile Bootstrap UCL	471.4
95% BCA Bootstrap UCL	471.1		
90% Chebyshev(Mean, Sd) UCL	497.4	95% Chebyshev(Mean, Sd) UCL	523.8
97.5% Chebyshev(Mean, Sd) UCL	560.4	99% Chebyshev(Mean, Sd) UCL	632.2

Suggested UCL to Use

95% Student's-t UCL	472.9

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Cadmium

General Statistics

Total Number of Observations	18	Number of Distinct Observations	6
		Number of Missing Observations	0
Minimum	6	Mean	9.542
Maximum	21.18	Median	6
SD	5.967	Std. Error of Mean	1.407
Coefficient of Variation	0.625	Skewness	1.19

Normal GOF Test

Shapiro Wilk Test Statistic	0.613	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.446	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	11.99	95% Adjusted-CLT UCL (Chen-1995)	12.28
		95% Modified-t UCL (Johnson-1978)	12.05

Gamma GOF Test

A-D Test Statistic	3.745	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.744	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.455	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.205	Data Not Gamma Distributed at 5% Significance Level

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	3.516	k star (bias corrected MLE)	2.967
Theta hat (MLE)	2.714	Theta star (bias corrected MLE)	3.216
nu hat (MLE)	126.6	nu star (bias corrected)	106.8
MLE Mean (bias corrected)	9.542	MLE Sd (bias corrected)	5.539
		Approximate Chi Square Value (0.05)	83.96
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	82.02

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	12.14	95% Adjusted Gamma UCL (use when n<50)	12.43

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.598	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.448	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Lognormal at 5% Significance Level

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	1.792	Mean of logged Data	2.107
Maximum of Logged Data	3.053	SD of logged Data	0.526

Assuming Lognormal Distribution

95% H-UCL	12.25	90% Chebyshev (MVUE) UCL	12.97
95% Chebyshev (MVUE) UCL	14.61	97.5% Chebyshev (MVUE) UCL	16.88
99% Chebyshev (MVUE) UCL	21.33		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	11.86	95% Jackknife UCL	11.99
95% Standard Bootstrap UCL	11.82	95% Bootstrap-t UCL	12.79
95% Hall's Bootstrap UCL	11.46	95% Percentile Bootstrap UCL	11.75
95% BCA Bootstrap UCL	12.03		
90% Chebyshev(Mean, Sd) UCL	13.76	95% Chebyshev(Mean, Sd) UCL	15.67
97.5% Chebyshev(Mean, Sd) UCL	18.33	99% Chebyshev(Mean, Sd) UCL	23.54

Suggested UCL to Use

95% Chebyshev (Mean, Sd) UCL	15.67

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Chromium

General Statistics

Total Number of Observations	18	Number of Distinct Observations	2
		Number of Missing Observations	0
Minimum	29.14	Mean	41.76
Maximum	42.5	Median	42.5
SD	3.149	Std. Error of Mean	0.742
Coefficient of Variation	0.0754	Skewness	-4.243

Normal GOF Test

Shapiro Wilk Test Statistic	0.253	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.538	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level	

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	43.05	95% Adjusted-CLT UCL (Chen-1995)	42.19
		95% Modified-t UCL (Johnson-1978)	42.93

Gamma GOF Test

A-D Test Statistic	6.444	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.737	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.541	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.203	Data Not Gamma Distributed at 5% Significance Level

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	149.5	k star (bias corrected MLE)	124.6
Theta hat (MLE)	0.279	Theta star (bias corrected MLE)	0.335
nu hat (MLE)	5383	nu star (bias corrected)	4487
MLE Mean (bias corrected)	41.76	MLE Sd (bias corrected)	3.74
		Approximate Chi Square Value (0.05)	4332
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	4318

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	43.25	95% Adjusted Gamma UCL (use when n<50)	43.39

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.253	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.538	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Lognormal at 5% Significance Level

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	3.372	Mean of logged Data	3.729
Maximum of Logged Data	3.75	SD of logged Data	0.089

Assuming Lognormal Distribution

95% H-UCL	N/A	90% Chebyshev (MVUE) UCL	44.4
95% Chebyshev (MVUE) UCL	45.6	97.5% Chebyshev (MVUE) UCL	47.25
99% Chebyshev (MVUE) UCL	50.5		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	42.98	95% Jackknife UCL	N/A
95% Standard Bootstrap UCL	N/A	95% Bootstrap-t UCL	N/A
95% Hall's Bootstrap UCL	N/A	95% Percentile Bootstrap UCL	N/A
95% BCA Bootstrap UCL	N/A		
90% Chebyshev(Mean, Sd) UCL	43.98	95% Chebyshev(Mean, Sd) UCL	44.99
97.5% Chebyshev(Mean, Sd) UCL	46.39	99% Chebyshev(Mean, Sd) UCL	49.14

Suggested UCL to Use

95% Student's-t UCL	43.05	or 95% Modified-t UCL	42.93

Recommended UCL exceeds the maximum observation

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Note: For highly negatively-skewed data, confidence limits (e.g., Chen, Johnson, Lognormal, and Gamma) may not be reliable. Chen's and Johnson's methods provide adjustments for positvely skewed data sets.

Copper

General Statistics

Total Number of Observations	18	Number of Distinct Observations	2
		Number of Missing Observations	0
Minimum	17.5	Mean	19.41
Maximum	51.93	Median	17.5
SD	8.115	Std. Error of Mean	1.913
Coefficient of Variation	0.418	Skewness	4.243

Normal GOF Test

Shapiro Wilk Test Statistic	0.253	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.538	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level	

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	22.74	95% Adjusted-CLT UCL (Chen-1995)	24.6
		95% Modified-t UCL (Johnson-1978)	23.06

Gamma GOF Test

A-D Test Statistic	6.469	**Anderson-Darling Gamma GOF Test**	
5% A-D Critical Value	0.739	Data Not Gamma Distributed at 5% Significance Level	
K-S Test Statistic	0.543	**Kolmogrov-Smirnoff Gamma GOF Test**	
5% K-S Critical Value	0.203	Data Not Gamma Distributed at 5% Significance Level	

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	11.71	k star (bias corrected MLE)	9.796
Theta hat (MLE)	1.658	Theta star (bias corrected MLE)	1.982
nu hat (MLE)	421.6	nu star (bias corrected)	352.7
MLE Mean (bias corrected)	19.41	MLE Sd (bias corrected)	6.202
		Approximate Chi Square Value (0.05)	310.1
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	306.3

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	22.07	95% Adjusted Gamma UCL (use when n<50)	22.35

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.253	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.538	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.209	Data Not Lognormal at 5% Significance Level	

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	2.862	Mean of logged Data	2.923
Maximum of Logged Data	3.95	SD of logged Data	0.256

Assuming Lognormal Distribution

95% H-UCL	21.52	90% Chebyshev (MVUE) UCL	22.68
95% Chebyshev (MVUE) UCL	24.27	97.5% Chebyshev (MVUE) UCL	26.48
99% Chebyshev (MVUE) UCL	30.81		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	22.56	95% Jackknife UCL	N/A
95% Standard Bootstrap UCL	N/A	95% Bootstrap-t UCL	N/A
95% Hall's Bootstrap UCL	N/A	95% Percentile Bootstrap UCL	N/A
95% BCA Bootstrap UCL	N/A		
90% Chebyshev(Mean, Sd) UCL	25.15	95% Chebyshev(Mean, Sd) UCL	27.75
97.5% Chebyshev(Mean, Sd) UCL	31.36	99% Chebyshev(Mean, Sd) UCL	38.44

Suggested UCL to Use

95% Student's-t UCL	22.74	or 95% Modified-t UCL	23.06

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Iron

General Statistics

Total Number of Observations	18	Number of Distinct Observations	18
		Number of Missing Observations	0
Minimum	7444	Mean	12354
Maximum	27400	Median	10772
SD	4641	Std. Error of Mean	1094
Coefficient of Variation	0.376	Skewness	2.203

Normal GOF Test

Shapiro Wilk Test Statistic	0.775	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.23	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	14258	95% Adjusted-CLT UCL (Chen-1995)	14761
		95% Modified-t UCL (Johnson-1978)	14352

Gamma GOF Test

A-D Test Statistic	0.836	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.739	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.201	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.203	Detected data appear Gamma Distributed at 5% Significance Level

Detected data follow Appr. Gamma Distribution at 5% Significance Level

Gamma Statistics

k hat (MLE)	9.971	k star (bias corrected MLE)	8.346
Theta hat (MLE)	1239	Theta star (bias corrected MLE)	1480
nu hat (MLE)	359	nu star (bias corrected)	300.5
MLE Mean (bias corrected)	12354	MLE Sd (bias corrected)	4276
		Approximate Chi Square Value (0.05)	261.3
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	257.8

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50)	14206	95% Adjusted Gamma UCL (use when n<50)	14399

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.907	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data appear Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.18	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data appear Lognormal at 5% Significance Level

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	8.915	Mean of logged Data	9.371
Maximum of Logged Data	10.22	SD of logged Data	0.31

Assuming Lognormal Distribution

95% H-UCL	14171	90% Chebyshev (MVUE) UCL	15019
95% Chebyshev (MVUE) UCL	16257	97.5% Chebyshev (MVUE) UCL	17975
99% Chebyshev (MVUE) UCL	21351		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	14154	95% Jackknife UCL	14258
95% Standard Bootstrap UCL	14043	95% Bootstrap-t UCL	15380
95% Hall's Bootstrap UCL	21559	95% Percentile Bootstrap UCL	14224
95% BCA Bootstrap UCL	14953		
90% Chebyshev(Mean, Sd) UCL	15636	95% Chebyshev(Mean, Sd) UCL	17123
97.5% Chebyshev(Mean, Sd) UCL	19186	99% Chebyshev(Mean, Sd) UCL	23239

Suggested UCL to Use

95% Adjusted Gamma UCL	14399

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Lead

General Statistics

Total Number of Observations	18	Number of Distinct Observations	18
		Number of Missing Observations	0
Minimum	6.5	Mean	15.33
Maximum	27.24	Median	15.29
SD	4.726	Std. Error of Mean	1.114
Coefficient of Variation	0.308	Skewness	0.706

Normal GOF Test

Shapiro Wilk Test Statistic	0.949	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data appear Normal at 5% Significance Level
Lilliefors Test Statistic	0.141	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data appear Normal at 5% Significance Level

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	17.27	95% Adjusted-CLT UCL (Chen-1995)	17.36
		95% Modified-t UCL (Johnson-1978)	17.3

Gamma GOF Test

A-D Test Statistic	0.34	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.739	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.14	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.203	Detected data appear Gamma Distributed at 5% Significance Level

Detected data appear Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	11.01	k star (bias corrected MLE)	9.21
Theta hat (MLE)	1.393	Theta star (bias corrected MLE)	1.664
nu hat (MLE)	396.3	nu star (bias corrected)	331.5
MLE Mean (bias corrected)	15.33	MLE Sd (bias corrected)	5.051
		Approximate Chi Square Value (0.05)	290.4
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	286.7

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	17.5	95% Adjusted Gamma UCL (use when n<50)	17.73

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.954	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.158	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.209	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	1.872	Mean of logged Data	2.684
Maximum of Logged Data	3.305	SD of logged Data	0.32

Assuming Lognormal Distribution

95% H-UCL	17.8	90% Chebyshev (MVUE) UCL	18.88
95% Chebyshev (MVUE) UCL	20.48	97.5% Chebyshev (MVUE) UCL	22.69
99% Chebyshev (MVUE) UCL	27.04		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	17.16	95% Jackknife UCL	17.27
95% Standard Bootstrap UCL	17.1	95% Bootstrap-t UCL	17.55
95% Hall's Bootstrap UCL	18.08	95% Percentile Bootstrap UCL	17.15
95% BCA Bootstrap UCL	17.2		
90% Chebyshev(Mean, Sd) UCL	18.67	95% Chebyshev(Mean, Sd) UCL	20.18
97.5% Chebyshev(Mean, Sd) UCL	22.28	99% Chebyshev(Mean, Sd) UCL	26.41

Suggested UCL to Use

95% Student's-t UCL	17.27

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Manganese

General Statistics

Total Number of Observations	18	Number of Distinct Observations	18
		Number of Missing Observations	0
Minimum	215.1	Mean	332.9
Maximum	681	Median	285.3
SD	122	Std. Error of Mean	28.77
Coefficient of Variation	0.367	Skewness	1.813

Normal GOF Test

Shapiro Wilk Test Statistic	0.784	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.237	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	382.9	95% Adjusted-CLT UCL (Chen-1995)	393.4
		95% Modified-t UCL (Johnson-1978)	385

Gamma GOF Test

A-D Test Statistic	1.081	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.739	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.19	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.203	Detected data appear Gamma Distributed at 5% Significance Level

Detected data follow Appr. Gamma Distribution at 5% Significance Level

Gamma Statistics

k hat (MLE)	10.12	k star (bias corrected MLE)	8.471
Theta hat (MLE)	32.89	Theta star (bias corrected MLE)	39.3
nu hat (MLE)	364.4	nu star (bias corrected)	305
MLE Mean (bias corrected)	332.9	MLE Sd (bias corrected)	114.4
		Approximate Chi Square Value (0.05)	265.5
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	262

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50)	382.4	95% Adjusted Gamma UCL (use when n<50)	387.5

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.881	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.181	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data appear Lognormal at 5% Significance Level

Data appear Approximate Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	5.371	Mean of logged Data	5.758
Maximum of Logged Data	6.524	SD of logged Data	0.309

Assuming Lognormal Distribution

95% H-UCL	381.7	90% Chebyshev (MVUE) UCL	404.4
95% Chebyshev (MVUE) UCL	437.6	97.5% Chebyshev (MVUE) UCL	483.7
99% Chebyshev (MVUE) UCL	574.2		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	380.2	95% Jackknife UCL	382.9
95% Standard Bootstrap UCL	378.5	95% Bootstrap-t UCL	410.6
95% Hall's Bootstrap UCL	407.6	95% Percentile Bootstrap UCL	380.2
95% BCA Bootstrap UCL	391.3		
90% Chebyshev(Mean, Sd) UCL	419.2	95% Chebyshev(Mean, Sd) UCL	458.3
97.5% Chebyshev(Mean, Sd) UCL	512.6	99% Chebyshev(Mean, Sd) UCL	619.1

Suggested UCL to Use

95% Adjusted Gamma UCL	387.5

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Nickel

General Statistics

Total Number of Observations	18	Number of Distinct Observations	8
		Number of Missing Observations	0
Minimum	32.5	Mean	51.95
Maximum	99.25	Median	32.5
SD	26.26	Std. Error of Mean	6.19
Coefficient of Variation	0.506	Skewness	0.787

Normal GOF Test

Shapiro Wilk Test Statistic	0.72	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level	
Lilliefors Test Statistic	0.382	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level	

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	62.71	95% Adjusted-CLT UCL (Chen-1995)	63.35
		95% Modified-t UCL (Johnson-1978)	62.9

Gamma GOF Test

A-D Test Statistic	2.595	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.743	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.393	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.204	Data Not Gamma Distributed at 5% Significance Level

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	4.671	k star (bias corrected MLE)	3.929
Theta hat (MLE)	11.12	Theta star (bias corrected MLE)	13.22
nu hat (MLE)	168.1	nu star (bias corrected)	141.5
MLE Mean (bias corrected)	51.95	MLE Sd (bias corrected)	26.21
		Approximate Chi Square Value (0.05)	115
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	112.7

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	63.91	95% Adjusted Gamma UCL (use when n<50)	65.21

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.7	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.387	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Lognormal at 5% Significance Level

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	3.481	Mean of logged Data	3.839
Maximum of Logged Data	4.598	SD of logged Data	0.471

Assuming Lognormal Distribution

95% H-UCL	65.26	90% Chebyshev (MVUE) UCL	69.34
95% Chebyshev (MVUE) UCL	77.38	97.5% Chebyshev (MVUE) UCL	88.52
99% Chebyshev (MVUE) UCL	110.4		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	62.13	95% Jackknife UCL	62.71
95% Standard Bootstrap UCL	61.86	95% Bootstrap-t UCL	64.13
95% Hall's Bootstrap UCL	61.5	95% Percentile Bootstrap UCL	62.05
95% BCA Bootstrap UCL	62.76		
90% Chebyshev(Mean, Sd) UCL	70.51	95% Chebyshev(Mean, Sd) UCL	78.93
97.5% Chebyshev(Mean, Sd) UCL	90.6	99% Chebyshev(Mean, Sd) UCL	113.5

Suggested UCL to Use

95% Student's-t UCL	62.71	or 95% Modified-t UCL	62.9

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Uranium

General Statistics

Total Number of Observations	18	Number of Distinct Observations	11
		Number of Missing Observations	0
Minimum	9.65	Mean	29.66
Maximum	155.8	Median	10.39
SD	40.83	Std. Error of Mean	9.623
Coefficient of Variation	1.377	Skewness	2.491

Normal GOF Test

Shapiro Wilk Test Statistic	0.562	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.318	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	46.4	95% Adjusted-CLT UCL (Chen-1995)	51.53
		95% Modified-t UCL (Johnson-1978)	47.34

Gamma GOF Test

A-D Test Statistic	2.61	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.764	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.322	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.209	Data Not Gamma Distributed at 5% Significance Level

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	1.121	k star (bias corrected MLE)	0.971
Theta hat (MLE)	26.46	Theta star (bias corrected MLE)	30.54
nu hat (MLE)	40.35	nu star (bias corrected)	34.96
MLE Mean (bias corrected)	29.66	MLE Sd (bias corrected)	30.1
		Approximate Chi Square Value (0.05)	22.43
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	21.47

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	46.22	95% Adjusted Gamma UCL (use when n<50)	48.29

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.719	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.312	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Lognormal at 5% Significance Level

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	2.267	Mean of logged Data	2.881
Maximum of Logged Data	5.049	SD of logged Data	0.892

Assuming Lognormal Distribution

95% H-UCL	45.49	90% Chebyshev (MVUE) UCL	43.58
95% Chebyshev (MVUE) UCL	51.64	97.5% Chebyshev (MVUE) UCL	62.82
99% Chebyshev (MVUE) UCL	84.79		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	45.49	95% Jackknife UCL	46.4
95% Standard Bootstrap UCL	44.65	95% Bootstrap-t UCL	78.06
95% Hall's Bootstrap UCL	107.8	95% Percentile Bootstrap UCL	45.97
95% BCA Bootstrap UCL	53.68		
90% Chebyshev(Mean, Sd) UCL	58.53	95% Chebyshev(Mean, Sd) UCL	71.61
97.5% Chebyshev(Mean, Sd) UCL	89.76	99% Chebyshev(Mean, Sd) UCL	125.4

Suggested UCL to Use

95% Chebyshev (Mean, Sd) UCL	71.61

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

Zinc

General Statistics

Total Number of Observations	18	Number of Distinct Observations	18
		Number of Missing Observations	0
Minimum	38.22	Mean	174.1
Maximum	833	Median	98.71
SD	212.7	Std. Error of Mean	50.14
Coefficient of Variation	1.222	Skewness	2.512

Normal GOF Test

Shapiro Wilk Test Statistic	0.602	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.336	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	261.3	95% Adjusted-CLT UCL (Chen-1995)	288.3
		95% Modified-t UCL (Johnson-1978)	266.2

Gamma GOF Test

A-D Test Statistic	1.573	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.759	Data Not Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.293	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.208	Data Not Gamma Distributed at 5% Significance Level

Data Not Gamma Distributed at 5% Significance Level

Gamma Statistics

k hat (MLE)	1.363	k star (bias corrected MLE)	1.173
Theta hat (MLE)	127.7	Theta star (bias corrected MLE)	148.4
nu hat (MLE)	49.08	nu star (bias corrected)	42.24
MLE Mean (bias corrected)	174.1	MLE Sd (bias corrected)	160.7
		Approximate Chi Square Value (0.05)	28.34
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	27.25

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50))	259.4	95% Adjusted Gamma UCL (use when n<50)	269.8

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.885	**Shapiro Wilk Lognormal GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Lognormal at 5% Significance Level
Lilliefors Test Statistic	0.236	**Lilliefors Lognormal GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Lognormal at 5% Significance Level

Data Not Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	3.643	Mean of logged Data	4.75
Maximum of Logged Data	6.725	SD of logged Data	0.824

Assuming Lognormal Distribution

95% H-UCL	262	90% Chebyshev (MVUE) UCL	258.5
95% Chebyshev (MVUE) UCL	303.7	97.5% Chebyshev (MVUE) UCL	366.6
99% Chebyshev (MVUE) UCL	490.1		

Nonparametric Distribution Free UCL Statistics

Data do not follow a Discernible Distribution (0.05)

Nonparametric Distribution Free UCLs

95% CLT UCL	256.5	95% Jackknife UCL	261.3
95% Standard Bootstrap UCL	256.2	95% Bootstrap-t UCL	457.6
95% Hall's Bootstrap UCL	632.8	95% Percentile Bootstrap UCL	262.1
95% BCA Bootstrap UCL	299.3		
90% Chebyshev(Mean, Sd) UCL	324.5	95% Chebyshev(Mean, Sd) UCL	392.6
97.5% Chebyshev(Mean, Sd) UCL	487.2	99% Chebyshev(Mean, Sd) UCL	672.9

Suggested UCL to Use

95% Chebyshev (Mean, Sd) UCL	392.6

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

High molecular weight PAHs

General Statistics

Total Number of Observations	18	Number of Distinct Observations	15
		Number of Missing Observations	0
Minimum	0.029	Mean	1.02
Maximum	5.1	Median	0.29
SD	1.41	Std. Error of Mean	0.332
Coefficient of Variation	1.382	Skewness	2.096

Normal GOF Test

Shapiro Wilk Test Statistic	0.697	**Shapiro Wilk GOF Test**
5% Shapiro Wilk Critical Value	0.897	Data Not Normal at 5% Significance Level
Lilliefors Test Statistic	0.255	**Lilliefors GOF Test**
5% Lilliefors Critical Value	0.209	Data Not Normal at 5% Significance Level

Data Not Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	1.598	95% Adjusted-CLT UCL (Chen-1995)	1.742
		95% Modified-t UCL (Johnson-1978)	1.626

Gamma GOF Test

A-D Test Statistic	0.546	**Anderson-Darling Gamma GOF Test**
5% A-D Critical Value	0.783	Detected data appear Gamma Distributed at 5% Significance Level
K-S Test Statistic	0.224	**Kolmogrov-Smirnoff Gamma GOF Test**
5% K-S Critical Value	0.212	Data Not Gamma Distributed at 5% Significance Level

Detected data follow Appr. Gamma Distribution at 5% Significance Level

Gamma Statistics

k hat (MLE)	0.69	k star (bias corrected MLE)	0.612
Theta hat (MLE)	1.479	Theta star (bias corrected MLE)	1.668
nu hat (MLE)	24.83	nu star (bias corrected)	22.02
MLE Mean (bias corrected)	1.02	MLE Sd (bias corrected)	1.304
		Approximate Chi Square Value (0.05)	12.35
Adjusted Level of Significance	0.0357	Adjusted Chi Square Value	11.66

Assuming Gamma Distribution

95% Approximate Gamma UCL (use when n>=50)	1.819	95% Adjusted Gamma UCL (use when n<50)	1.926

Lognormal GOF Test

Shapiro Wilk Test Statistic	0.967	**Shapiro Wilk Lognormal GOF Test**	
5% Shapiro Wilk Critical Value	0.897	Data appear Lognormal at 5% Significance Level	
Lilliefors Test Statistic	0.159	**Lilliefors Lognormal GOF Test**	
5% Lilliefors Critical Value	0.209	Data appear Lognormal at 5% Significance Level	

Data appear Lognormal at 5% Significance Level

Lognormal Statistics

Minimum of Logged Data	-3.54	Mean of logged Data	-0.858
Maximum of Logged Data	1.629	SD of logged Data	1.452

Assuming Lognormal Distribution

95% H-UCL	3.965	90% Chebyshev (MVUE) UCL	2.413
95% Chebyshev (MVUE) UCL	3.01	97.5% Chebyshev (MVUE) UCL	3.839
99% Chebyshev (MVUE) UCL	5.467		

Nonparametric Distribution Free UCL Statistics

Data appear to follow a Discernible Distribution at 5% Significance Level

Nonparametric Distribution Free UCLs

95% CLT UCL	1.567	95% Jackknife UCL	1.598
95% Standard Bootstrap UCL	1.557	95% Bootstrap-t UCL	2.208
95% Hall's Bootstrap UCL	4.312	95% Percentile Bootstrap UCL	1.591
95% BCA Bootstrap UCL	1.719		
90% Chebyshev(Mean, Sd) UCL	2.017	95% Chebyshev(Mean, Sd) UCL	2.469
97.5% Chebyshev(Mean, Sd) UCL	3.096	99% Chebyshev(Mean, Sd) UCL	4.327

Suggested UCL to Use

95% Adjusted Gamma UCL	1.926

Note: Suggestions regarding the selection of a 95% UCL are provided to help the user to select the most appropriate 95% UCL.
These recommendations are based upon the results of the simulation studies summarized in Singh, Singh, and Iaci (2002)
and Singh and Singh (2003). However, simulations results will not cover all Real World data sets.
For additional insight the user may want to consult a statistician.

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ATTACHMENT E3

SWMU 229 ECOLOGICAL SCREENING

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Table E3.1. Ecological Screening

Analysis	Unit	Bkgd[a]	Soil NFA	Max Screening Value	HQ (Max)	Below Bkgd?	EPC	HQ (EPC)
2-Methylnaphthalene	mg/kg			0.18				
Aluminum	mg/kg	13000	50	6210	124.2	Yes	6210	124.2
Antimony	mg/kg	0.21	0.27	150.45	557.2	No	104.8	388.1
Arsenic	mg/kg	12	18	21.2	1.2	No	9.464	0.5
Barium	mg/kg	200	330	616.18	1.9	No	472.9	1.4
Benzo(ghi)perylene	mg/kg		119	0.79	0.0			
Beryllium	mg/kg	0.67	2.5	0.79	0.3	No		
Cadmium	mg/kg	0.21	0.36	21.18	58.8	No	15.67	43.5
Calcium	mg/kg	200000		238000				
Chromium	mg/kg	16	26	42.5	1.6	No	43.05	1.7
Cobalt	mg/kg	14	13	7.7	0.6	Yes		
Copper	mg/kg	19	28	51.93	1.9	No	22.74	0.8
Dibenzofuran	mg/kg		1.52	0.18	0.1	No		
Fluorene	mg/kg		30	0.18	0.0	No		
High molecular weight PAHs	mg/kg		1.1	16.86	15.3	No	1.926	1.8
Iron	mg/kg	28000	200	27400	137.0	Yes	14399	72.0
Lead	mg/kg	36	11	27.24	2.5	Yes	17.27	1.6
Low molecular weight PAHs	mg/kg		29	5.71	0.2	No		
Magnesium	mg/kg	7700	440000	7270	0.0	Yes		
Manganese	mg/kg	1500	220	681	3.1	Yes	387.5	1.8
Mercury	mg/kg	0.2	0.1	5	50.0	No	5	50.0
Molybdenum	mg/kg		2	7.5	3.8	No	7.5	3.8
Nickel	mg/kg	21	38	99.25	2.6	No	62.71	1.7
Selenium	mg/kg	0.8	0.52	10	19.2	No	10	19.2
Silver	mg/kg	2.3	4.2	5	1.2	No	5	1.2
Sodium	mg/kg	320		132				
Uranium	mg/kg	4.9	5	155.81	31.2	No	71.61	14.3
Vanadium	mg/kg	38	7.8	35	4.5	Yes	35	4.5
Zinc	mg/kg	65	46	832.98	18.1	No	392.6	8.5
Americium-241	pCi/g		2160	0.074	0.0	No		
Cesium-137	pCi/g	0.49	20.8	0.321	0.0	Yes		
Neptunium-237	pCi/g	0.1	814	1.69	0.0	No		
Plutonium-238	pCi/g	0.073	1750	0.1	0.0	No		
Plutonium-239/240	pCi/g	0.025	1270	0.269	0.0	No		
Technetium-99	pCi/g	2.5	2190	43.4	0.0	No		
Thorium-228	pCi/g	1.6	530	0.625	0.0	Yes		
Thorium-230	pCi/g	1.5	9980	2.42	0.0	No		
Thorium-232	pCi/g	1.5	1520	0.647	0.0	Yes		
Uranium-234	pCi/g	1.2	5140	1610	0.3	No		
Uranium-235	pCi/g	0.06	2750	103	0.0	No		
Uranium-238	pCi/g	1.2	1570	1710	1.1	No	1710	1.1
Total					**1038.0**			**741.6**

[a] Background (Bkgd) values are taken from Table A.12 of *Methods for Conducting Risk Assessment and Risk Evaluation at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* Volume 1, *Human Health*, DOE/LX/07-0107&D2/R6/V1, July 2015.

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APPENDIX F

ANALYTICAL DATA (CD)

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APPENDIX F

ANALYTICAL DATA (CD)

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