APPENDIX E

TECHNICAL INFORMATION

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CONTENTS

E.1. DATA AND DOCUMENTS USED TO ESTABLISH BACKGROUND CONCENTRATIONS E-7

E.2. SITE-SPECIFIC EXPOSURE INFORMATION E-19
- E.2.1 PHASE I SITE INVESTIGATION RESULTS OF SURFACE WATER AND GROUNDWATER USERS SURVEY TO DETERMINE GROUNDWATER USE NEAR PGDP E-19
- E.2.2 SUMMARY OF AGRICULTURAL PRACTICES IN BALLARD COUNTY, KENTUCKY E-19
- E.2.3 SUMMARY OF AGRICULTURAL PRACTICES IN MCCRACKEN COUNTY, KENTUCKY E-21
- E.2.4 AREA OF CROP LAND IN BALLARD AND MCCRACKEN COUNTY, KENTUCKY E-22
- E.2.5 RECREATIONAL USE OF BAYOU AND LITTLE BAYOU CREEKS NEAR PGDP E-22
- E.2.6 ANNUAL HARVESTS OF TURKEYS AND DEER IN MCCRACKEN AND BALLARD COUNTIES, KENTUCKY, AND WATERFOWL IN BALLARD COUNTY, KENTUCKY E-25
- E.2.7 USE OF EXPOSURE UNITS IN RISK CALCULATIONS AND REMEDIAL DECISIONS E-32

E.3. KENTUCKY REGULATORY GUIDANCE E-49

E.4. FLOWCHART FOR UNCERTAINTY MANAGEMENT FOR UNKNOWN AREAS OF CONTAMINATION E-51

E.5. COMPILED PARAMETERS FOR PROBABILISTIC RISK ASSESSMENTS E-55

E.6. LEAD-210 AT PGDP E-99

E.7. PAH CONTAMINATION AND ESTABLISHMENT OF REMEDIAL GOALS E-111

E.8. SITE-SPECIFIC SOIL SCREENING LEVELS AND SITE-SPECIFIC DILUTION ATTENUATION FACTORS AT THE PADUCAH GASEOUS DIFFUSION PLANT E-123

E.9. HUMAN HEALTH INFORMATION FOR THE PADUCAH VAPOR INTRUSION EVALUATION E-137

E.10. PERTINENT TOXICITY VALUES AND INFORMATION E-163

E.11. MEETING MINUTES FROM PADUCAH RISK ASSESSMENT WORKING GROUP E-167

E.12. ANTHROPOGENIC BACKGROUND AT PGDP E-233

E.13. PFAS ANTHROPOGENIC BACKGROUND AT PGDP E-249

ATTACHMENT E1: 1995 QUESTIONNAIRE AND RESPONSES REGARDING RECREATIONAL USAGE OF BAYOU AND LITTLE BAYOU CREEKS E1-1

ATTACHMENT E2: 2014 E-MAIL UPDATE REGARDING RECREATIONAL USAGE OF BAYOU AND LITTLE BAYOU CREEKS E2-1

FIGURES

E.1. Map of West Kentucky Wildlife Management Area E-26
E.2. Map of West Kentucky Wildlife Management Area Horse Trails E-27
E.3. Map of Ballard Wildlife Management Area E-28
E.4. Wildlife Management Area Map Legend E-29
E.5. Total Turkey Harvest in Ballard and McCracken Counties 2000–2016 ..... E-30
E.6. Total Deer Harvest in Ballard and McCracken Counties 2000–2016 ..... E-31
E.7. Lead-210 Decay Chain E-99
E.8. Lead-210 Soil/Sediment Samples E-100
E.9. Total PAH Concentrations by Depth E-113
E.10. Total PAH in Surface (0-1 ft bgs) Soil/Sediment Samples E-115
E.11. Total PAH Subsurface (1-10 ft bgs) Soil/Sediment Samples E-117
E.12. Total PAH Deep Subsurface (>10 ft bgs) Soil/Sediment Samples E-119
E.13. Probabilistic DAF Distribution E-126

TABLES

E.1. Turkey Harvested on Public Land in Western Kentucky in 2016 ..... E-30
E.2. Deer Harvested on Public Land in Western Kentucky in 2016 ..... E-31
E.3. Waterfowl Counts in Ballard Wildlife Management Area E-32
E.4. Sample Results for Lead-210, Radium-226, and Uranium-238 in Soil and Sediment E-102
E.5. Results of Filtering E-106
E.6. Maximum Benzo(a)pyrene Concentrations by Sample Depth E-112
E.7. Maximum Total PAHs by Depth E-112
E.8. Modeling Matrix for Groundwater E-127
E.9. Example Site-Specific and Default Inputs for Key COPCs E-130
E.10. Vapor Intrusion Screening Levels (VISLs) for Analytes of Interest for PGDP—Commercial E-139

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E.1. DATA AND DOCUMENTS USED TO ESTABLISH BACKGROUND CONCENTRATIONS

As early as the late 1950s, the U.S. Department of Energy (DOE) and its predecessor organization determined the importance of identifying background concentrations for metals and radionuclides in the environment. Routine monitoring programs were established for air and grass. In 1971, the monitoring program was expanded to include surface soil samples taken at four locations at the plant perimeter, with the only analyte being total uranium.

In 1973, the locations of sampling were changed from the perimeter locations mentioned herein to four locations five miles from the plant perimeter. The only analyte was total uranium. From 1975 until 1985, the environmental monitoring program for soils continued as described.

The environmental report for 1986 states that the analyte list for soil samples was expanded from only uranium to thorium-230, neptunium-237, plutonium-239, and isotopic uranium. Starting in 1988, the radionuclide analyte list for soil samples taken as part of the environmental monitoring programs was expanded to include total uranium, uranium-238, cesium-237, potassium-40, neptunium-237, plutonium-239, thorium-230, and technetium-99. Also, beginning in 1988, analyses were performed for 36 metals. Metals included in the analyte list were aluminum, antimony, arsenic, barium, beryllium, bismuth, calcium, cadmium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, mercury, molybdenum, nickel, niobium, phosphorus, potassium, ruthenium, silver, sodium, silicon, strontium, tantalum, thallium, thorium, tin, titanium, tungsten, vanadium, zinc, and zirconium.

PHASE I AND II SITE INVESTIGATIONS REFERENCE SAMPLING

In 1988, DOE and the U.S. Environmental Protection Agency (EPA) entered into a Consent Order that defined the mutual objectives of the EPA and DOE to study groundwater contamination and the threat of releases from the Paducah Gaseous Diffusion Plant (PGDP). A copy of that Consent Order can be found at the following link: https://eic.pad.pppo.gov/Search.aspx?accession=I-02004-0002.

As part of the effort to address the Consent Order, a Site Investigation was performed in two phases. The *Results of the Site Investigation, Phase I, at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, (ER/KY-4) was completed in 1991; and *Results of the Site Investigation, Phase II, at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, KY/SUB/13B-97777C P-03/1991/1, was completed in 1992. During the completion of Phase I and II Site Investigations, the need for background or reference concentrations for inorganic analytes and reference activities radionuclides was recognized. To meet this need, the Site Investigations included the collection of soil samples from areas outside known plant influence. To establish reference activities for radionuclides, 33 surface soil samples (from 0 to 12 inches in depth) were collected from areas at least 5 miles east and southeast of PGDP in May and June of 1990. The analytes for this sampling effort included gross alpha and gross beta, neptunium-237, technetium-99, plutonium-239, thorium-230, uranium-238, uranium-234, and uranium-235.

To establish reference concentrations for inorganic and metals, five surface samples (from 0 to 6 inches in depth) were taken during the Phase II Site Investigation in areas near the PGDP, but outside areas suspected to be influenced by the plant operations. The metals included aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, cyanide, iron, lead, magnesium, manganese, mercury, nickel, potassium, selenium, silver, sodium, thallium, vanadium and zinc. A report entitled *Inorganic Soil and Groundwater Chemistry Near Paducah Gaseous Diffusion Plant; Paducah, Kentucky*, ORNL/TM-12897, was prepared and sent to the regulatory agencies for information purposes. While this

report was not prepared to establish background groundwater and soil concentrations, it did discuss potential background concentrations for soil and groundwater at PGDP.

In response to comments on *Soil and Groundwater Chemistry Near Paducah Gaseous Diffusion Plant; Paducah, Kentucky*, ORNL/TM-12897 (1996), DOE prepared another internal report with a more extensive evaluation of existing data (primarily data from the Phase I and II Site Investigations, entitled *Background Concentrations and Human Health Risk-based Screening Criteria for Metals in Soil at the Paducah Gaseous Diffusion Plant*, KY/EM-77&D1. The report contained data for 146 surface sampling locations and 597 samples for subsurface soils for metals analysis. The metals included all of those analyzed in the Phase II report with the exception of cyanide in surface and subsurface soils and thallium in subsurface soils. A consensuses of reviewers believed that the data evaluation in this report was not sufficient to establish background of metals in soil and requested that the document be revised.

In response, a revised report, *Background Concentrations and Human Health Risk-based Screening Criteria for Metals in Soil at the Paducah Gaseous Diffusion Plant*, DOE/OR/07-1417&D2, was prepared (DOE 1996). EPA conditionally approved this revised document. The conditions included the reanalysis of four metals including antimony, beryllium, cadmium, and thallium. Also in 1996, the Commonwealth of Kentucky accepted the revised report. The Commonwealth also called for additional sampling to verify the background concentrations of antimony, beryllium, cadmium, and thallium.

DOE issued the final revision of a work plan entitled *Project Plan for the Background Soils Project for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1414&D2 (DOE 1996). As described in this work plan, DOE was to verify with additional sampling the background concentrations for the four metals listed in the conditional approval letters for DOE/OR/07-1417&D2 and to determine the background concentrations of selected radionuclides.

DOE issued the final revision of the report for the background soils project entitled, *Background Levels of Selected Radionuclides and Metals in Soils and Geologic Media at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1586&D2. In this report, the values selected by DOE as background concentrations for soil in the DOE/OR/07-1417 report were combined with the background concentrations analyzed for antimony, beryllium, cadmium, thallium, and selected radionuclides, and final background concentration data sets were established. This report included 15 surface soil and 41 subsurface soil sampling locations for the four metals listed above. In addition the significant radionuclides included cesium-137, neptunium-237, plutonium-239, plutonium-238, potassium-40, radium-226, strontium-90, technetium-99, thorium-228, thorium-230, thorium-232, uranium-238, uranium-234, and uranium-235. A variety of statistical methods as described in *Background Levels of Selected Radionuclides and Metals in Soils and Geologic Media at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-1586&D2, were used to evaluate the data and ultimately these data were used with data from previous investigations to establish the background values for soils at PGDP. The background values are presented in Appendix A.

APR 1 1996

JAMES E. BICKFORD
SECRETARY

PAUL E. PATTON
GOVERNOR

received
4/3/96 Dsq

COMMOMWEALTH OF KENTUCKY
NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION CABINET
DEPARTMENT FOR ENVIRONMENTAL PROTECTION
FRANKFORT OFFICE PARK
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FRANKFORT KY 40601

March 21, 1996

Mr. Jimmie Hodges, Site Manager
U.S. Department of Energy
Paducah Site Office
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Paducah, Kentucky 42001

Mr. Jimmy Massey, Plant Manager
Lockheed Marietta Energy Systems
761 Veterans Avenue
Kevil, Kentucky 42053

RE: Comments to Comment Summary Response for the Background Concentrations and Human Health Risk-based Screening Criteria for Metals in Soil at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky. Document Number DOE/OR/07-1417&D1 (formerly known as KY/EM-77).
EPA Number KY8-890-008-982

Gentlemen:

This letter is intended to serve as the response to DOE's Comment Response Summary dated February 5, 1996, for the above mentioned document. In addition, the following comments have been generated in response to our phone conversations of January 16 and 17, 1996 with Tony Able of EPA Region IV, Carlos Alvarado of DOE, and their contractors.

Background concentrations must be determined at this facility under condition IV.D.3.b. of DOE's Kentucky Hazardous Waste Permit (#KY8-890-008-982). To satisfy this condition for inorganics in soil, DOE submitted *Inorganic Soil and Groundwater Chemistry Near Paducah Gaseous Diffusion Plant* (Moore Report, released as Lockheed Martin document # ORNL/TM-12897) and the *Background Concentrations and Human Health Risk-based Screening Criteria for Metals in Soil at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (released as Lockheed Martin document # KY/EM-77) in April 1995. The Division of Waste Management (Division), after review of these two documents, rejected the Moore Report and asked DOE to resubmit the EM-77 report. The EM-77 Report was resubmitted in September 1995 under DOE Document # DOE/OR/07-1417 with the same title.

After further review of the EM-77 Report, the Division's accepts the background values based on

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the fact they are comparable to background values established by H. T. Shacklette, 1981. Additionally, the selected background values for PGDP are comparable to the Western Kentucky Region. The selected background values, which are summarized below, are found in Tables 2.14 and 2.15 of DOE's current background soils document.

	SURFACE SOILS (mg/kg)	SUBSURFACE SOILS (mg/kg)
Aluminum	15,700	17,300
Arsenic	12.0	18.7
Barium	198	341
Calcium	293,000	236,000
Chromium	16.0	112
Cobalt	14.0	16.0
Copper	19.0	61.5
Iron	27,700	47,400
Lead	38.0	119
Magnesium	8,250	3,250
Manganese	2,700	1,920
Mercury	0.33	0.42
Nickel	21.0	84.7
Potassium	1,870	1,640
Selenium	0.98	0.87
Silver	2.3	3.8
Sodium	344	404
Vanadium	38	68.9
Zinc	65	190

The remaining four analytes, which are antimony, beryllium, cadmium, and thallium, will be addressed in the *Project Plan for the Background Soils Project for Paducah (BSPP) Gaseous Diffusion Plant, Paducah, Kentucky* (DOE/OR/07-1414&D2). The Division understands that the BSPP is scheduled to start field work late this summer.

Additionally, the Division understands that these numbers are maximum background values where variability of the soil has been taken into consideration. Therefore, any value exceeding these numbers will be considered contamination.

If you have any comments or questions, please call Tuss Taylor at (502) 564-4797.

Sincerely,

Robert H. Daniell, Director
Kentucky Division of Waste Management

RHD/tt/ke

cc: Tony Able, EPA Region IV
Robert Sleeman, DOE
John Morgan, LMES
Carlos Alvarado, DOE
Ken Yates, KDWM-Paducah
Pending File # 95-0019

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 4
345 COURTLAND STREET, N.E.
ATLANTA, GEORGIA 30365

MAR 22 1996

4WD-FFB

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U.S. Department of Energy
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Mr. Jimmy C. Massey, Plant Manger
Martin Marietta Energy Systems, Inc.
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Paducah, Kentucky 42001

Mr. Robert C. Sleeman, Manager
Enrichment Restoration Programs
U.S. Department Of Energy
Oak Ridge Operations
P.O. Box 2001
Oak Ridge, Tennessee 37831-8541

SUBJ: Background Concentrations and Human Health Risk-based Screening Criteria for Metals in Soil at the Paducah Gaseous Diffusion Plant (DOE/OR/07-1417&D1)

Dear Gentlemen:

The Environmental Protection Agency (EPA) has completed review of the subject document dated September 1995. EPA is hereby conditionally approving the subject document. The basis of approval will be the reanalysis of the four (4) analytes including Antimony, Beryllium, Cadmium, and Thallium. Per discussions between our staffs, reanalysis of these metals will be completed during the Background Soils Project to be initiated later this fiscal year. Of the four analytes, Beryllium and Cadmium will require surface sampling. Antimony and Cadmium will require subsurface sampling.

The development of the Background Soils Concentrations will be useful in future investigations. Specifically, it will save time and investigation costs by eliminating the need for background sampling for each new investigation.

If you have questions regarding this matter, please contact me at 404-347-3555, extension 6429.

Sincerely Yours,

Tony Able

Tony Able
Remedial Project Manager
Waste Management Division

cc: Tuss Taylor, KDEP
Arnold Guevara, DOE-HQ
John W. Morgan, MMES
Pat Haight, KDEP

3233

DWM# 850-6

CABINET FOR HEALTH SERVICES
COMMONWEALTH OF KENTUCKY
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DEPARTMENT FOR PUBLIC HEALTH

MAY 15 1997

May 15, 1997

Myrna Redfield
U.S. Department of Energy
Paducah Site Office
P.O. Box 1410
Paducah, Kentucky 42001.

Tuss Taylor
UKFFOU
14 Reilly Road
Frankfort, Kentucky 40601

Re: Background Levels of Selected Radionuclides and Metals in Soils and Geologic Media at the Paducah Gaseous Diffusion Plant, PGDP, Paducah Kentucky (DOE/OR/07-1586&D1).

Dear Ms. Redfield and Mr. Taylor:

The Radiation Control Program (RCP) has completed its' review of the subject document. The RCP's concerns and questions were addressed during the scoping, data analysis, and data assessment processes. The RCP has no comments at this time.

The RCP commends the Department of Energy for conducting a scientifically sound project that has provided reference data for the assessment of radionuclide contamination and risk at the Paducah Gaseous Diffusion Plant. Because of the sound scientific approach utilized during this project, I have sent the document to the Multi-Agency Radiation Laboratory Analytical Procedure Committee for consideration as a model to be used by all federal and state agencies for project planning and execution.

If you have questions regarding the RCP's position on the subject document, feel free to contact Dr. John A. Volpe (502) 564-3700 or Steve Hampson (502) 564-8390.

Sincerely,

John A. Volpe, Ph.D., Supervisor
Radiation and Toxic Agents Control Section

c: Steve Hampson

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JAMES E. BICKFORD
SECRETARY

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COMMONWEALTH OF KENTUCKY
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May 28, 1997

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United States Department of Energy
Paducah Site Office
P. O. Box 1410
Paducah, Kentucky 42001

Mr. Jimmy C. Massey, Plant Manager
Lockheed Martin Energy Systems, Inc.
761 Veterans Avenue
Kevil, Kentucky 42053

I-04202-0001

Re: Background Levels of Selected Radionuclides and Metals in Soils and Geologic Media at the Paducah Gaseous Diffusion Plant, Paducah, KY (DOE/OR/07-1586&D1)
Permit # KY8-890-008-982
McCracken County

Gentlemen:

The Division of Waste Management has reviewed the background values presented in the above document. The values presented for the radionuclides, beryllium, thallium, antimony, and cadmium are approved. The investigation has provided valuable data for background at this site. We commend DOE for working closely with personnel from the Agreement in Principle and the Cabinet for Health Services Radiation Control Branch to develop a scientifically sound background investigation. It is our hope that DOE will continue this trend when developing future workplans for investigating contamination at the Paducah Gaseous Diffusion Plant.

The Division approves the following values for beryllium, thallium, antimony, and cadmium in soil as presented in the *Background Levels of Selected Radionuclides and Metals in Soils and Geologic Media at the Paducah Gaseous Diffusion Plant, Paducah, KY (DOE/OR/07-1586&D1):*

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5/9/22 — Date

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Analyte	surface (0-1 ft) (mg/Kg)	subsurface (below 1 ft) (mg/Kg)
beryllium	0.673	0.686
thallium	0.209	0.336
antimony	0.21	0.21
cadmium	0.21	0.21

If you have any question or need additional information, please call Tuss Taylor at (502) 564-4797.

Sincerely,

Robert H. Daniell, Director
Division of Waste Management

RHD/tt/ke

cc: Carl R. Froede, Jr., USEPA Region 4
Robert Sleeman, DOE
Carlos Alvarado, DOE
Margie Williams, DWM-Paducah Regional Office
John Morgan, LMES
John Volpe, CHS
DWM file #830

7/15/97

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Paducah Site Office
P.O. Box 1410
Paducah, Kentucky 42001

Mr. Jimmy C. Massey, Plant Manager
Lockheed Martin Energy Systems, Inc.
761 Veterans Avenue
Kevil, Kentucky 42053

SUBJ: D2 - Background Levels of Selected Radionuclides and Metals in Soils and Geologic Media at the Paducah Gaseous Diffusion Plant (DOE/OR/07-1586&D2)

Gentlemen:

The Environmental Protection Agency (EPA) has completed our review of the revised D2 version of the Background Levels of Selected Radionuclides and Metals in Soils and Geologic Media at the Paducah Gaseous Diffusion Plant. This revised document adequately addresses all of our previous comments. This document is approved in this version.

Any and all concerns raised by the Kentucky Department of Environmental Protection must be addressed within this document as required under their authority.

Any questions concerning these matters should be directed to me, at (404) 562-8550.

I-04202-0002

Sincerely,

Carl R. Froede Jr.

Carl R. Froede Jr., P.G.
DOE Remedial Section
Federal Facilities Branch
Waste Management Division

REVIEWED FOR CLASSIFICATION
G. Lamb 5/9/22
Name Date
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cc: T. Taylor, KDEP/Frankfort
R. Thomas, KDEP/Frankfort
J. Stickney, KDEP/Frankfort

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E.2. SITE-SPECIFIC EXPOSURE INFORMATION

This section of the appendix contains copies or excerpts of reports, memoranda, articles, and links to reports that are useful in developing exposure assessments for PGDP and justifying various assumptions made when completing risk assessments and analyses. These include the following:

- Site Investigation surface water and groundwater users survey to determine groundwater use near PGDP (CH2M HILL 1991);
- Summary of agricultural practices in Ballard County, Kentucky;
- Summary agricultural practices in McCracken County, Kentucky;
- Area of crop land in Ballard and McCracken Counties, Kentucky;
- Recreational use of Bayou and Little Bayou Creeks near PGDP;
- Annual harvests of geese, ducks, turkeys, and deer in McCracken and Ballard Counties, Kentucky; and
- Reports entitled, "Planning Issues for Superfund Site Remediation," and "Quantitative Decision Making in Superfund: A Data Quality Objectives Case Study," from *Hazardous Materials Control* regarding use of exposure units in risk calculations and remedial decisions.

E.2.1 PHASE I SITE INVESTIGATION RESULTS OF SURFACE WATER AND GROUNDWATER USERS SURVEY TO DETERMINE GROUNDWATER USE NEAR PGDP

A surface water and groundwater user's survey was conducted as part of the Site Investigation Phase I, and is included in the document's Appendix 2B-15 (CH2M HILL 1991). The appendix in its entirety can be found at the following link: https://eic.pad.pppo.gov/Search.aspx?accession=I-02300-0001 (part f). Appendix 2B-15 begins on page 276 of the pdf.

Because the Site Investigation Phase I is large, it is broken into several parts. Part "f" contains Appendix 2B-15. Click "View" at the left of the screen of the above link to see the document.

E.2.2 SUMMARY OF AGRICULTURAL PRACTICES IN BALLARD COUNTY, KENTUCKY

This section summarizes information obtained from a 2017 search of various public records to identify the parameters of agricultural practices in Ballard County, Kentucky.

Population. Population information for Ballard County is taken from http://www.city-data.com/county/Ballard_County-KY.html, accessed October 2017.

- 8,240 population (as of 2014)
- Size of family households: 1,179 2-persons; 552 3-persons; 405 4-persons; 157 5-persons; 52 6-persons; 27 7-or-more-persons

- Size of nonfamily households: 881 1-person; 131 2-persons; 5 3-persons; 6 4-persons; 1 5-persons; 1 6-persons

Agriculture in Ballard County. Agriculture information for Ballard County is taken from http://www.city-data.com/county/Ballard_County-KY.html, accessed October 2017.

- Average size of farms: 233 acres
- Average value of agricultural products sold per farm: $70,647
- Average value of crops sold per acre for harvested cropland: $213.68
- The value of nursery, greenhouse, floriculture, and sod as a percentage of the total market value of agricultural products sold: 0.18%
- The value of livestock, poultry, and their products as a percentage of the total market value of agricultural products sold: 55.27%
- Average total farm production expenses per farm: $60,366
- Harvested cropland as a percentage of land in farms: 63.59%
- Irrigated harvested cropland as a percentage of land in farms: 0.29%
- Average market value of all machinery and equipment per farm: $50,268
- The percentage of farms operated by a family or individual: 91.56%
- Average age of principal farm operators: 55 years
- Average number of cattle and calves per 100 acres of all land in farms: 8.31
- Milk cows as a percentage of all cattle and calves: 5.09%
- Corn for grain: 22,422 harvested acres
- All wheat for grain: 10,372 harvested acres
- Soybeans for beans: 39,814 harvested acres
- Vegetables: 15 harvested acres
- Land in orchards: 5 acres

Gardening. Gardening information was updated from a 1994 interview with the Agricultural Extension Agent of Ballard County. The current Ballard County Agricultural Extension Agent confirmed in December 2013 that most of the information is feasible; however, the percentage of the population with a garden has dropped considerably.

(1) Approximately 25–30% of the population have a garden
(2) Commonly grown garden vegetables are squash, corn, tomatoes, green beans, and peas
(3) The average garden site is one-fourth acre
(4) Approximately 0.1 to 0.2 pounds of garden grown vegetables are consumed per individual per day

(5) Approximately 80% of gardeners can their produce
(6) Growing season is April 5 to October 12: 4,560 hours

E.2.3 SUMMARY OF AGRICULTURAL PRACTICES IN MCCRACKEN COUNTY, KENTUCKY

This section summarizes information obtained from a 2017 search of various public records to identify the parameters of agricultural practices in McCracken County, Kentucky.

Population. Population information for McCracken County is taken from http://www.city-data.com/county/McCracken_County-KY.html, accessed October 2017.

- 65,316 population (as of 2014)
- Size of family households: 8,862 2-persons; 4,185 3-persons; 3,035 4-persons; 1,200 5-persons; 411 6-persons; 198 7-or-more-persons
- Size of nonfamily households: 8,993 1-person; 1,153 2-persons; 119 3-persons; 50 4-persons; 11 5-persons; 5 6-persons; 5 7-or-more-persons

Agriculture in McCracken County: Agriculture information for McCracken County is taken from http://www.city-data.com/county/McCracken_County-KY.html, accessed October 2017.

- Average size of farms: 161 acres
- Average value of agricultural products sold per farm: $29,777
- Average value of crops sold per acre for harvested cropland: $215.65
- The value of nursery, greenhouse, floriculture, and sod as a percentage of the total market value of agricultural products sold: 11.92%
- The value of livestock, poultry, and their products as a percentage of the total market value of agricultural products sold: 26.35%
- Average total farm production expenses per farm: $22,605
- Harvested cropland as a percentage of land in farms: 63.19%
- Irrigated harvested cropland as a percentage of land in farms: 0.21%
- Average market value of all machinery and equipment per farm: $34,300
- The percentage of farms operated by a family or individual: 96.80%
- Average age of principal farm operators: 55 years
- Average number of cattle and calves per 100 acres of all land in farms: 3.63
- Corn for grain: 9,160 harvested acres
- All wheat for grain: 3,899 harvested acres

- Soybeans for beans: 37,579 harvested acres
- Vegetables: 85 harvested acres
- Land in orchards: 122 acres

Gardening. Gardening information was updated from a 1994 interview with the Agricultural Extension Agent of McCracken County. The current McCracken County Agricultural Extension Agent confirmed in January 2014, that most of the information still is feasible; however, the percentage of the population with a garden has dropped considerably, as has the average garden size.

(1) Approximately 10% of the population have a garden.

(2) Common grown garden vegetables are squash, com, tomatoes, green beans, and lettuce.

(3) The average garden size is one-eighth acre.

(4) During harvest season (three months), approximately 2 pounds of garden grown vegetables are consumed per individual per day.

(5) Approximately all gardeners can their produce.

E.2.4 AREA OF CROP LAND IN BALLARD AND MCCRACKEN COUNTY, KENTUCKY

The following information is taken from USDA's National Agricultural Statistics Service in cooperation with the Kentucky Department of Agriculture. The information is available at the following web site, accessed October 2017:

http://www.nass.usda.gov/Statistics_by_State/Kentucky/Publications/State_Census_Summaries/Historical_Ag_Statistics/

	Harvested Acres	
Year	**Ballard**	**McCracken**
1982	80,133	45,870
1987	62,583	40,444
1992	69,662	36,450
1997	74,158	46,291
2002	71,870	54,003
2007	70,700	43,272
2012	78,427	41,832

E.2.5 RECREATIONAL USE OF BAYOU AND LITTLE BAYOU CREEKS NEAR PGDP

The usage information originally was provided by Charlie Logsdon, West Kentucky Wildlife Management Area (WKWMA) Supervisor, in November 1995, in response to a questionnaire sent to him by Fuller, Mossbarger, Scott, and May Engineers, Inc., of Lexington, Kentucky (see Attachment E1). The information was used by the United States Army Corps of Engineers to support a preliminary risk calculation for Bayou and Little Bayou Creeks that was completed in 1997. In response to a recommendation from the Paducah Risk Assessment Working Group (RAWG) in October 2013, the information was provided to Tim Kreher, the current WKWMA Manager, for review and update. Mr. Kreher returned the updated information to the RAWG on January 21, 2014. Mr. Kreher's e-mail to LeAnne Garner, chair of the Risk Assessment Working

Group, is included in Attachment E2.The information below provides a summary of the updated information.

E.2.5.1. Bayou Creek

1. What is the average number of visitors per year to Bayou Creek?

The number of visits by people using Bayou Creek specifically is estimated to be 225 visits. This is for a specific activity involving Bayou Creek, such as fishing. More people may be in the vicinity while using the WKWMA, but their use of Bayou Creek maybe for only an instant (i.e., using a log to cross Bayou Creek to hunt on the other side of the creek).

2. Of this number, how many are adults and how many are children?

Of the 225 visits of people using Bayou Creek, 150 are adults and 75 are children. This is an estimate based on our observations of people using the area.

3. Are most of your visitors repeat or one-time visitors on a yearly basis?

Most of these people would be one-time users; however, 10% of the total number of users could be classified as repeat users. The highest number of visits by one person specifically using Bayou Creek would probably be < 15.

4. What is the average time (hours) spent in Bayou Creek? Is there a difference in average time spent between adult and child usage?

The average time spent in Bayou Creek by users is unknown; however, the amount of time spent/trip would be similar to other activities. An estimate of the average number of hours spent/trip for activities were as follows: Quail hunting ~ 5, rabbit hunting ~ 5, bowhunting for deer ~ 5, duck hunting ~ 4, and raccoon hunting ~ 4. Raccoon hunting and duck hunting would be the activities most likely associated with Bayou Creek. There would be little, if any, difference between adult and child usage of the area.

Actual time spent in the creek may be cases where hunters cross one or both creeks by wading through shallow spots; in most cases, these people are wearing rubber boots or waders. When hunters do wade through the creeks, again it is a brief exposure of less than 30 seconds each time.

5. What are the common recreational usages in the area? What is the percentage breakdown of usages by the visitors (i.e., what percentage of visitors fish, hunt, hike, swim. etc.)?

WKWMA is used heavily by a wide variety of users. Annually, the estimated number of visits for the following activities are the following: fishing ~ 7,500 visits/year; hunting and dog training ~ 6,000-9,000; field trials ~ 2,250; hiking ~ 150; berry and nut picking ~ 300; driving through for a variety of reasons ~ 75,000.

There are brief exposures to both Bayou and Little Bayou Creeks by dog trainers riding horses where they cross the creek via the method of the horse and dog wading through the creek while the rider is mounted (i.e., the riders does not have contact with the water for the most part). Such crossings are brief, less than 10 seconds at a time. For activities involving Bayou Creek alone: fishing—225 (see Question 1).

6. What is the number of repeat visits per year by anyone individual or group of individuals? What is the average time spent (hours) in the area by the higher frequency visitors?

Refer to Questions 3 and 4.

7. For individuals who are fishing in the area, are they mostly bank fishing or wade fishing? Can you estimate the percentage breakdown between the two? What is the average time spent in the area by a fisherman?

Most, if not all, would be bank fishermen. Most of the fishing would occur at three points: (1) where the iron bridge in Tract 4 crosses Bayou Creek, (2) where the collapsed bridge in Tract 4 crosses Bayou Creek (by weir constructed by PGDP), and (3) where the concrete crossing bridges Bayou Creek in Tract 6. While it may occur, no wade fishing has been observed. No actual data are available, but should be similar to the length of visits noted in Question 4.

8. Is there a harvestable fish population in Bayou Creek? If there is, is there enough to support subsistence fishing (i.e., 0.284 kg of meat flesh/meal) for one person to eat 128 meals a year? If not, how much fish, and how often could a person best expect to harvest a meal for consumption?

There is a harvestable fish population in Bayou Creek. A person potentially could expect to catch 0.284 kg of fish on a regular basis; however, this is assuming that the person is not culling (throwing back extremely small fish). The frequency of being able to catch 0.248 kg of fish would increase as one approaches the mouth of Bayou Creek. Also, the only way the creek could support 128 meals a year is if there were a major influx of fish from the Ohio River. This does occur when there is a backwater. During the backwater periods, catches of 50 to several hundred pounds of catfish can be taken (this has been observed) on trotlines. This would not be indicative of risks associated with the plant.

Fishing activity in the creeks rarely is observed outside of the portion that crosses through TVA-owned property near where the creeks join and meet the Ohio River (referred to as Tract 6 of the WKWMA).

E.2.5.2. Little Bayou Creek

1. What is the average number of visitors per year to Little Bayou Creek?

The number of people visiting Little Bayou Creek essentially is zero, with the exception of PGDP personnel and a few fishermen (maybe 30 visits annually) who fish a large beaver pond above the outfalls of the plant. A few people (bowhunters and dog trainers) may cross the creek occasionally, but these visits would be brief (the majority would be measured in seconds or minutes). Field trial galleries do cross the creek (over a large dirt-covered culvert) north of McCaw Road; however, they do not enter the creek, and the whole process takes seconds.

2. Of this number, how many are adults and how many are children?

The visitors would be adults.

3. Are most of your visitors repeat or one-time visitors on a yearly basis?

Refer to Bayou Creek Question 3 (Section E.2.5.1). Visitors to Little Bayou Creek would be repeat users, probably less than 15 visits per year, and most of them fall into the brief encounter scenario described in Question 1.

4. What is the average time (hours) spent in Little Bayou? Is there a difference in average time spent between adult and child usage?

Most encounters with Little Bayou Creek would be measured in seconds. Fishermen who use the beaver pond above the outfalls may fish on average 3 hours.

5. What are the common recreational usages in the area? What is the percentage breakdown of usages by the visitors (i.e. what percentage of visitors fish, hunt, hike, swim, etc.)?

See Bayou Creek Question 5 (Section E.2.5.1).

6. What is the number of repeat visits per year by anyone individual or group of individuals? What is the average time spent (hours) in the area by the higher frequency visitors?

Field trials that cross the creek may occur 12–15 weekends of the year. Most of the participants would be repeat users. The sum of all the encounters with Little Bayou Creek would be measured in minutes for the most frequent user, and most would cross the creek only on the culvert and dirt crossings.

7. For individuals who are fishing in the area, are they mostly bank fishing or wade fishing? Can you estimate the percentage breakdown between the two? What is the average time spent in the area by a fisherman?

All fishermen in the beaver pond would be bank fishermen because the pond is too deep to wade.

8. Is there a harvestable fish population in Little Bayou? If there is, is there enough to support subsistence fishing (i.e., 0.284 kilograms of meat flesh/meal) for one person to eat 128 meals a year? If not, how much fish, and how often could a person best expect to harvest a meal for consumption?

Other than the beaver pond above the outfalls, it would be nearly impossible to catch 0.284 kg of fish from Little Bayou Creek. There is a fish population, but most would fall in the minnow category and are not desirable by fishermen. In the beaver pond, it would be possible to catch this amount, but it would not support subsistence fishing (128 meals/year).

E.2.6 ANNUAL HARVESTS OF TURKEYS AND DEER IN MCCRACKEN AND BALLARD COUNTIES, KENTUCKY, AND WATERFOWL IN BALLARD COUNTY, KENTUCKY

PGDP is surrounded by the WKWMA (Figures E.1 and E.2). Additionally, several solid waste management units (SWMUs) (currently listed as no further action) are located in the Ballard Wildlife Management Area (WMA) (Figure E.3). Figure E.4 provides a legend for features in the WMAs. Both of these areas are home to hunting and fishing. Huntable populations of turkey, deer, dove, squirrel, rabbits, and quail exist in the area. Migratory geese and ducks also are abundant in the area. Table E.1 and Figure E.5 and Table E.2 and Figure E.6 show the hunting statistics for turkey and deer in western Kentucky.

The figures and tables within this subsection include additional information regarding wildlife harvests of turkey and deer recorded by Kentucky's telecheck program. Additionally, the reported inventories of ducks and geese found in the Ballard WMA during the 2015/2016 and 2016/2017 hunting seasons are presented in Table E.3. Maps and information regarding game were taken from the Kentucky Department of Fish and Wildlife Resources web site, http://fw.ky.gov accessed in October 2017.

A map legend and additional information are provided on PDF pages that accompany this map.

Publication Date: 11/22/2016
Land Classification from National Land Cover Database 2011
Imagery from Farm Service Agency 2016

0 0.25 0.5 0.75 1 Mile

Scale 1:55,000

Note to Map Users

Map prepared by Kentucky Department of Fish & Wildlife Resources (KDFWR). Although KDFWR strives for accuracy, data used to create this map are from a variety of sources and dates; as such, KDFWR makes no representations regarding the accuracy or fitness for use of the information furnished herein.

Figure E.1. Map of West Kentucky Wildlife Management Area

A map legend and additional information are provided on PDF pages that accompany this map.

Publication Date: 11/19/2016
Land Classification from National Land Cover Database 2011

0 0.25 0.5 0.75 1 Mile

Scale 1:37,000

Note to Map Users

Map prepared by Kentucky Department of Fish & Wildlife Resources (KDFWR). Although KDFWR strives for accuracy, data used to create this map are from a variety of sources and dates; as such, KDFWR makes no representations regarding the accuracy or fitness for use of the information furnished herein.

Figure E.2. Map of West Kentucky Wildlife Management Area Horse Trails

A map legend and additional information are provided on PDF pages that accompany this map.

Publication Date: 11/16/2016

0 0.25 0.5 0.75 1 Mile

Scale 1:55,000

Note to Map Users

Map prepared by Kentucky Department of Fish & Wildlife Resources (KDFWR). Although KDFWR strives for accuracy, data used to create this map are from a variety of sources and dates; as such, KDFWR makes no representations regarding the accuracy or fitness for use of the information furnished herein.

Figure E.3. Map of Ballard Wildlife Management Area

Wildlife Management Area Map Notes & Legend

NOTE TO MAP USERS:

For most WMA maps the landscape is depicted using a combination of elevation contours, hillshading and a green tint indicating woodland areas that is derived from satellite imagery. On WMAs that are relatively small or have a history of surface mining aerial photography is used.

WMA Map Legend

- WMA Office
- Information Kiosk
- Check station
- Mobility-impaired Hunting Site
- Trailhead
- Horseback Trailhead
- Parking Lot
- Picnic Area
- Restrooms
- Wildlife Viewing Site
- Interpretive Site
- Retriever Training Site
- Gate
- Campground
- Cemetery
- Corps of Engineers Office
- Waterfowl Blind
- Shooting Range
- Established Bank Access
- Fishing Pier
- Carrydown Launch
- Small Boat Ramp
- Large Boat Ramp
- State Park Office

- WMA Boundary
- Aerial photograph
- Other Public Hunting Areas
- Area Off Limits
- No Hunting
- Seasonally Restricted Access
- Mobility Impaired Hunting Area
- Primitive Hunting Only
- Foot Traffic Only
- Open Water
- Wetland
- Woodland

- Populated Place
- Kentucky Boundary
- Interstate Highway
- Kentucky Parkway
- U.S. Highway
- State Highway
- Local Road
- Forest Service Road
- Active Railroad
- Abandoned Railroad
- Federal Recreation Trail
- WMA Road
- WMA Foot Trail
- WMA Horse Trail
- Gas Pipeline
- Powerline
- Rivers and Streams
- Dam
- Trout Waters
- Elevation Contour

Figure E.4. Wildlife Management Area Map Legend

Table E.1. Turkey Harvested on Public Land in Western Kentucky in 2016[a]

Public Land	Male	Female	Total	Archery	Firearm	Muzzle loader	Crossbow
Ballard WMA	23	1	24	0	24	0	0
Beechy Creek WMA	2	0	2	0	2	0	0
Boatwright WMA	7	0	7	0	7	0	0
Clarks River National Wildlife Refuge	19	3	22	0	21	1	0
Coil Estate WMA	1	0	1	0	1	0	0
Doug Travis WMA	14	4	18	1	17	0	0
Jones-Keeney WMA	1	0	1	0	1	0	0
Kaler Bottoms WMA	6	0	6	00	6	0	0
Kentucky Lake WMA	3	0	3	0	3	0	0
Lake Barkley WMA	11	0	11	0	11	0	0
Land Between the Lakes National Recreational Area	54	0	54	0	54	0	0
Livingston County WMA and State Natural Area	9	2	11	1	10	0	0
Obion Creek WMA	4	0	4	0	4	0	0
Ohio River Islands WMA	0	0	0	0	0	0	0
Pennyrile State Forest	21	0	21	0	21	0	0
Reelfoot National Wildlife Refuge	0	0	0	0	0	0	0
Tradewater WMA	1	0	1	0	1	0	0
West Kentucky WMA	32	2	34	1	33	0	0
Winford WMA	0	0	0	0	0	0	0
Totals	208	12	220	3	216	1	0

[a] Numbers are indicative of telechecked game (http://app.fw.ky.gov/harvestweb/TurkeyPublicLandRegion.aspx, accessed 10/6/2017). Both spring and fall hunting seasons are included.

Figure E.5. Total Turkey Harvest in Ballard and McCracken Counties 2000–2016

Table E.2. Deer Harvested on Public Land in Western Kentucky in 2016[a]

Public Land	Male	Female	Total	Archery	Firearm	Muzzle loader	Crossbow
Ballard WMA	24	26	50	17	33	0	0
Beechy Creek WMA	12	9	21	3	18	0	0
Boatwright WMA	25	15	40	2	36	1	1
Clarks River National Wildlife Refuge	79	94	173	20	139	13	1
Coil Estate WMA	0	0	0	0	0	0	0
Doug Travis WMA	17	14	31	3	26	2	0
Jones-Keeney WMA	6	3	9	1	7	1	0
Kaler Bottoms WMA	11	18	29	3	25	1	0
Kentucky Lake WMA	37	28	65	6	55	3	1
Lake Barkley WMA	45	47	92	8	65	17	2
Land Between the Lakes National Recreational Area	168	61	229	57	155	15	2
Livingston County WMA and State Natural Area	34	32	66	11	5	49	1
Obion Creek WMA	19	23	42	4	37	1	0
Ohio River Islands WMA	1	1	2	0	2	0	0
Pennyrile State Forest	22	18	40	37	1	1	1
Reelfoot National Wildlife Refuge	0	0	0	0	0	0	0
Tradewater WMA	1	4	5	4	1	0	0
West Kentucky WMA	15	27	42	40	0	0	2
Winford WMA	3	0	3	0	3	0	0
Totals	**519**	**420**	**939**	**216**	**608**	**104**	**11**

[a]Numbers are indicative of telechecked game (http://app.fw.ky.gov/harvestweb/deerpubliclandregion.aspx, accessed 10/6/2017).

Figure E.6. Total Deer Harvest in Ballard and McCracken Counties 2000–2016

Table E.3. Waterfowl Counts in Ballard Wildlife Management Area

Date	Population Count		Harvest			Date	Population Count		Harvest		
	Ducks	Geese	Ducks	Canada Geese	Other Geese		Ducks	Geese	Ducks	Canada Geese	Other Geese
12/16/2015	43,000	2,600	19	0	1	12/7/2016	35,900	65	85	2	1
12/17/2015	43,000	2,600	16	0	0	12/8/2016	35,900	65	72	3	0
12/18/2015	43,000	2,600	24	0	0	12/9/2016	35,900	65	27	0	0
12/19/2015	41,500	500	26	0	0	12/10/2016	35,900	65	17	0	1
12/20/2015	41,500	500	28	0	0	12/11/2016	35,900	65	70	0	0
12/30/2015						12/14/2016	60,672	120	45	0	0
12/31/2015						12/15/2016	60,672	120	6	0	0
1/1/2016						12/16/2016	60,672	120	19	2	0
1/2/2016						12/17/2016	60,672	120	88	2	0
1/3/2016						12/18/2016	60,672	120	78	0	0
1/6/2016						12/21/2016	64,122	564	55	0	0
1/7/2016	No counts on					12/22/2016	64,122	564	62	0	0
1/8/2016	waterfowl due to		WMA closed			12/23/2016	64,122	564	56	0	0
1/9/2016	flood waters					12/28/2016	54,000	350	73	2	2
1/10/2016						12/29/2016	54,000	350	50	2	0
1/13/2016						12/30/2016	54,000	350	41	0	0
1/14/2016						12/31/2016	54,000	350	80	2	0
1/15/2016						1/4/2017	22,500	350	49	0	0
1/16/2016						1/5/2017	22,500	350	40	0	0
1/17/2016						1/6/2017	22,500	350	0	0	1
1/27/2016			93	1	0	1/7/2017	22,500	350	5	0	0
1/28/2016			104	1	4	1/8/2017	22,500	350	2	0	0
1/29/2016			86	2	4	1/11/2017	55,000	600	61	1	6
1/30/2016			114	0	0	1/12/2017	55,000	600	62	0	3
1/31/2016			110	0	2	1/13/2017	55,000	600	88	0	6
						1/14/2017	55,000	600	31	0	0
						1/15/2017	55,000	600	57	1	2
						1/18/2017	41,500	150	53	0	0
						1/19/2017	41,500	150	20	0	0
						1/20/2017	41,500	150	21	0	0
						1/21/2017	41,500	150	57	0	0
						1/22/2017	41,500	150	44	0	2
						1/25/2017	39,000	480	22	0	1
						1/26/2017	39,000	480	20	0	1
						1/27/2017	39,000	480	51	0	2
						1/28/2017	39,000	480	40	6	0
						1/29/2017	39,000	480	71	0	0
						2/4/2017	30,010	415	62	0	3
						2/5/2017	30,900	415	50	0	1

E.2.7 USE OF EXPOSURE UNITS IN RISK CALCULATIONS AND REMEDIAL DECISIONS

According to two reports ("Planning Issues for Superfund Site Remediation" and "Quantitative Decision Making in Superfund: A Data Quality Objectives Case Study," from *Hazardous Materials Control*) received by the risk analysis section, industrial workers range 0.5 acres per day. This area is where the worker may be exposed to contamination. This area is called an exposure unit. For risk assessment purposes, it is reasoned that an exposure unit of 0.5 acres is consistent with the activities at PGDP. Exposure was weighted based on the size of the SWMU and the 0.5-acre exposure units. If the size of the SWMU was smaller than the 0.5-acre exposure unit, then the fraction was introduced into the chronic daily intake equation. The fraction, however, cannot exceed 1. Copies of the two reports are provided as references.

PLANNING ISSUES FOR SUPERFUND SITE REMEDIATION

Randall T. Ryti
Dean Neptune

One function of the Superfund program is to assess the risk posed by hazardous waste sites. Sites that merit inclusion on the National Priorities List (NPL) are analyzed intensively through the Remedial Investigation/Feasibility Studies (RI/FS) process, which provides estimates of the risk posed by the site and the cost of cleanup. In this article we will review the planning issues for RI/FS through a case study of a specific Superfund site—a former transformer storage and rehabilitation facility in North Carolina.

The planning process used for this example is the Data Quality Objectives (DQO) process, which consists of the following steps: define the problem, define the question, define the data needs (the domain and decision rule), and define the data performance for the main question (*1,2*).

The planning approach is flexible; we have successfully

Abandoned drums located behind the "burn shed" at the site

applied the DQO process to two other Superfund sites. This site differed in the complexity of the problem, as well as the time frame within the Superfund assessment and cleanup process. We have observed that using the DQO process has not increased the resources expended (either time or money). Indeed, the process has resulted in substantial savings at a dioxin site in Missouri (3,4).

Another advantage of the planning process is that data collection can be focused. If one or a few contaminants are of interest, then more specific tests can be used. The planning process also sets goals for data collection, so that a criterion for the adequacy of data collection can be specified. The question of "how much is enough" develops naturally during the planning process.

Site history

The site is a former transformer storage and rehabilitation facility located on 4.8 acres of swampy terrain. The site lies within the 100 year floodplain of the Cape Fear River. Rebuilding of transformers was discontinued in 1982, but storage of transformers continued until 1986 when the site was abandoned. The initial sampling in 1978 found chlorobenzene in the well water on the site. Adjacent residences were placed on city water at that time. In 1979, PCBs were found in both the soil and well water, but no other action was taken. An Emergency Removal Action (ERA) was conducted in 1984 to remove contaminated soil. Sampling after the ERA detected PCBs at up to 140 ppm in the sub-surface soil.

The United States Environmental Protection Agency (EPA) Region 4 is administering the assessment and cleanup activities at the site. Discussions with the Region indicated that there were two phases to these activities. In Phase 1, the short list of contaminants of concern (COCs) and the general location of these COCs are determined. In Phase 2, the locations of the COCs are determined more precisely and the costs of various remedial alternatives are estimated. Through the steps of the DQO process, these general statements were refined and quantitative error tolerances were specified.

Phase 1

Discussion with EPA Region 4 indicated that Phase 1 of the assessment should answer two questions: What is the list of COCs at the Carolina Transformer site, and what is the x, y and z location of these contaminants?

Determining the list of COCs and the spatial scale of the contamination are essentially interrelated. For example, a "hot spot" of dioxin at a concentration of 10 ppb, but only in a few grams of soil at one location is not a threat to human health. Thus a contaminant causes concern if it exists above a specific concentration over an area where exposure is possible.

What logic can be used to define the area and concentration that makes a particular contaminant a concern? One approach is to compute the concentration and exposure area from a risk perspective. A second approach is to consider the way that the contaminant came to be distributed on the site.

EPA policy puts an acceptable risk level between 1 in 10,000 and 1 in 10,000,000 additional cancers (5). In this case, Region 4 decided that an acceptable risk is an additional 1 in 1,000,000 cancer incidence.

For PCBs in soil, the likely exposure route is through ingestion of contaminated soil. Exposure scenarios were investigated for adult workers on the site or children trespassers.

A risk scenario is based on assumptions about the absorption rate of the contaminant, the soil ingestion rate, and the length of the exposure. For example, a 70 kg adult is assumed to absorb 30% of the PCBs ingested. Adults are assumed to ingest a total of 100 mg of soil per day. These PCBs accumulate over 30 years, where the worker is present at the site 5 days a week for 50 weeks a year. Based on laboratory models and these exposure assumptions, an additional one in one million risk is equivalent to a PCB concentration of 1 ppm in the soil. For children trespassers, the end concentration is roughly the same, although the assumptions are different.

Over what area is this exposure accumulated? Some construction workers work over (and thus integrate exposure) an area of 1/2 acre. Children playing on a baseball field would also cover about 1/2 acre. We define an exposure unit (EU) as 1/2 acre. Since exposure is integrated over a large area (1/2 acre), small "hot spots" are only important if the overall average in a 1/2 acre area is greater than 1 ppm.

The preceding scenario was based on ingestion of surface soil. Based on CFR guidelines (an ARAR for PCBs), subsurface soil can be backfilled with clean soil if the concentration of PCBs are less than 10 ppm at a depth of 10 inches; thus <1 ppm PCBs is acceptable for soil in the 0–10 in. layer, and <10 ppm PCBs is acceptable below 10 in.

The likely source of the contamination was from leaking transformers. Thus a "hot spot" could result from a single leaking transformer. The Region decided that a leaking transformer would likely result in a 10 ft by 10 ft footprint. This implies that the smallest area that should need remediation is also a 10-ft square. The spatial scale is now bounded between 100 ft^2 and 22,500 ft^2. (1/2 acre). What concentration of PCBs in 100 ft^2 would result in an average of 1 ppm over 1/2 acre? If the remainder of the 1/2 acre were clean, then a single hot spot would have to measure more than 225 ppm for that EU to pose an unacceptable risk.

The main goal of Phase 1 is to define the list of COCs for the site and estimate the risk posed to the public. To address these goals, some information on the spatial distribution of the contaminants must be collected. Based on the historical use of the site and aerial photos, the site was divided into three areas: administration, operations and storage; PCB contamination was expected to be lowest in administration, intermediate in storage, and highest in operations. This stratification should lead to a more precise estimate of the average PCB concentration on the site. The list of COCs was confirmed on a subset of samples submitted for the full scan analysis. Region 4 had expected that PCBs would be the sole COC on the site. The initial data also indicated that PCBs were much greater than 1 ppm in the surface soil. If these expectations are met, then the data collected in Phase 1 will only have to describe the general location of PCBs across the site.

Because no reliable information on the distribution of PCBs and the presence of other contaminants was available, a pilot study was recommended. In the case that the problem was truly as simple as described above, the pilot study could give enough information to lead to the second phase of the RI/FS.

Before describing the development of the pilot and the results obtained, let us consider the decision rule and the data quality required in Phase 1. The decision is to find if any area of the Carolina Transformer site poses an unacceptable health risk to the public. The data quality for the decision are the acceptable probabilities of making [illegible]e positive or false negative errors. [illegible]e positive is where the actual risk posed by the site is less than 1 in 1,000,000 addi-

TABLE 1

Assumptions about the site used to design the pilot

Sub-unit	Area/acres	Probability 10' x 10' is contaminated	Number of samples
Administration	0.75	0.05	5
Storage	1.5	0.25	15
Operations	0.75	0.50	25

FIGURE 1

"Discomfort curve," or acceptable error rate for decision

onal cancers, but the risk is measured as being greater than 1 in 1,000,000 additional cancers. The consequences of a false positive are that resources (time and money) are diverted to sites that do not pose a significant risk. The possible consequences of a false negative (actual risk posed by the site is greater than 1 in 1,000,000 additional cancers but is measured as less) are additional cancers. Region 4 stated their quantitative discomfort with various magnitudes of false negatives and false positives (Figure 1).

The pilot survey was designed by using simple assumptions about the site. Based on the historical activities at the site, PCBs were assumed to be the most important (or only) contaminants on the site. Thus the Region agreed to run most of the soil samples through a quick-turnaround (QT) analysis procedure for PCBs. In addition to providing results more quickly, the QT method was also less expensive per analysis than the total contaminant list (TCL) scan ($150 vs. $1250). Based on the amount of data collected in other RI/FS Phase 1 surveys, approximately 45 QT soil samples could be analyzed. This amount is based on $30,000 total for Phase 1 analyses; spending one-half of the total in the pilot at $350 per analysis. An additional 10 samples were run by the TCL method to search for other contaminants. The 45 QT samples were allocated based on simple assumptions of the distribution of PCBs. PCB presence or absence was assumed to follow a binomial distribution on the scale of 10 ft by 10 ft areas (with no spatial correlation beyond 10 ft). The probability of presence was assumed to vary according to the sub-units of the site (Table 1).

The TCL samples taken in the pilot confirmed that PCBs were the only significant COC. The QT samples showed that the magnitude of PCB concentration did vary in the predicted manner among the three sub-units of the site. Table 2 shows these concentrations.

The concentration of PCBs was variable both within and between sub-units of the site. For example, stations close to a hot spot (e.g., 10 ppm) were not likely to measure 10 ppm. The spatial pattern of PCBs fits a "hot spot model"; the contamination is located in a binomial fashion, either contaminated or not contaminated. The most important result is that 41 of 45 samples were greater than 1 ppm PCBs; nearly the entire site is a "hot spot" from a risk perspective. Thus the initial assumptions about the frequency of "hot spots" were not correct.

Because the pilot identified PCBs as the only significant contaminant, we can restate the decision as: do any 1/2-acre areas of the site exceed 1 ppm PCBs? What is the approximate location of the contaminated soil? The Region had two options at this point: accept the results of the pilot survey for Phase 1, or conduct a Phase 1 survey where the number of samples is based on the results of the pilot.

Based on the laboratory measurement error for PCBs and the spatial sampling variation, the number of samples taken in the pilot did not meet all of the error constraints set by the Region. The false negative error rate for the Phase 1 decision based on the pilot data was slightly larger than the rate specified by the discomfort curve (7.5% vs. 5%). The advantage of accepting the pilot for the Phase 1 results is that Phase 2 can be started more quickly. False negatives are not important, since all 1/2 acre units were positives (i.e., PCBs >1 ppm), the Region decided to accept the results of the pilot in making the preliminary risk assessment for the site.

Phase 2

The purpose of the Phase 2 RI/FS survey is to define the location of the contamination and the cleanup costs. The cleanup costs are based on two components: a per unit volume cost and the total volume to remediate. The per volume remedial cost is dependent on the particular remedial sequence selected (for example: excavation, incineration, disposal, and back-filling with clean soil). We assume that the per volume remedial cost can be estimated exactly, so the only error is in the estimate of the volume of soil to be remediated. Thus the total volume can be computed from the location estimate.

EPA policy states that the cost should be estimated to within +30% and -50% of the actual RD/RA cost. To simplify the problem, the Region wanted the Phase 2 survey to be designed to estimate the

cleanup cost to within 30% with 90% or greater probability. An obvious difficulty is that sub-surface contamination must be estimated before the surface soil is remediated. A simplifying assumption is that two discrete soil layers will be sampled. Soil above 1 ppm PCBs in the top 10 in. and soil below 10 in. and containing more than 10 ppm PCBs will be remediated.

The data resolution needed for the location question is dependent on the spatial distribution of the contaminant within the exposure units (EU) (1/2 acres units in this example). Should an all-or-none approach be used for EU cleanup, or should remediation units (RUs) be defined as sub-units of EUs? In some cases, the additional sampling is cost-effective in that a "surgical" cleanup can remove hot spots of contamination (4). At a dioxin contaminated site in Missouri, the lowest total cost for sampling and cleanup was for RUs that were 1/24th the size of EUs (4). But in the present case, the pilot data indicated that there was little local pattern in the contamination, and that PCBs were nearly uniformly above 1 ppm. Field sampling and laboratory analysis costs were estimated for four sizes of RUs (1/2 acre, 1/8 acre, 1/18 acre, and 1/32 acre). Designs were evaluated by a Monte Carlo simulation approach (see Ref. 6 for additional examples; contact Dean Neptune for details on the simulations). Based on cost considerations, Region 4 selected 50 ft by 50 ft (about 1/18th acre) as the remedial unit size. This design has a cost of about $50,000 for sampling and laboratory analyses.

TABLE 2
Results of the pilot survey

Sub-unit	Mean concentration (standard deviation, n)	Median
Administration	7.5 (10.7, 5)	1.1
Storage	19.3 (21.4, 15)	11.3
Operations	34.7 (24.5, 25)	32.4

Each EU (or 1/2 acre) contains a three by three grid of RUs. Partial RUs (containing less than 1250 ft^2) are lumped with an adjacent RU. Sixty-two RUs were sampled in the legal boundaries of the site. Two soil samples were taken: a 0–2 in. sample that represented the 0–8 in. soil layer, and a 8–10 in. sample that represented the 8–16 in. soil layer. For each layer, 14 grab samples were taken in the Administration area, and 4 grabs elsewhere (Storage/Operations). The grabs were homogenized, and a single aliquot was bagged for laboratory analysis. Each aliquot contained enough material for four laboratory analyses. Two laboratory analyses were made of each aliquot in the Administration area and one analysis elsewhere.

The results of the Phase 2 RI/FS survey showed that PCBs are highly variable over the site (Table 3).

Large electrical transformers at the site—a former transformer rehabilitation and storage facility

PCB concentration varied over four orders of magnitude in both soil layers. There was greater contamination in the 0–2 in. layer on average, as compared with the 8–10 in. layer (compare Figures 2,3). But in 13 of 61 RUs the 8–10 in. layer was more contaminated (in many locations, by an order of magnitude) than the 0–2 in. layer. We would expect that PCBs would ordinarily migrate slowly down through the soil profile, without some kind of mechanical disturbance (or churning) of the soil. To what extent the soil was churned as a result of the operations at the facility or by the actions taken during the Emergency Removal Action is not known.

To estimate the volume of contaminated soil, the following cleanup strategy (Figure 4) was developed. It was based on the depth that can excavated by a backhoe (about 8 and the two cleanup criteria. The surface soil is considered to be clean if the PCB concentration is less than 1 ppm. An excavated area can be backfilled with clean soil if the PCB concentration is less than 10 ppm at a depth below 10 inches. Three different depths are excavated (8, 10 or 16 in.), or no soil is removed based on the PCB concentration (Table 4). The total amount of soil to be excavated is estimated at 5389 yd^3.

In the Administration area, 6 of 16 RUs (62.5%) were greater than 1 ppm in the 0–2 in. layer, and in the Operations/Storage all 46 RUs measured greater than 1 ppm in the 0–2 in. layer. These numbers are similar to the assumptions used in the volume estimation design computations (50% contaminated assumed for Administration and 90% contaminated assumed for Operations/Storage).

Fifteen quality assessment (QA) samples were analyzed. The QA samples were laboratory sub-samples of the core composites. The relative standard deviation of these QA samples was 15%, excluding one outlier.

Discussion

The goal of Superfund program is to

remediate sites that pose an unacceptable health hazard. Because resources are limited, the Superfund program must be able to rank sites and to rank the hazards within sites. The information for these rankings becomes more detailed at each step in the process. Three main questions about sites are: Does the site pose a hazard? What remedial plan will remove the hazard? How will I verify the site is "clean?"

The Data Quality Objectives (DQO) process provides a way for managers to define a general question about a site that is later refined to a quantitative decision rule. The other parallel effort in the DQO process is to define error tolerances. The initial error tolerances are qualitative, and these are later quantified. These two components (decision rule and error tolerances), are the building blocks for a statistically-based design.

In the case of the North Carolina transformer site, the managers in Region 4 asked for the lowest cost designs that would meet their error tolerances for selected cleanup unit (RU) sizes. They were able to compare the cost of these surveys against a survey that would estimate the volume of soil that was contaminated. In this way they could balance the importance of these main questions in the Phase 2 survey.

The advantage of the DQO process is that the decision constraints (the decision rule and the error tolerances) are based on the initial responses of the decision-maker. The decision-maker can see how different ways of stating the decision rule can have profound implications on the proposed survey design. Where no proposed sampling design is within budget, then the decision-maker has the option to either increase the budget or modify some of the constraints (look at larger RUs).

Conclusions

We have shown that the Data Quality Objectives process can help define questions and the data quality in ways that can lead to statistically-based sampling designs. The DQO process allowed Region 4 to collect the right data at the right time. It should be noted that at each step from the pilot survey to the Phase 1 design, and finally for the Phase 2 study design, the question was further clarified and more information was gathered about PCB distribution across the site. One problem with the Superfund program in general has been to decide when enough data has been collected.

TABLE 3
Results of Phase 2 survey

Soil layer	Median	Range low	Range high	Number of RUs <1 ppm	Number of RUs <10 ppm
0–2"[1]	21	0.4	2500	3	21
8–10"[2]	7.25	0.2	1100	18	36

[1] n=62
[2] n=61, one RU was concrete below the top 8"

FIGURE 2
PCB concentrations in 0–2 in. soil layer

Hatched areas represent buildings or concrete pads

FIGURE 3
PCB concentrations in 8–10 in. soil layer

Hatched areas indicate buildings or concrete pads

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TABLE 4
'mmary of cleanup strategy

Soil depth and concentration	Depth to excavate	Number of RUs	Volume cubic yards
0–2" <1 ppm	0"	3	—
8–10" <1 ppm	8"	18	969
8–10" < 10 ppm	10"	18	1297
8–10" >10 ppm[1]	16"	22	3123

[1] These RUs need to be sampled at 16–18" to verify PCBs are <10 ppm

FIGURE 4
Cleanup strategy for the site

Hatched areas represent buildings or concrete pads

It is through the steps of the DQO process that the data user specifies the stopping point (the decision rule with error tolerances).

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Quantitative Decision Making in Superfund:

A Data Quality Objectives CASE STUDY

What type and quality of data are needed to answer key questions and how do we know when we have enough? Data quality objectives (DQOs) offer decision makers a tool to answer both questions. DQOs provide a qualitative and quantitative framework around which data collection surveys are designed, and can serve as performance criteria for assessing ongoing or completed remedial investigation/feasibility studies (RI/FSs). DQOs allow remedial project managers to make decisions based on RI/FS data with a predetermined and acceptable level of confidence.

Here we present a case study demonstrating the practicality and benefits of using the DQO process as an up-front planning tool for designing RI/FS data collection activities. The RI/FS decision maker and technical support staff (typically including environmental toxicologists and field and laboratory scientists) must work together to develop DQOs and associated RI/FS survey designs. With these individuals in mind, this article illustrates the issues raised during the DQO process, and demonstrates how the process can help resolve them at a Superfund site before an RI survey design is developed.

Development of DQOs involves a step-wise planning process (see box, "Data quality objectives") that may be applied to any problem involving the collection and use of environmental data (*1*). We begin the DQO process by carefully stating the environmental problem to be addressed or the decision to be made; then we identify the information required to select an appropriate course of action and carefully articulate the specific role data will play in making the selection. Specifications regarding the type of data needed, the way data will be used, and the desired degree of certainty in conclusions to be derived from the data are then developed through an iterative process that involves the decision maker and data generators (technical support staff).

When applied to Superfund sites, the DQO process provides a quantitative basis for designing rigorous, defensible, and cost-effective remedial investigations. The DQO planning process recognizes that decision making in Superfund is driven by risks to public health and that the uncertainty in decisions will be affected by the type and quality of data collected. The focus on planning, as presented here, is consistent with ideas developed as part of Superfund's endeavor to streamline its remedial process (*2*).

The case study was developed cooperatively by EPA's Region IV Waste Management Division and Environmental Services Division, and the Quality Assurance Management Staff. Our study involved a retrospective application of the DQO process to an actual Superfund site that had already been studied and the remedial investigation design already implemented. (The RI designs reported here were not actually implemented.) By using a completed site, Region IV expects to compare and contrast the DQO process with the current approach to planning such investigations. All decisions regarding the DQOs were made by Region IV personnel, just as they would for other sites where RIs are planned. We chose an actual site for several reasons: to avoid a purely hypothetical exercise; to ensure that realistic issues were confronted; and to facilitate an objective assessment of the practicality of implementing the DQO process for Superfund problems. Here we report the results of our planning efforts, following the generic structure illustrated in the box "Data quality objectives."

Problem statement

The starting point for any planning process is gathering background information on the specific problem at hand. The site addressed in this case study was used for storing and burning railroad ties and creosote-soaked timbers (*3*) (see photo). Information collected at various times (e.g., during previous site studies and during the Superfund site listing process) suggested that a logical exposure scenario consistent with future use of the site includes site workers and visitors as hazard targets.

Toxicologists determined that the exposure route of greatest concern for these targets is direct ingestion of contaminated surface soils; other routes of exposure are not addressed in the case study. Existing data from preliminary investigations and site visits also suggested that while several contaminants are to be expected in such surface soils, the most toxic are polyaromatic hydrocarbons (PAHs) associated with creosote.

Decisions and decision elements

The key decision posed by the RI/FS is: "What remedial actions, if any, must be taken to reduce the risk posed by the site to an acceptable level?" A logical starting point, and the focus of this study, is to determine whether the site poses an unacceptable risk in its current state—whether it is a problem.

The next step is to work logically toward increasingly specific and hence focused questions that will require environmental data for resolution. We know that PAH contamination of soil is the most likely source of public health risk from the site. Thus, the element of interest can be restated as a question: "Which, if any, surface soil areas have PAHs at concentrations that pose an unacceptable risk to the hazard targets?"

Domain and logic statement

The next step was to determine the concentrations of PAHs that, if present over some defined area, would pose an unacceptable risk. This approach to the problem raised three related questions:

- What level of public health risk from this site is acceptable to the remedial project manager?
- What concentration of PAHs is associated with the acceptable level of risk, given reasonable assumptions about target exposure?
- What is the smallest area on the site over which we can reasonably assume that the targets' exposure to contaminants may occur?

Addressing these issues required assumptions about the population at risk (people), their activities, exposure routes, and the risks associated with specific contaminants. Recognizing that the number of samples ultimately collected at a site depends in part on the smallest area of concern, we focused attention on defining the size of this area first, and then dealt with the issues of acceptable risk and corresponding concentrations.

To divide the site into discrete areas for study in a manner consistent with our interest in controlling risk, assumptions about exposure and activity patterns were used to define an area called an "exposure unit" (EU). An EU is the area over which people are expected to integrate exposure when routinely working at or visiting the site (see white grid on site photo).

A separate decision will be made for each EU: if an area is found to contain PAHs at a concentration that poses an unacceptable risk, that EU (and thus the site) will be considered a problem. Further investigations and remedial alternatives will address only the EUs found to

Data quality objectives

To build total quality into data operations, EPA quality assurance management staff have developed a planning tool for assuring that key planning steps are taken in a thoughtful, methodical manner. This tool, known as the Data Quality Objectives (DQO) process, begins with a careful statement of the environmental problem and produces a design for collecting the information needed to make an informed decision with a desired degree of confidence. The stepwise structure of the DQO process is to:

- state the problem, then
- identify decisions that address the problem, then
- select elements or factors that affect the decision, then
- specify the domain of the decision.
- Then develop a logic statement.
- establish constraints on uncertainty, and, finally,
- optimize the design for data collection.

The DQO process provides a logical, objective, and quantitative framework for finding an appropriate balance between the time and resources that will be used to generate the product (data) and the quality of that product.

DQOs enable EPA to develop, optimize, and evaluate statistically valid sampling and analysis designs that achieve the constraints on uncertainty. In general several options are developed for a range of costs that will generate the type and quality of data required to make a reliable decision. In the final step of the DQO process, the decision maker selects the design option that best fits his or her needs.

contain PAHs at concentrations posing unacceptable risks. If no such EUs are found, then a "no-action" alternative may be appropriate for the entire site.

Superfund risk assessment guidance stresses the importance of considering future land use and related reasonable exposure scenarios (*4*). According to the National Utility Contractor's Association, people working at or visiting a site such as this, where light industrial equipment is operated, would typically work within or traverse an area roughly one-half acre in size (about 2,000 m^2) on a given day (*5*). This is the area in which people can be expected to receive their daily dose of contamination. In a very real sense, people "sample" surface soil contaminants over this half-acre; hence the average concentration of contaminants over each half-acre is a meaningful basis for assessing risk. Thus, for this site, a half-acre area of soil is an EU. Since a separate estimate of the average surface soil concentration will be generated for each EU, and a separate decision made about whether each EU poses an unacceptable risk, the EU defines the spatial domain of the decision.

Based on discussions of the potential risks posed by the site, the EPA Region IV remedial staff decided that remedial action should be taken if the site (i.e., any EU at the site) poses an increased cancer risk greater than 10^{-4}. The 10^{-4} risk level is therefore the decision point between acceptable and unacceptable risk. This decision point is consistent with EPA's policy that 10^{-4} and 10^{-7} is the range for acceptable risk limits (*6*). (*Note:* The 10^{-4} level was used specifically for this case study and does not necessarily reflect EPA Region IV policy or standard practice for other sites.)

We used exposure assumptions and standard Superfund risk equations (*6*) to determine the surface soil contaminant concentration that corresponds to a risk level of 10^{-4}. Region IV typically treats total PAHs as though the sole contaminant is benzo[*a*]pyrene, the most toxic of the PAH family of compounds. This approach is conservative in that it will generally overestimate the risk posed by total PAHs. Risk calculations indicate that an EU is a problem (i.e., presents a 10^{-4} increased risk of cancer) when the average PAH concentration in the EU is at or above 122 ppm.

A "logic statement" is a concise quantitative summary of how data will be used to reach a decision. The logic statement follows directly from the formulation of the problem above.

Data collected during the remedial investigation will be used to determine the average surface soil concentration of PAHs within each half-acre. Average PAH concentrations will be compared to the risk-derived concentration of concern, 122 ppm, to determine which, if any, surface soil EUs have PAHs at concentrations that would pose an unacceptable risk.

If an EU has an unacceptable average PAH concentration ≥122 ppm, then further study should be undertaken to develop a list of remedial alternatives. This "if-then" logic statement will be applied for each of the EUs, and any EU posing an unacceptable risk will need to be remediated.

Constraints on uncertainty

If the estimates of average PAH concentration within EUs are inaccurate, decisions about whether an EU poses unacceptable risk may be incorrect. The remedial investigation should be designed to limit the probability of incorrect decisions to an acceptable level. After the logic statement was specified, the project manager developed constraints on uncertainty, expressed as acceptable false positive and false negative error rates. These are shown in Figure 1. The *y*-axis provides the acceptable error rates (probability of making an incorrect decision) given various possible true risk levels, shown on the upper *x*-axis.

Acceptable error rates were not assigned in the 61–122-ppm range because the manager considered either decision would acceptable in this range. The error rates expressed in Figure 1 provided the statistician with quantitative constraints to be used in developing survey designs, which specify the number, location, and type of samples needed in the remedial investigation.

Stated in terms of the risk-based decision point, decisions about EUs may be incorrect in two ways:

The first type of error occurs when it is decided that an EU does not pose an unacceptable risk when, in fact, the risk posed by the EU exceeds 10^{-4}. This is a false negative error. If the investigation leads to this false conclusion, the project manager may stop further investigations at the EU and people eventually may be exposed to unacceptable risks. The seriousness of this type of error, and therefore the project manager's desire to avoid it, becomes greater as the true level of risk gets larger and larger. To help the manager establish limits on false negatives, a toxicologist was consulted to assess the consequences for three ranges of incremental risk, all of which exceed 10^{-4}:

- 1.0×10^{-4} to 5.0×10^{-4};
- 5.0×10^{-4} to 1.0×10^{-3}; and
- above 1.0×10^{-3}.

After carefully considering the human health consequences, the project manager assigned acceptable probabilities for failing to detect a problem if the risk posed by the EU is actually within each of the above ranges (shown in the right-hand portion of Figure 1). The manager

expressed differing levels of acceptable error rates for the three risk ranges. These error rates (probabilities), which reflect the manager's increasing desire to avoid false negative errors at higher and higher contaminant concentrations, are the maximum acceptable rates established for this type of error. Notice that the manager desired lower false negative rates when the true risk is above 1.0×10^{-3} because the consequences to the public and to workers on-site are potentially much more serious than the consequences associated with the other ranges of risk.

The second type of error occurs when it is decided that an EU poses an unacceptable risk when, in fact, the risk posed by the EU is less than 10^{-4}. This is a false positive error. If data collected during the remedial investigation lead to this false conclusion, the manager will decide, unnecessarily, to continue to study the EU. New data may eventually reveal that an EU is not a problem, and hence, correct the false positive error. Otherwise, unnecessary remedial action will be taken. A false positive error results in wasted time, money, and effort on EUs that are actually not a problem. The manager consulted with the toxicologist and site engineers to assess the consequences of such error for three risk ranges, all of which are below 10^{-4}:

- below 5×10^{-6};
- 5.0×10^{-6} to 1.0×10^{-5}; and
- 1.0×10^{-5} to 5.0×10^{-5}.

The project manager stated that the remedial investigation should be designed to have a low probability of false positives when very low risk levels exist at an EU (e.g., when the EU is "clean"). The manager was willing to tolerate higher probabilities of false positives for risk levels near the threshold. The manager assigned acceptable probabilities for determining when an EU is a problem when in reality it is not for each of the above ranges (shown in the left-hand portion of Figure 1). These values are the acceptable rates for this type of error.

Risk equations (*6*) were used to determine the PAH concentrations that correspond to the risk ranges for which acceptable error rates had been defined. These concentrations are shown on the lower *x*-axis in Figure 1.

The logic statement, discussed earlier, indicated that we want to conclude that an EU is a problem if the true average PAH concentration in the EU is >122 ppm. Figure 1 indicates that the project manager is willing to accept a 0.15 probability or less for making an incorrect decision at true concentrations of 122 ppm. It also indicates the manager's desire to avoid developing remedial alternatives for EUs that have PAH concentrations below 61 ppm. The figure specifies that for PAH concentrations falling between 122 ppm and 61 ppm, the manager will accept either decision (indicated by the grey region in Figure 1).

Because the project manager is indifferent about the decision in the range of 61–122 ppm, but wants to limit the probability of a false negative at 122 ppm or above, our original question was refined as follows: "Which, if any, surface soil EUs have an average PAH concentration above 61 ppm?" At 122 ppm and above, the manager has specified the false negative error rates that are acceptable. At values below 61 ppm, the manager also specified the false positive error rates that are acceptable. The qualitative and quantitative criteria established for addressing this question are the DQOs for the remedial investigation, and will focus the statistician's search for an optimal design (see box, "DQOs for case study").

Design and optimization

After the DQOs were established, a statistician applied conventional techniques to explore and evaluate various designs for data collection. The statistician was asked to design a survey that, first, would attempt to identify any EUs that have average PAH concentrations >61 ppm; and second, would be subject to error rates no greater than those specified in the DQO statement from the project manager.

One concern the statistician noted was

FIGURE 1

Acceptable limits for decision error

DQOs for case study

Decision: Determine whether sections of the site pose unacceptable risks to human health or the environment and require remediation.

Domain: Exposure units are half-acre areas of surface soils. (Temporal aspects of the domain are not at issue because the contaminant of concern at this site is stable, not mobile.)

Logic statement: If the mean PAH concentration in an exposure unit exceeds 122 ppm (10^{-4} risk), then the exposure unit will require remediation.

Uncertainty constraints

PAH risk range	Concentration range (ppm)	Acceptable probability for false positives (%)
Below 5×10^{-6}	Below 6.1	20
5×10^{-6} to 1×10^{-5}	6.1–12.2	25
1×10^{-5} to 5×10^{-5}	12.2–61	30

PAH risk range	Concentration range (ppm)	Acceptable probability for false negatives (%)
1×10^{-4} to 5×10^{-4}	122–610	15
5×10^{-4} to 1×10^{-3}	610–1,220	10
Above 1×10^{-3}	Above 1,220	5

Workers collect soil samples at the Superfund site

that any attempt to divide the site into spatially distinct, uniform exposure units for testing runs the risk of missing an unacceptably contaminated area which lies across two or more EUs. This weakness is more than offset by two conservative measures included earlier: the assumption that the only PAH present is benzo[*a*]pyrene (the most toxic of the PAHs), and the decision to test for concentrations above 61 ppm when concern for false negative errors begins above 122 ppm.

The statistician framed the if–then logic statement as a statistical test that would allow us to determine whether PAHs within an EU are greater than 61 ppm, and began the search for designs that would control the decision uncertainty to the levels specified in the DQOs. To develop a statistically based sampling and analysis plan (the design), the statistician needed rough estimates of the spatial pattern and variability of the distribution of contaminant concentrations within EUs. He also required an estimate of the additional variability that would be introduced through the process of taking samples and analyzing them in the laboratory. Finally, since the statistician was asked to find the least expensive design that meets all the DQOs (the optimal solution), estimates of the costs of taking and analyzing a sample were required.

Since prior data on average PAHs across half-acre units were not available, the statistician used prior data from ran-

dom samples of surface soils across the site (Figure 2). The statistician assumed that point-by-point spatial variability of PAHs within half-acre EUs was identical to the point-by-point variability of samples taken across the entire site, without grouping into half-acre units. This is probably a conservative assumption, since it is likely that there is some degree of similarity within EUs as compared to points that are more widely separated.

These data indicated the form of the distribution of contaminant concentrations (in this case a log-normal distribution) and provided the basis for estimating the variability of contaminant concentrations across the site. An estimate of the most probable total variance (on a log scale) is $\sigma_T^2 = 1.64$ (24 degrees of freedom). Quality control data from analyses of PAHs, using the same analytical methods as those used to generate historical data for this site, indicate that analytical imprecision is on the order of 25% relative standard deviation. If the statistician had determined the historical data were not suitable for estimating the distribution and variability of concentrations within EUs, a pilot study would have been required to obtain these estimates.

Using the above information and the approximate per-sample costs of sampling ($80) and analysis ($800), the statistician began to evaluate various statistical sampling designs that would allow us to achieve the desired control over uncertainty. Recall that uncertainty is measured in terms of the probability of reaching an incorrect conclusion about whether an EU is a problem, i.e., the probability of false positives and false negatives. Among the options considered were uniform random sampling across the site, systematic sampling, stratified sampling, and sample compositing within each EU. After considering these options, the statistician recommended an approach that uses a compositing technique in which 10 or more scoops of soil, taken randomly within each EU, are combined, homogenized, and subsampled for analysis. When the potential difficulties and errors introduced through mixing and subsampling were recognized, five soil scoops were considered to be an efficient, practical number that could be combined routinely.

A statistical evaluation of several different designs, presented in Table 1, led to the following conclusions:

First, the expected performance data indicate that two survey designs have favorable cost and acceptable performance (i.e., were expected to meet or come close to meeting the 0.15 acceptable false negative and 0.3 false positive error rates specified over the range of important concentrations). The most favorable designs involved compositing five scoops per analytical sample. One design required the analysis of two composited samples per EU, while the other required three. Our notation for these designs are (5,2) and (5,3), respectively.

Second, compositing five scoops transformed the underlying log-normal distribution into one that is more like a normal distribution in shape. A computer simulation was needed to assess more accurately the anticipated performance of the two designs, i.e., the "power" or capability of each design to detect EUs with PAH concentrations above the criterion. (Details on the statistical evaluation may be obtained by writing author Dean Neptune.)

The (5,2) and (5,3) designs were evaluated by simulation to determine how

FIGURE 2
Frequency distribution of soil PAH concentrations

TABLE 1
Results of initial power calculations

No. scoops /analysis	No. analyses/EU	Cost /EU ($)	Probability of error[a]
1	4	3,520	.53
3	5	5,200	.15
4	2	2,240	.27
4	3	3,360	.18
4	4	4,480	.12
5	2	2,400	.20
5	3	3,600	.11

[a] When μ = 122 ppm and α = .30.
Note: α = probability of concluding EU is a problem when μ is 61 ppm.

well they can be expected to perform at the critical values of 122 and 61 ppm, and at other concentrations higher and lower than these values. The rough estimates of performance in Table 1 were based on the assumption that the distribution of total PAHs was log-normal with a total variability of 1.64. The true variability of concentrations within EUs may prove to be greater or less than this estimate. To determine the effect that more or less variability might have on reaching a correct conclusion with either of these designs, the performance of each design was evaluated at three different levels of total variability: 1.64 (most probable—our estimate of variability based on historical data), 1.00 (assumes less variability—a lower 95% confidence limit on the historical estimate), and 3.17 (assumes more variability—an upper 95% confidence limit on the historical estimate).

Figures 3 and 4 show the results of the simulations presented as expected performance curves. The shaded regions of the two figures are areas in which the constraints on uncertainty—control on false negative and false positive error rates—are achieved. In the region between 61 and 122 ppm, the shaded area shows that any amount of error can be tolerated. The shaded regions above 122 and below 61 ppm are those for which the error rates are of concern. A design performance curve that lies entirely in the shaded regions would satisfy all the DQOs (see box, "DQOs for the case study").

The figures show that the two designs can be expected to perform similarly and to achieve most of the constraints on uncertainty (most of the curve appears in the shaded region). If variability is 1.64, the figures reveal that both designs fail slightly when the true average PAH concentrations are between 50 and 60 ppm. Neither of the designs is likely to meet uncertainty constraints if the total variability is high (3.17). Points labeled "A" and "B" are slightly outside the regions of desired performance. Points labeled "A" are of concern if the variability is lower than we anticipate (1.00). Points labeled "B" are of concern if the variability is greater than we anticipate (3.17). Thus, if we use either the (5,2) or (5,3) design, and the variability of PAH concentrations within an EU is substantially lower or higher than assumed (1.64), we can expect slightly higher error rates than specified by the DQOs.

Considering the conservative measures built into the designs, the project manager determined that failing to meet uncertainty constraints at these specific points is not serious. Finally, because the design (5,2) represents a 33% cost savings over the (5,3) design, and its ability to achieve the uncertainty constraints is approximately equal to that of the (5,3) design, the (5,2) design was recommended for the remedial investigation.

Summary

The data quality objectives produced in the manner described do much more than simply guide the survey design. The DQOs provide a focused decision statement, boundaries on the domain of interest (the EU), an "if-then" logic statement that specifies how data will be used in the decision, and constraints on the amount of uncertainty (limits on both false positives and false negatives) acceptable. They provide the information needed to ensure that the number of samples per EU is adequate and the sampling and analysis methods used will provide the

FIGURE 3

Results of simulation for the (5,2) design

FIGURE 4

Results of simulation for the (5,3) design

quality of data required to support decisions with the desired certainty. The most important benefits of this approach are that the decisions regarding Superfund site remediation can be made at the desired level of certainty, and that the project manager has specific quantitative criteria for deciding how much data is enough.

References

(1) Quality Assurance Management Staff. "Development of Data Quality Objectives: Description of Stages I and II." In *EPA Information Guide;* EPA: Washington, D.C., July 1986.

(2) Environmental Protection Agency Office of Emergency and Remedial Response. "RI/FS Improvements Phase II, Streamlining Recommendations"; EPA: Washington, D.C., January 1989; OSWER Directive No. 9355.3-06.

(3) Environmental Protection Agency. "Region IV Remedial Investigation Report for this Uncontrolled Hazardous Waste Site", EPA: Washington, D.C., 1988.

(4) Environmental Protection Agency. *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual;* EPA: Washington, D.C., June 30, 1989; draft. *Note:* The calculations used to estimate reasonable maximum exposure in this case study are found in Reference 6.

(5) Connor, B., National Utility Contractor's Association, Arlington, Va., personal communication. Reasonableness of this estimate was confirmed by EPA ORD and Region IV risk assessment experts.

(6) Office of Emergency and Remedial Response. *Superfund Public Health Evaluation Manual;* OSWER/EPA: Washington, D.C., October 1986; EPA 540/1-86/060.

Acknowledgments

The individuals listed below played a substantive role in the development of the DQOs for this hazardous waste site. Region IV used the planning issues raised through the DQO process to set survey design constraints (the DQOs) for the case study. The DQOs then were used as the basis for optimizing the possible survey designs for this site. The DQO process and its adaptation to Superfund planning issues for the remedial investigation/feasibility study was led by the quality assurance management staff, with DQO application support from Research Triangle Institute, Montana State University, and NUS Corp. The authors of this paper have summarized the outputs of a series of activities in which all of these individuals participated directly: James Pickett, Ph.D., and Randall Ryti, Ph.D., Montana State University; Robert Hubbard, NUS Corp.; Eugene P. Brantly, C. Andrew Clayton, Daniel I. Michael, Michael Messner, Research Triangle Institute; Elmer Akin, Meredith Anderson, William Bokey, Beverly Houston, David Kleusner, M.D. Lair, William Patton, EPA Region IV; Dean Neptune, Ph.D., EPA Headquarters quality assurance management staff.

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E.3. KENTUCKY REGULATORY GUIDANCE

Copies of regulatory guidance listed below previously have been presented in this chapter. This regulatory guidance is available in Appendix E, of *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/R8/V1 (DOE 2017). Several guidance documents also are available online.

- Kentucky Risk Assessment Guidance, Risk Assessment Branch, Department of Environmental Protection, Commonwealth of Kentucky, June 8, 2002.
  https://eec.ky.gov/Environmental-Protection/Waste/superfund/Documents/KY%20Risk%20Assessment%20Guidance%20_Final_.pdf

- Kentucky Guidance for Ambient Background Assessment, Risk Assessment Branch, Department of Environmental Protection, Commonwealth of Kentucky, January 8, 2004.
  https://eec.ky.gov/Environmental-Protection/Waste/superfund/Documents/Kentucky%20Guidance%20for%20Ambient%20Background%20Assessment.pdf

- Kentucky Guidance for Groundwater Assessment Screening, Risk Assessment Branch, Department of Environmental Protection, Commonwealth of Kentucky, January 15 2004.
  https://eec.ky.gov/Environmental-Protection/Waste/superfund/Documents/GroundwaterAssessmentScreening.pdf

- Trichloroethylene Environmental Levels of Concern, Risk Assessment Branch, Department of Environmental Protection, Commonwealth of Kentucky, April 2004.
  Guidance is not available online. See https://www.epa.gov/iris for additional information.

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E.4. FLOWCHART FOR UNCERTAINTY MANAGEMENT FOR UNKNOWN AREAS OF CONTAMINATION

The annotated flowchart presented in this section was provided to KDWM under cover letter from the DOE Paducah Site Lead on April 1, 2008, (PPPO-02-130-08) as a condition to be met for DOE to receive an Environmental Indicator of "Yes" with regard to the Government Performance and Results Act milestone of having human exposures under control. The flowchart applies to newly identified areas of contamination that may be identified in the future on DOE-owned property licenses for use at PGDP, which are outside the controlled area and not currently assigned to an operable unit under the Federal Facility Agreement (FFA). The flowchart describes the uncertainty management for nonworker exposures associated with DOE-owned property described above.

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Enclosure

Flow Chart for Uncertainty Management

This flowchart applies to newly identified areas of contamination that may be identified in the future on DOE-owned property licensed for use at the Paducah Gaseous Diffusion Plant, which are outside the controlled area and not currently assigned to an operable unit under the federal Facility Agreement. The flowchart describes uncertainty management for non-worker exposures associated with DOE-owned property described above.

1 "Process Knowledge" is defined as information identifying releases from past or current processes at the PGDP.

2 "Contamination" is defined in the Risk Methods Document as the presence of a constituent at a concentration greater than background.

3 "Direct contact" is exposure by a human to environmental medium [i.e., surface soil, sediment, debris (e.g., rubble), and surface water] through ingestion, dermal contact, inhalation (particulates and vapors), or external exposure.

Enclosure
(Cont)
Further Explanation of Flow Chart Steps

Uncertainty Management Assumption: Empirical data is available or Process Knowledge[1] (PK) exists that establish contamination is present in an area	This flowchart applies to newly identified areas of contamination that may be identified in the future on DOE-owned property licensed for use at the Paducah Gaseous Diffusion Plant, which are outside the controlled area and not currently assigned to an operable unit under the federal Facility Agreement. The flowchart describes uncertainty management for non-worker exposures associated with DOE-owned property described above. Sufficient data or credible Process Knowledge must exist for this process to be activated.
Is contamination[2] in Surface Water Bodies or Soil/Rubble Areas where direct contact[3] under current use scenarios by a person possible?	Contamination definition is identified in Footnote 2. This process focuses on areas of surface soil, sediment, debris (e.g., rubble), and surface water that are located in the licensed area and available for direct contact exposure. Examples of exposure scenarios are riding horses or ATVs in the creek and bank areas, walking or hiking through wildlife habitat, or hunting.
Are data available meeting site quality objectives (as defined in data quality assessment guidelines) and representative of site conditions?	An evaluation of the available data will be performed to determine if data are of sufficient quality to be used for risk assessment. Additional data may be collected to determine appropriate protective actions.
Compare average concentration of contaminant to human health risk-based concentrations for current use scenarios derived per the Risk Methods Document.	Average concentrations from existing data will be compared to the human health risk-based concentrations. Risk-based concentrations used will be based on guidance in the current site Risk Methods Document.
Place Temporary Institutional Controls in areas as appropriate	Temporary institutional controls may vary depending on the nature of contamination. DOE may place temporary institutional controls under CERCLA, perform a maintenance action, or post under 10 *CFR* 835.
Bin area in appropriate Operable Unit, as necessary, for further evaluation	DOE, EPA, and KY will determine the appropriate Operable Unit under which the area may be placed for future evaluation in accordance with the FFA. These agencies will determine if immediate actions such as sampling or removal actions are warranted based on potential risk and exposure to the public.

E.5. COMPILED PARAMETERS FOR PROBABILISTIC RISK ASSESSMENTS

A probabilistic risk assessment (PRA) of migration of contaminants to groundwater was conducted for the *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky*, DOE/OR/07-2180&D2/R1 (June 2007). The parameters used in that modeling effort were presented in Attachment 2 of Appendix F of the site investigation report. This set of parameter values is appropriate for use in modeling for other PRAs, though the information on these values should be reviewed during the PRA development to ensure the assumptions made in setting the values are appropriate for each site being evaluated. Parameter values should be modified, if necessary, to reflect conditions for the individual site under consideration.

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Appendix F, Attachment 2, of the *Site Investigation Report for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/OR/07-2180&D2/R1.

INPUT PARAMETERS FOR PROBABILISTIC MODELING

1. INTRODUCTION

Probabilistic (stochastic) modeling was performed for the trichloroethene (TCE) sources at (Solid Waste Management Unit (SWMU) 1 and the C-720 Building areas in order to understand better the uncertainties in the transport modeling for these sources, to estimate the likely TCE concentrations at the points of exposure (POEs) using the most likely input parameters, and to determine the error bounds on the predicted TCE concentrations. This modeling was based upon the nature and extent discussion in the Site Investigation (SI) Report and the transport modeling results completed earlier.

The fate and transport modeling was performed using Spatial Analysis/Decision Assistance (SADA) software (UT 2002); Crystal Ball® (Decisioneering, Inc. 2000), an add-in to Microsoft Excel®; Seasonal Soil Compartment Model (SESOIL) (GSC 1996, Bonazountas and Wagner 1984); and Analytical Transient One-, Two-, and Three-Dimensional Simulation Model (AT123D) (GSC 1998, Yeh 1981). The key input parameters for the modeling were developed using SADA and Crystal Ball®, while the modeling itself was performed using SESOIL and AT123D.

2. INPUT PARAMETERS

The input parameters for the modeling were in two groups: fixed and variable. The values of the fixed parameters were from earlier work (DOE 2003). The values of the variable parameters were set considering earlier work and employing a probabilistic method. This was done by developing a distribution for each variable parameter and sampling the distribution using the Monte Carlo sampling technique provided in Crystal Ball®.

3. PARAMETER DISTRIBUTIONS

Several distributions were considered when selecting the best distribution for each of the variable input parameters. A general discussion of each distribution considered is provided below.

1. **Triangular Distribution:** This distribution is used to describe a variable with known minimum, maximum, and most likely values (Decisioneering, Inc. 2000). Three conditions underlying this distribution are as follows:

    - The minimum value of the variable is fixed.
    - The maximum value of the variable is fixed.

- The most likely value of the variable falls between the minimum and maximum values forming a triangular-shaped distribution and showing that values near the minimum and maximum are less likely to occur than those near the most likely values.

2. **Normal Distribution:** This is the most important distribution in the probability theory because it describes many natural phenomena (Decisioneering, Inc. 2000). Three conditions underlying this distribution are as follows:

   - Some value of the variable is the most likely (the mean of the distribution).
   - The value of the variable could as likely be below the mean as it could be above the mean (symmetrical about the mean).
   - The value of the variable is more likely to be near the mean than far away.

   Generally, if the coefficient of variability is less than 30%, a normal distribution is recommended. A skewness value between -0.5 and +0.5 indicates a fairly symmetrical distribution (Decisioneering, Inc. 2000).

3. **Log-Normal Distribution:** This distribution is widely used to describe a variable with values that are positively skewed (Decisioneering, Inc. 2000). The three conditions underlying this distribution are as follows:

   - The variable can increase without limits but cannot fall below zero.
   - The variable is positively skewed with most of the values near the lower limit.
   - The natural logarithm of the variable yields a normal distribution

   Generally, if the coefficient of variability is greater than 30%, a log-normal distribution is recommended. A skewness value less than -1 or greater than +1 indicates a highly skewed distribution (Decisioneering, Inc. 2000).

4. **Uniform Distribution:** This distribution is used to describe a variable when each value of the variable has the same probability of occurrence within a selected range. This distribution is often used when no information about variable's distribution is available. The three conditions underlying this distribution are as follows:

   - The minimum value of the variable is fixed.
   - The maximum value of the variable is fixed.
   - The probability of any value being selected within the range between the minimum and maximum values is equal.

4. SESOIL PARAMETERS

The SESOIL software was used to simulate contaminant transport through the Upper Continental Recharge System (UCRS) to the Regional Gravel Aquifer (RGA). The parameters used for SESOIL are listed in Tables F.2.1 and F.2.2. As mentioned earlier, there are two groups of parameters. Remarks for each parameter are provided in these tables to clarify the source of the value and the justification for its selected value. Additional remarks for each variable parameter, including the values input into Crystal Ball, are provided in Table F.2.3. Finally, summary statistics for each variable parameter output by

Crystal Ball are provided in Table F.2.4. Histograms of the values output by Crystal Ball for the variable parameters are in Figs. F.2.1 through F.2.18.

1. **Fixed Parameters:** These parameters are summarized in Tables F.2.1 and F.2.2.

    - **Soil Type:** The upper portion of the UCRS is loam, while the bottom portion of it is silty clay (DOE 1999). The soil type was considered to be silty loam for each area.

    - **Bulk Density:** The bulk density of the UCRS is 1.46 g/cm^3 (DOE 1999). The bulk density was set to this value for each area.

    - **Disconnectedness Index:** The disconnected index was set to a site-specific approximate value of 10 used in earlier work. The value was estimated by calibrating the deterministic model to an average recharge of 11.38 cm/yr.

    - **Porosity:** The porosity of the UCRS is 0.45 (DOE 1999). The porosity was set to this value for each area.

    - **Depth to Water Table:** The depth to the water table was estimated for each area considering site-specific data. The depths were estimated as 16.76 m (55 ft), and 18.29 m (60 ft) for SWMU 1 and C-720 areas, respectively.

    - **Freundlich Equation Exponent:** The Freundlich equation exponent typically ranges from 0.9 to 1.4; the default value of 1.0 is recommended if the actual value is not known (GSC 1996). The exponent was set to 1 for each area.

    - **Contaminant of Concern (COC):** The COC of interest was TCE.

    - **Source Area:** The source area was developed analyzing site-specific data for each area. Soil concentration for the area was analyzed layer-by-layer using SADA. A limitation of SESOIL required that all layers have the same area. Source areas and the average soil concentration in each layer were estimated, and the source area with the maximum contaminant mass was identified and set as the "uniform area." Concentrations within each layer were then normalized against the "uniform area" (discussed later). The "uniform areas" used for SWMU 1 and the C-720 area were 324 m^2 and 1394 m^2, respectively.

    - **Molecular Weight:** The molecular weight was set to 131 g/gm-mol (EPA 1994).

    - **Solubility in Water:** The solubility in water was set to 1100 mg/L (EPA 1996).

    - **Diffusion in Air:** The diffusion in air was set to 0.08 cm^2/sec (EPA 1996).

    - **Henry's Constant:** The Henry's constant was set to 0.0103 atm-m^3/mol (EPA 1996).

    - **Soil Organic Carbon/Water Partition coefficient (K_{oc}):** The K_{oc} was set to 94 L/kg (EPA 1996).

2. **Variable Parameters:** These parameters are summarized in Tables F.2.1 through F.2.4.

- **Intrinsic Permeability:** Site-specific data were available for the vertical hydraulic conductivity of the UCRS. Therefore, the intrinsic permeability was estimated from vertical hydraulic conductivity using the following equation.

$$K = k\frac{g}{\nu} \qquad (1)$$

where K = vertical hydraulic conductivity of soil, k = intrinsic permeability of soil, ν = kinematic viscosity of water, and g = gravitational acceleration (Bear 1979). Taking ν = 0.01 cm^2/sec and g = 981 cm/sec^2 (Mills et al. 1985), and substituting in Equation 1 leads to

$$k\left(cm^2\right) = \frac{K\left(cm/\sec\right)}{9.81\,x\,10^4\left(1/cm-\sec\right)} \qquad (2)$$

The intrinsic permeability was estimated from the saturated vertical hydraulic conductivity using Equation 2.

The site-specific vertical hydraulic conductivities measured earlier were assumed to be representative of that expected in the UCRS at each area. Summary statistics for the site-specific data are in Table F.2.3. A set of 13 results was available (DOE 1997a, DOE 1997b). These results ranged from 1.00E-08 cm/sec to 2.00E-04 cm/sec with a likeliest (mean) value of 1.64E-05 cm/sec. The coefficient of variation was estimated as 336%, and the skewness was estimated as 3.6. Next, the statistics were studied. The maximum value, when used in SESOIL produced an unreasonable recharge; therefore, a second estimate of maximum was sought through calibration. The maximum was re-estimated as 3.20E-05 through calibration to a recharge of 22 cm/yr (DOE 2000). Given that a range and a most likely value could be determined from the site-specific data, a triangular distribution was assumed. The vertical hydraulic conductivity was assumed not correlated to any other parameter. The summary statistics for the values output by Crystal Ball are in Table F.2.4. Histograms for the output values for the resulting intrinsic permeabilities for each of the two source areas are in Figs. F.2.1 and F.2.2.

- **Organic Carbon Content:** Site-specific data were available for the organic carbon content of the UCRS. The site-specific organic carbon contents measured earlier were assumed to representative of that expected in the UCRS at each source area. Summary statistics for the site-specific data are in Table F.2.3. A set of 138 results was available. The coefficient of variation was estimated as 66%, and the skewness was estimated as 4.3. Given the coefficient of variation and skewness, a log-normal distribution was assumed. The organic carbon content was assumed not correlated to any other parameter. The summary statistics for the values output by Crystal Ball are in Table F.2.4. Histograms for the output values for organic carbon content for each of the two source areas are in Figs. F.2.3 and F.2.4.

- **Soil Concentration:** Site-specific data were available for the TCE soil concentrations in each source area. Summary statistics for each layer are in Table F.2.3. For SWMU 1, a set of 135 results was available. The coefficient of variation for these results was

estimated as 523%, and the skewness was estimated as 6.42. Given the coefficient of variation and skewness, a log-normal distribution was assumed. Using site-specific data, the correlation between Layers 1 and 2 soil concentrations was determined to be 0.92. (Please see Section 4.3 for additional discussion of correlations between layers.) Similar analyses led to choosing the log-normal distribution for Layer 1 at the C-720 area. The correlation coefficients between Layers 1 and 2 for the C-720 area were determined to be 0 and -0.50, respectively. Site-specific data were also available for the soil concentrations in Layer 2 through Layer 6. Summary statistics for each of these layers at each location are in Table F.2.3. For each layer at each location, a log-normal distribution was chosen, and correlations between layers were derived.

As mentioned earlier, a limitation of the SESOIL model required normalization of soil concentrations in each layer at each location to a "uniform area." To accomplish this, the layer with the maximum contaminant mass at each source was used as that source's "uniform area," and a simple ratio was used to normalize each layer's concentration to that of the "uniform area." The summary statistics for the value output by Crystal Ball are in Table F.2.4. Histograms for each layer at each location are in Figs. F.2.5 through F.2.16.

- **Degradation Half-Life/Degradation Rate:** Site-specific data were limited for the degradation half-life of TCE in the UCRS; therefore, a range of half-lives estimated for the RGA (3.2 to 11.3 years) were selected with uniform distribution for the UCRS. (Please see Attachment F.3 of Appendix F for additional information on the estimation of degradation half-life of TCE in the RGA at PGDP.) The degradation half-life was assumed not correlated to any other parameter. Summary statistics for the values output by Crystal Ball are in Table F.2.4. Histograms of the output values for degradation rate for each of the two source areas are in Figs. F.2.17 and F.2.18. Note that only histograms of degradation rate are presented because the rate, and not the half-life, was the value input into SESOIL. Where, the degradation rate is derived from the degradation half-life using the following expression:

$$\lambda = \frac{\ln 2}{t_{1/2}} \tag{3}$$

where λ = degradation rate (day^{-1}), and $t_{1/2}$ = degradation half-life (days).

An additional scenario termed the "fixed degradation scenario" was also assessed in the probabilistic analysis. The degradation half-life was set equal to 26.6 years for these runs, while the remaining parameters listed above were allowed to vary.

5. AT123D PARAMETERS AND SOURCE TERM MODELING PARAMETERS

The AT123D software was used to simulate contaminant transport from the source areas through the RGA to the POEs. The parameters used for AT123D modeling are listed in Tables F.2.5, F.2.6, and F.2.7. Remarks for each parameter are provided in the table to clarify the source and justification of selected values. Additional remarks for each variable parameter are provided in Table F.2.8. Finally, the summary

statistics for each variable parameter sampled output by Crystal Ball and used in the runs for AT123D and source term modeling are provided in Table F.2.9. Histograms of the values output by Crystal Ball for the variable parameters are in Figs. F.2.19 through F.2.24.

1. **Fixed Parameters:** These parameters are summarized in Tables F.2.5, F.2.6, and F.2.7.

    - **Dispersivity:** The longitudinal dispersivity was set to 1.5 m for each area (DOE 1999). Similarly, the transverse (lateral) dispersivity and the vertical dispersivity were set to 1.5 m and 0.03 m, respectively, for the area.

    - **Bulk Density:** The bulk density of the RGA is 1670 kg/m^3 (DOE 1999). The bulk density was set to this value for each area.

    - **Density of Water:** The density of water was set to 1000 kg/m^3 (Mills et al. 1985).

    - **COC:** As mentioned earlier, the COC was TCE.

    - **Source Area:** The area used in AT123D modeling for each source was the "uniform area" developed for the source in SESOIL modeling.

    - **Diffusion in Water:** The diffusion in water was set to 3.28E-6 m^2/hr (EPA 1996).

    - **K_{oc}:** As mentioned earlier, the K_{oc} was set to 94 L/kg (EPA 1996).

    - **Distance to POEs:** The distance from the center of each source area to the POEs was estimated from plant maps. Each of the POEs was placed at the centerline of the estimated path of contaminant migration.

2. **Variable Parameter:** These parameters are summarized in Tables F.2.5 through F.2.9.

    - **Aquifer Depth (Thickness):** The aquifer depth was allowed to vary in order to account for changes in the thickness of RGA as a contaminant migrates from a source area to the Ohio River. Site-specific data were available from field measurements, and these data were assumed to be applicable to the RGA at each source area and along the estimated contaminant flow paths. A set of 24 results was available. The coefficient of variation was estimated as 31%, and the skewness was estimated as -0.61. Given the coefficient of variation and skewness, the distribution was assumed to be normal. The aquifer depth was assumed not correlated to any other parameter. Summary statistics for the values output by Crystal Ball® and used in runs for AT123D modeling are provided in Table F.2.9. A histogram of the output values for aquifer depth is in Fig. F.2.19. (Note that each source area used the same set of parameters in AT123D modeling; therefore, only one histogram is presented for each of the AT123D variable parameters.)

    - Hydraulic Conductivity: Site specific data were available for the hydraulic conductivity of the RGA, and these data were assumed to be applicable to the RGA at each source area and along the contaminant flow paths. A set of 62 results was available. The data ranged from 1.00E-04 ft/day to 8.50E+05 ft/day with a likeliest value of 1.93E+04 ft/day. The coefficient of variation was estimated as 563%, and the skewness was estimated as 7.53. A value of 1500 ft/day was used in DOE 1999. During model set-up, the range was judged to be too variable given the site-specific soil condition, and a second estimate was

sought from the PGDP groundwater flow model. This estimate was developed using an analysis based upon a plan area from the PGDP site-wide groundwater model and the path of contaminant migration from the source areas to the Ohio River (please see Fig.5.1 of the main report). Based upon this analysis, the minimum, maximum, and most likely values chosen were 75, 1500, and 967 ft/day, respectively. The coefficient of variation was estimated as 65%, and the skewness was estimated as -0.35. Subsequently, the selected most likely value was determined to be inconsistent with probable site conditions, and after consultation with site experts these value was changed to 350 ft/day (i.e., the geometric mean of the minimum and maximum in the plan area). The standard deviation was assumed equal to the likeliest value yielding a coefficient of variation of 100%. Given this coefficient of variation and the skewness from the earlier analyses (i.e., that related to site-specific data and plan area), a log-normal distribution was assumed. In addition, the hydraulic conductivity was assumed correlated to the hydraulic gradient and the porosity. The correlation coefficients selected by site experts were -0.50 and 0.20 for correlating the hydraulic conductivity to the hydraulic gradient and to the porosity, respectively. Summary statistics for the values output by Crystal Ball® and used in runs for AT123D modeling are provided in Table F.2.9. A histogram of the output values for hydraulic conductivity is in Fig. F.2.20.

Hydraulic Gradient: Site-specific data were available for the hydraulic gradient of the RGA, and these data were assumed applicable to the RGA at each source area and along the contaminant flow paths. A set of 12 results was available. The coefficient of variation was estimated as 111%, and the skewness was estimated as 1.95. Given the coefficient of variation and skewness, a log-normal distribution was assumed with minimum, maximum, and most likely values of 1.00E-04, 4.00E-03, and 1.01E-03 m/m, respectively. The standard deviation was set at 1.12E-03 m/m. Additionally, the hydraulic gradient was assumed correlated to the hydraulic conductivity and the porosity. The correlation coefficients were assumed as -0.50 and -0.20 for correlating the hydraulic gradient to the hydraulic conductivity and to the porosity, respectively. Summary statistics for the values output by Crystal Ball® and used in runs for AT123D modeling are provided in Table F.2.9. A histogram of the output values for hydraulic gradient is in Fig. F.2.21.

Effective Porosity: Site-specific data were available for the porosity of the RGA; therefore, the effective porosity was estimated from the porosity using a conversion value of 81% taken from DOE 1999. [In that report, an effective porosity of 0.30 and a porosity of 0.37 were reported (i.e., 0.30/0.37 = 0.81 or 81%).] The data were assumed applicable to the RGA at each source area and along the contaminant flow paths. A set of 28 results was available. The minimum, maximum, and most likely values selected for porosity were 27, 54, and 39%. The coefficient of variation was estimated as 15%, and the skewness was estimated as 0.43. Given the coefficient of variation and skewness, a normal distribution was assumed. Additionally, the porosity was assumed correlated to the hydraulic conductivity and the hydraulic gradient. The correlation coefficients were assumed as 0.20 and -0.20 for correlating the porosity to the hydraulic conductivity and to the hydraulic gradient, respectively. Summary statistics for the values output by Crystal Ball® and the resulting effective porosity values used in runs for AT123D modeling are provided in Table F.2.9. A histogram of the effective porosity values is in Fig. F.2.22[1]. Note that only a histogram of effective porosity is presented because effective porosity and not porosity was the value input into AT123D.

[1] Future groundwater modeling efforts at PGDP will utilize 35% as a practical upper-bound for effective porosity values.

- **Organic Carbon Content:** Site-specific data were available for the organic carbon content of the RGA, and these data were assumed applicable to the RGA at each source area and along the contaminant flow paths. A set of 38 results was available. The minimum, maximum, and most likely values selected were 3.0E-03, 2.53E-01, and 3.5E-02%, respectively. The coefficient of variation was estimated as 1.05%, and the skewness was estimated as 4.0. Given the coefficient of variation and skewness, a log-normal distribution was assumed. The organic carbon content was assumed not correlated to any other parameter. Summary statistics for the values output by Crystal Ball® and used in runs for AT123D modeling are provided in Table F.2.9. A histogram of the output values for organic carbon content is in Fig. F.2.23.

- **Degradation Half-Life:** Recently, as part of response actions, the U.S. Department of Energy (DOE) has developed revised biodegradation rates that were incorporated into the SI modeling. Attachment F.3 to this appendix presents a detailed discussion of the derivation of the degradation rates. Additionally, the degradation half-life was observed to be correlated with groundwater flow which is a direct function of hydraulic conductivity and hydraulic gradient. However, for this analysis the degradation half-life was assumed 100% correlated to the hydraulic gradient. Summary statistics for the values output by Crystal Ball® and used in runs for AT123D modeling are provided in Table F.2.9. A histogram of the output values for degradation rate is in Fig. F.2.24. Note that only histograms of degradation rate are presented because the rate, and not the half-life, was the value input into AT123D. It should be noted here that although hydraulic gradient assumed a normal distribution, Crystal Ball output for degradation rate presented in Fig. F2.24 does not appear to be normally distributed. An additional scenario termed the "fixed degradation scenario" was also assessed in the probabilistic analysis. No degradation was assumed for these runs, while the remaining parameters listed above were allowed to vary.

6. CORRELATION MATRIX

As mentioned earlier, the soil concentration in each layer was assumed correlated to the adjacent layers for a given area. To estimate the correlation coefficient between two adjacent layers, sets of ordered pairs of concentrations were analyzed. Because data were sparse, ordered pairs were difficult to establish using the sampling date; therefore, the source developed using SADA was used for the estimation. For SADA data, the size and shape of the source areas in the adjacent layers differed; therefore, an ordered pair was formed only in the parts of the source where two layers overlapped.

The correlation values are presented in Table F.2.3.

7. SENSITIVITY ANALYSIS

Although there was not any sensitivity analysis performed under this task to select the parameters that were allowed to vary, previous groundwater modeling efforts at the PGDP have included sensitivity analyses of several of the parameters input into SESOIL and AT123D in order to understand some of the modeling uncertainties. The analyses are included in these documents:

- U-Landfill Design and Analysis (DOE 2002)
- K_d-Sensitivity Analysis (SAIC 2002)
- Northeast and Northwest Plume Groundwater Modeling (BJC 2003)
- Recharge- and Ohio River Stage-Sensitivity Analysis (DOE 2002)

Based on these analyses, the following parameters were determined to be the most sensitive parameters for fate and transport modeling using SESOIL and AT123D:

- Contaminant's concentration in the soil/source term,
- Contaminant's degradation half-life,
- Contaminant's distribution coefficient (K_d) (i.e., directly related to the organic carbon content of source soils for organic compounds)
- Percolation rate (controlled by source vertical permeability)
- Saturated hydraulic conductivity,
- Hydraulic gradient,
- Effective porosity, and
- Aquifer thickness

The contaminant concentration in the source term is one of the most sensitive parameters; increasing the source term concentration increases the predicted groundwater concentration at the POE by increasing contaminant flux and lengthening the time required for depletion of contaminant in the source. The percolation rate is also a very sensitive parameter; increasing the percolation rate results in increased contaminant flux to the RGA and, potentially, a greater peak concentration at the POE. An increased percolation rate, however, is related to faster depletion of contaminant in the source. The contaminant's distribution coefficient, K_d, is a very sensitive parameter for the SESOIL and AT123D models and may rank only behind contaminant concentration in terms of importance. Sensitivity analyses have shown that increasing the K_d of any layer included in the SESOIL model or of the RGA included in the AT123D model decreases contaminant concentrations at the POE because of retardation and attenuation due to sorption. Therefore, with higher K_d's the rate of source depletion is slowed, and the time required for source depletion is increased. Degradation half-life is also important if the time taken for source depletion or required for contaminant migration from the source to the POE is long relative to the contaminant's degradation half-life (i.e., 3 or more times half-life). This is the case because, under this condition, the rate of contaminant degradation in the source or as the contaminant migrates from the source to the POE results in markedly lower contaminant concentrations at the POE.

For AT123D modeling, the earlier sensitivity analyses have identified three additional input parameters. These parameters are hydraulic conductivity, hydraulic gradient, and effective porosity. In the AT123D model, hydraulic conductivity, hydraulic gradient, and effective porosity work together to control seepage velocity (i.e., seepage velocity equals hydraulic conductivity times hydraulic gradient divided by effective porosity), and an increase in seepage velocity increases the rate of contaminant migration to the POE. The values chosen for the Southwest Plume model indicates that the hydraulic gradient varies over a relatively narrow range in the RGA. Therefore, the impact of hydraulic gradient on seepage velocity is expected to be relatively smaller than that of hydraulic conductivity. Table 2.10

presents an overall summary of qualitative sensitivity of modeling results to input parameters for this analysis.

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Table F.2.1. Sil-specific parameters for SESOIL modeling (see Table F.46a)

Input Parameter	Unit	SWMU 1	C-720 Building	Remark
Soil Type	-	Silty Loam	Silty Loam	DOE 1999
Bulk Density	g/cm^3	1.46	1.46	DOE 1999
Intrinsic Permeability	cm^2	Variable	Variable	Probabilistic method
Disconnectedness Index	-	10	10	Site-specific (to PGDP) approximate value used in earlier work
Porosity	-	0.45	0.45	DOE 1999
Depth to Water Table	m	16.76	18.29	Site-specific (to RGA) field data
Organic Carbon Content	%	Variable	Variable	Probabilistic method
Freundlich Equation Exponent	-	1	1	Default

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Table F.2.2. Chemical-specific parameters for SESOIL modeling (see Table F.46b)

Input Parameter	Unit	SWMU 1	C-720 Building	Remark
Contaminant of Concern	-	Trichloroethene	Trichloroethene	
Source Area	m^2	324	1394	Site-specific (to TCE) SADA analysis
Soil Concentration - Layer 1	mg/kg	Variable	Variable	Probabilistic method
Soil Concentration - Layer 2	mg/kg	Variable	Variable	Probabilistic method
Soil Concentration - Layer 3	mg/kg	Variable	Variable	Probabilistic method
Soil Concentration - Layer 4	mg/kg	Variable	Variable	Probabilistic method
Soil Concentration - Layer 5	mg/kg	Variable	Variable	Probabilistic method
Soil Concentration - Layer 6	mg/kg	Variable	Variable	Probabilistic method
Molecular Weight	g/gmol	131	131	EPA 1994
Solubility in Water	mg/L	1100	1100	EPA 1996
Diffusion in Air	cm^2/s	0.08	0.08	EPA 1996
Henry's Constant	$atm.m^3/mol$	0.0103	0.0103	EPA 1996
Koc	L/kg	94	94	EPA 1996
Degradation Rate	day^{-1}	Variable	Variable	Probabilistic method

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Table F.2.3. Statistics of variable inputs used in Monte Carlo sampling for SESOIL modeling (see Table F.45)

Input Parameter	Statistics	Unit	SWMU 1	C-720 Building	Remark
Vertical Hydraulic Conductivity[a]	Minimum	cm/sec	1.00E-08	1.00E-08	DOE 1997a, DOE 1997b
	Likeliest	cm/sec	1.64E-05	1.64E-05	DOE 1997a, DOE 1997b
	Maximum	cm/sec	2.00E-04	2.00E-04	[b]DOE 1997a, DOE 1997b
	Standard Deviation	cm/sec	5.52E-05	5.52E-05	DOE 1997a, DOE 1997b
	Count	#	13	13	DOE 1997a, DOE 1997b
	Coefficient of Variation	%	336.49	336.49	DOE 1997a, DOE 1997b
	Skew	-	3.60	3.60	DOE 1997a, DOE 1997b
	Maximum	cm/sec	3.20E-05	3.20E-05	[c,d]Recharge-specific (to RGA) calibration
	Distribution	-	Triangular	Triangular	See Section 4.0, Intrinsic Permeability
	Correlation Pair	-	None	None	None
	Correlation Coefficient	-	NA	NA	NA
Organic Carbon Content	Minimum	%	2.48E-02	2.48E-02	Site-specific (to PGDP) field data
	Likeliest	%	8.01E-02	8.01E-02	Site-specific (to PGDP) field data
	Maximum	%	4.55E-01	4.55E-01	Site-specific (to PGDP) field data
	Standard Deviation	%	5.27E-02	5.27E-02	Site-specific (to PGDP) field data
	Count	#	138	138	Site-specific (to PGDP) field data
	Coefficient of Variation	%	65.82	65.82	Site-specific (to PGDP) field data
	Skew	-	4.30	4.30	Site-specific (to PGDP) field data
	Distribution	-	Log normal	Log normal	Site-specific (to PGDP) field data
	Correlation Pair	-	None	None	See Section 4.0, Organic Carbon Content
	Correlation Coefficient	-	NA	NA	NA
Soil Concentration - Layer 1	Minimum	mg/kg	0.00E+00	0.00E+00	Site-specific (to PGDP) field data
	Likeliest	mg/kg	2.14E+00	1.56E+00	Site-specific (to PGDP) field data
	Maximum	mg/kg	8.70E+01	1.70E+01	Site-specific (to PGDP) field data
	Standard Deviation	mg/kg	1.12E+01	5.12E+00	Site-specific (to PGDP) field data
	Count	#	135	11	Site-specific (to PGDP) field data
	Coefficient of Variation	%	522.90	328.48	Site-specific (to PGDP) field data
	Skew	-	6.42	3.32	Site-specific (to PGDP) field data
	Distribution	-	Log normal	Log normal	Site-specific (to PGDP) field data
	Correlation Pair	-	see Layer 2	see Layer 2	Site-specific (to TCE) SADA analysis
	Correlation Coefficient	-	see Layer 2	see Layer 2	Site-specific (to TCE) SADA analysis

Table F.2.3. Statistics of variable inputs used in Monte Carlo sampling for SESOIL modeling (see Table F.45) (continued)

Input Parameter	Statistics	Unit	SWMU 1	C-720 Building	Remark
Soil Concentration - Layer 2	Minimum	mg/kg	0.00E+00	0.00E+00	Site-specific (to PGDP) field data
	Likeliest	mg/kg	1.59E+01	1.22E+00	Site-specific (to PGDP) field data
	Maximum	mg/kg	4.39E+02	1.90E+01	Site-specific (to PGDP) field data
	Standard Deviation	mg/kg	7.87E+01	4.23E+00	Site-specific (to PGDP) field data
	Count	#	31	36	Site-specific (to PGDP) field data
	Coefficient of Variation	%	494.84	347.17	Site-specific (to PGDP) field data
	Skew	-	5.53	3.81	Site-specific (to PGDP) field data
	Distribution	-	Log normal	Log normal	Site-specific (to PGDP) field data
	Correlation Pair	-	Layer 1 and Layer 2	Layer 1 with Layer 2	Site-specific (to TCE) SADA analysis
	Correlation Coefficient	-	9.20E-01	-5.00E-01	Site-specific (to TCE) SADA analysis
Soil Concentration - Layer 3	Minimum	mg/kg	0.00E+00	0.00E+00	Site-specific (to PGDP) field data
	Likeliest	mg/kg	7.60E+00	5.94E+00	Site-specific (to PGDP) field data
	Maximum	mg/kg	8.50E+01	6.80E+01	Site-specific (to PGDP) field data
	Standard Deviation	mg/kg	1.82E+01	1.54E+01	Site-specific (to PGDP) field data
	Count	#	32	23	Site-specific (to PGDP) field data
	Coefficient of Variation	%	238.82	258.66	Site-specific (to PGDP) field data
	Skew	-	3.15	3.49	Site-specific (to PGDP) field data
	Distribution	-	Log normal	Log normal	Site-specific (to PGDP) field data
	Correlation Pair	-	Layer 2 and Layer 3	Layer 2 with Layer 3	Site-specific (to TCE) SADA analysis
	Correlation Coefficient	-	3.50E-01	5.90E-01	Site-specific (to TCE) SADA analysis
Soil Concentration - Layer 4	Minimum	mg/kg	0.00E+00	0.00E+00	Site-specific (to PGDP) field data
	Likeliest	mg/kg	5.12E+00	3.87E-01	Site-specific (to PGDP) field data
	Maximum	mg/kg	7.40E+01	1.80E+00	Site-specific (to PGDP) field data
	Standard Deviation	mg/kg	1.46E+01	6.50E-01	Site-specific (to PGDP) field data
	Count	#	27	33	Site-specific (to PGDP) field data
	Coefficient of Variation	%	285.55	168.18	Site-specific (to PGDP) field data
	Skew	-	4.37	1.44	Site-specific (to PGDP) field data
	Distribution	-	Log normal	Log normal	Site-specific (to PGDP) field data
	Correlation Pair	-	Layer 3 and Layer 4	Layer 3 with Layer 4	Site-specific (to TCE) SADA analysis
	Correlation Coefficient	-	2.10E-01	1.60E-01	Site-specific (to TCE) SADA analysis

Table F.2.3. Statistics of variable inputs used in Monte Carlo sampling for SESOIL modeling (see Table F.45) (continued)

Input Parameter	Statistics	Unit	SWMU 1	C-720 Building	Remark
Soil Concentration - Layer 5	Minimum	mg/kg	0.00E+00	0.00E+00	Site-specific (to PGDP) field data
	Likeliest	mg/kg	5.95E+00	2.00E-01	Site-specific (to PGDP) field data
	Maximum	mg/kg	6.60E+01	1.30E+00	Site-specific (to PGDP) field data
	Standard Deviation	mg/kg	1.42E+01	3.69E-01	Site-specific (to PGDP) field data
	Count	#	33	30	Site-specific (to PGDP) field data
	Coefficient of Variation	%	238.99	184.61	Site-specific (to PGDP) field data
	Skew	-	3.24	2.04	Site-specific (to PGDP) field data
	Distribution	-	Log normal	Log normal	Site-specific (to PGDP) field data
	Correlation Pair	-	Layer 4 with Layer 5	Layer 4 with Layer 5	Site-specific (to TCE) SADA analysis
	Correlation Coefficient	-	4.00E-01	9.90E-01	Site-specific (to TCE) SADA analysis
Soil Concentration - Layer 6	Minimum	mg/kg	0.00E+00	0.00E+00	Site-specific (to PGDP) field data
	Likeliest	mg/kg	7.20E-01	1.17E-01	Site-specific (to PGDP) field data
	Maximum	mg/kg	3.40E+00	6.30E-01	Site-specific (to PGDP) field data
	Standard Deviation	mg/kg	1.07E+00	2.04E-01	Site-specific (to PGDP) field data
	Count	#	12	16	Site-specific (to PGDP) field data
	Coefficient of Variation	%	148.61	174.34	Site-specific (to PGDP) field data
	Skew	-	1.71	1.61	Site-specific (to PGDP) field data
	Distribution	-	Log normal	Log normal	Site-specific (to PGDP) field data
	Correlation Pair	-	Layer 5 with Layer 6	Layer 5 with Layer 6	Site-specific (to TCE) SADA analysis
	Correlation Coefficient	-	9.20E-01	5.00E-01	Site-specific (to TCE) SADA analysis
Degradation Half-life	Minimum	yr	3.20E+00	3.20E+00	See Attachment F.3
	Likeliest	yr	NA	NA	NA
	Maximum	yr	1.13E+01	1.13E+01	See Attachment F.3
	Standard Deviation	yr	NA	NA	NA
	Distribution	-	Uniform	Uniform	See Section 4.0, Degradation Half-Life
	Correlation Pair	-	None	None	See Section 4.0, Degradation Half-Life
	Correlation Coefficient	-	NA	NA	NA

Table F.2.3. Statistics of variable inputs used in Monte Carlo sampling for SESOIL modeling (see Table F.45) (continued)

[a] Field observation was available for vertical hydraulic conductivity. Therefore, intrinsic permeability was estimated from vertical hydraulic conductivity.
[b] The maximum from DOE 1997a and DOE 1997b was judged to be high and was re-estimated through calibration.
[c] The maximum was estimated through calibration to a recharge of 22 cm/yr (DOE 2000).
[d] The value selected for probabilistic method.

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DOE, 1997a. *Ground-Water Conceptual Model for the Paducah Gaseous Diffusion Plant Paducah, Kentucky*, DOE/OR/06-1628&D0, August.

DOE, 1997b. *Data Summary and Interpretation Report for Interim Remedial Design at Solid Waste Management Unit 2 of Waste Area Grouping 22 at the PGDP Paducah, Kentucky*, DOE/OR/07-1549&D1, February.

DOE 2000. *Feasibility Study for the Groundwater Operable Unit at Paducah Gaseous Diffusion Plant Paducah, Kentucky*, DOE/OR/07-1857&D1, July.

Table F.2.4. Statistics of variable inputs used in Monte Carlo runs for SESOIL modeling (see Table F.47)

Input Parameter	Statistics	Unit	SWMU 1	C-720 Building
Vertical Hydraulic Conductivity[a]	Minimum	cm/sec	2.75E-06	2.75E-06
	Median	cm/sec	1.64E-05	1.64E-05
	Maximum	cm/sec	2.82E-05	2.83E-05
	Arithmetic Mean	cm/sec	1.60E-05	1.58E-05
	Standard Deviation	cm/sec	6.57E-06	6.73E-06
Intrinsic Permeability[a]	Minimum	cm^2	2.80E-11	2.80E-11
	Median	cm^2	1.67E-10	1.67E-10
	Maximum	cm^2	2.87E-10	2.89E-10
	Arithmetic Mean	cm^2	1.63E-10	1.61E-10
	Standard Deviation	cm^2	6.70E-11	6.86E-11
Organic Carbon Content[b]	Minimum	mg/kg	2.53E+02	2.67E+02
	Median	mg/kg	6.76E+02	6.86E+02
	Maximum	mg/kg	2.78E+03	3.47E+03
	Arithmetic Mean	mg/kg	7.90E+02	8.37E+02
	Standard Deviation	mg/kg	4.71E+02	5.14E+02
Organic Carbon Content (%)[b]	Minimum	%	2.53E-02	2.67E-02
	Median	%	6.76E-02	6.86E-02
	Maximum	%	2.78E-01	3.47E-01
	Arithmetic Mean	%	7.90E-02	8.37E-02
	Standard Deviation	%	4.71E-02	5.14E-02
Soil Concentration - Layer 1[c]	Minimum	mg/kg	2.86E-03	2.33E-03
	Median	mg/kg	5.73E-01	2.37E-01
	Maximum	mg/kg	3.58E+01	4.63E+00
	Arithmetic Mean	mg/kg	2.37E+00	6.46E-01
	Standard Deviation	mg/kg	5.15E+00	1.03E+00
Soil Concentration - Layer 2[c]	Minimum	mg/kg	6.03E-02	5.20E-03
	Median	mg/kg	3.64E+00	2.14E-01
	Maximum	mg/kg	1.88E+02	5.80E+00
	Arithmetic Mean	mg/kg	1.41E+01	5.95E-01
	Standard Deviation	mg/kg	3.09E+01	1.12E+00
Soil Concentration - Layer 3[c]	Minimum	mg/kg	1.28E-01	2.34E-02
	Median	mg/kg	5.80E+00	1.67E+00
	Maximum	mg/kg	1.02E+02	4.82E+01
	Arithmetic Mean	mg/kg	1.14E+01	5.08E+00
	Standard Deviation	mg/kg	1.63E+01	8.66E+00
Soil Concentration - Layer 4[c]	Minimum	mg/kg	1.28E-01	5.11E-03
	Median	mg/kg	2.78E+00	7.76E-02
	Maximum	mg/kg	1.15E+02	5.91E-01
	Arithmetic Mean	mg/kg	8.93E+00	1.24E-01
	Standard Deviation	mg/kg	1.62E+01	1.23E-01
Soil Concentration - Layer 5[c]	Minimum	mg/kg	1.26E-01	1.01E-03
	Median	mg/kg	4.39E+00	3.56E-02
	Maximum	mg/kg	7.50E+01	4.01E-01
	Arithmetic Mean	mg/kg	1.04E+01	6.09E-02
	Standard Deviation	mg/kg	1.44E+01	6.68E-02

Table F.2.4. Statistics of variable inputs used in Monte Carlo runs for SESOIL modeling (see Table F.47) (continued)

Input Parameter	Statistics	Unit	SWMU 1	C-720 Building
Soil Concentration - Layer 6[c]	Minimum	mg/kg	5.30E-02	7.50E-04
	Median	mg/kg	1.04E+00	1.95E-02
	Maximum	mg/kg	6.65E+00	1.92E-01
	Arithmetic Mean	mg/kg	1.55E+00	3.31E-02
	Standard Deviation	mg/kg	1.53E+00	3.63E-02
Degradation Half-Life[d]	Minimum	yr	3.2	3.2
	Median	yr	4.9	4.9
	Maximum	yr	11.3	11.3
	Arithmetic Mean	yr	4.9	4.9
	Standard Deviation	yr	NA	NA
Degradation Rate[d]	Minimum	/hr	7.13E-06	7.21e-06
	Median	/hr	1.22E-05	1.13E-05
	Maximum	/hr	2.43E-05	2.43E-05
	Arithmetic Mean	/hr	1.32E-05	1.30E-05
	Standard Deviation	/hr	NA	NA

[a] Intrinsic permeability (cm^2) was estimated from the vertical hydraulic conductivity (cm/sec) using a conversion factor of 1.019E-5.
[b] Organic carbon content (%) was estimated from organic carbon content (mg/kg) using a conversion factor of 1E-4.
[c] Soil concentrations are normalized using the volume of the layer with the largest mass.
[d] Degradation rate was estimated from degradation half-life in units of days using the formula: rate = [(ln 2)/degradation half-life].

Table F.2.5. Hydrogeology-specific parameters for AT123D modeling (see Table F.49)

Input Parameter	Unit	SWMU 1	C-720 Building	Remark
Aquifer Thickness	m	Variable	Variable	Probabilistic method
Hydraulic Conductivity	m/hr	Variable	Variable	Probabilistic method
Hydraulic Gradient	m/m	Variable	Variable	Probabilistic method
Effective Porosity	-	Variable	Variable	Probabilistic method
Organic Carbon Content	%	Variable	Variable	Probabilistic method
Dispersivity - Longitudinal	m	15	15	DOE 1999
Dispersivity - Transverse	m	1.5	5	DOE 1999
Dispersivity - Vertical	m	0.03	5	DOE 1999
Bulk Density	kg/m^3	1670	1670	DOE 1999
Density of Water	kg/m^3	1000	1000	Mills et al. 1985

DOE 1999. *Remedial Investigation Report for Waste Area Grouping 27 at the Paducah Gaseous Diffusion Plant Paducah, Kentucky*, DOE/OR/07-1777/V4&D2, June.

Mills, W. B., D. B. Porcella, M. J. Ungs, S. A. Gherini, K. V. Summers, Lingfung Mok, G. L. Rupp, G. L. Bowie, and D. A. Hadith, 1985. *Water Quality Assessment: A Screening Procedure for Toxic and Conventional Pollutants, Parts II*, EPA-600/6-85/002b, September, U.S. Environmental Protection Agency, Environmental Research Laboratory, Office of Research and Development, Athens, GA.

Table F.2.6. Chemical-specific parameters for AT123D modeling (see Table F.49)

Input Parameter	Unit	SWMU 1	C-720 Building	Remark
Contaminant of Concern	-	Trichloroethene	Trichloroethene	Selected for analysis
Source Area	m^2	324	1394	Site-specific (to TCE) SADA analysis
Diffusion in Water	m^2/hr	3.28E-06	3.28E-06	EPA 1996
Koc	L/kg	94	94	EPA 1996
Degradation Rate (half-life)[a]	hr^{-1} (year)	Variable	Variable	Attachment F.3

[a] Degradation rate was estimated from degradation half-life (see text).

EPA 1996. *Soil Screening Guidance: Technical Background Document*, Office of Solid Waste and Emergency Response, Washington, D.C.

Table F.2.7. POE-specific parameters for AT123D modeling (see Table F.51)

Input Parameter	Unit	SWMU 1	C-720 Area	Remark
Distance to Plant Boundary	m (ft)	170 (558)	762 (2500)	See Fig. F.20
Distance to Property Boundary	m (ft)	915 (3000)	1460 (4789)	See Fig. F.20
Distance to Ohio River	m (ft)	7317 (24000)	7927 (26000)	See Fig. F.20

Table F.2.8. Statistics of variable inputs used in Monte Carlo sampling for AT123D modeling (see Table F.48)

Input Parameter	Statistics	SWMU 1 and C-720 Building				Remark
		Crystal Ball	Unit	AT123D	Unit	
Aquifer Thickness	Minimum Value	10.00	ft	3.05	m	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Likeliest Value	38.71	ft	11.80	m	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Maximum Value	63.50	ft	19.36	m	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Standard deviation	11.84	ft	3.61	m	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Count	24	#	24	#	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Coefficient of Variation	30.59	%	30.59	%	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Skew	-0.61	-	-0.61	-	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Distribution	Normal	-	Normal	-	DOE 1995, DOE 1997a, DOE 1997b, DOE 2000a, DOE 2000b, DOE 2004, KY 1992b
	Correlation pair	None	-	None	-	Assumed none
	Correlation coefficient	NA	-	NA	-	NA
Hydraulic Conductivity	Minimum Value	1.00E-04	ft/day	1.27E-06	m/hr	[a] BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a
	Likeliest Value	1.93E+04	ft/day	2.46E+02	m/hr	[a] BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a
	Maximum Value	8.50E+05	ft/day	1.08E+04	m/hr	[a] BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a
	Standard deviation	1.09E+05	ft/day	1.38E+03	m/hr	[a] BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a
	Count	62	#	62	#	[a] BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a
	Coefficient of Variation	563.17	%	563.17	%	[a] BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a
	Skew	7.53	-	7.53	-	[a] BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a

Table F.2.8. Statistics of variable inputs used in Monte Carlo sampling for AT123D modeling (see Table F.48) (continued)

Input Parameter	Statistics	SWMU 1 and C-720 Building				Remark
		Crystal Ball	Unit	AT123D	Unit	
Hydraulic Conductivity	Minimum Value	75.00	ft/day	0.95	m/hr	[a] PGDP Groundwater flow model
	Likeliest Value	966.85	ft/day	12.28	m/hr	[a] PGDP Groundwater flow model
	Maximum Value	1500.00	ft/day	19.05	m/hr	[a] PGDP Groundwater flow model
	Standard deviation	628.74	ft/day	7.99	m/hr	[a] PGDP Groundwater flow model
	Count	12166	#	12166	#	[a] PGDP Groundwater flow model
	Coefficient of Variation	65.03	%	65.03	%	[a] PGDP Groundwater flow model
	Skew	-0.35	-	-0.35	-	[a] PGDP Groundwater flow model
Hydraulic Conductivity	Minimum Value	75.00	ft/day	0.95	m/hr	[a,b] Minimum of the site-specific (to PGDP) groundwater flow model
	Likeliest Value	350.00	ft/day	4.45	m/hr	[a,b] Assumed approximate geomean of the minimum and maximum of the site-specific (to PGDP) groundwater flow model
	Maximum Value	1500.00	ft/day	19.05	m/hr	[a,b] Maximum of the site-specific (to PGDP) groundwater flow model
	Standard deviation	350.00	ft/day	4.45	m/hr	[a,b] Assumed equal to likeliest value
	Coefficient of Variation	100.00	%	100.00	%	[a,b] Assumed equal to likeliest value
	Distribution	Log normal	-	Log normal	-	BJC 2001a, BJC 2001b, DOE 1997a, DOE 1997b, DOE 1999a, DOE 1999b, DOE 1999c, KY 1992a
	Correlation pair	Hydraulic Conductivity and Porosity	-	Hydraulic Conductivity and Porosity	-	Assumed
	Correlation coefficient	NA	-	NA	-	NA
Hydraulic Gradient	Minimum Value	1.00E-04	ft/ft	1.00E-04	m/m	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
	Likeliest Value	1.01E-03	ft/ft	1.01E-03	m/m	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
	Maximum Value	4.00E-03	ft/ft	4.00E-03	m/m	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
	Standard deviation	1.12E-03	ft/ft	1.12E-03	m/m	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
	Count	12	#	12	#	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
	Coefficient of Variation	110.89	%	110.89	%	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
	Skew	1.95	-	1.95	-	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
	Distribution	Normal	-	Normal	-	BJC 2001a, DOE 1997a, DOE 1997b, DOE 1997, KY 1992a, KY 1997
Hydraulic Gradient	Correlation pair	Hydraulic Conductivity and Hydraulic Gradient	-	Hydraulic Conductivity and Hydraulic Gradient	-	Assumed

Table F.2.8. Statistics of variable inputs used in Monte Carlo sampling for AT123D modeling (see Table F.48) (continued)

Input Parameter	Statistics	SWMU 1 and C-720 Building				Remark
		Crystal Ball	Unit	AT123D	Unit	
	Correlation coefficient	-0.50	-	-0.50	-	Assumed
Porosity [c]	Minimum Value	27.00	%	27.00	%	DOE 1997a, DOE 1999a, DOE 1999c
	Likeliest Value	39.11	%	39.11	%	DOE 1997a, DOE 1999a, DOE 1999c
	Maximum Value	54.00	%	54.00	%	DOE 1997a, DOE 1999a, DOE 1999c
	Standard deviation	5.98	%	5.98	%	DOE 1997a, DOE 1999a, DOE 1999c
	Count	28	#	28	#	DOE 1997a, DOE 1999a, DOE 1999c
	Coefficient of Variation	15.29	%	15.29	%	DOE 1997a, DOE 1999a, DOE 1999c
	Skew	0.43	-	0.43	-	DOE 1997a, DOE 1999a, DOE 1999c
	Distribution	Normal	-	Normal	-	DOE 1997a, DOE 1999a, DOE 1999c
	Correlation pair	Hydraulic Gradient and Porosity	-	Hydraulic Gradient and Porosity	-	Assumed
	Correlation coefficient	-0.20	-	-0.20	-	Assumed
Organic Carbon Content	Minimum Value	0.003	%	0.003	%	KY 1992a, DOE 1997a, BJC 2006
	Likeliest Value	0.035	%	0.035	%	KY 1992a, DOE 1997a, BJC 2006
	Maximum Value	0.253	%	0.253	%	KY 1992a, DOE 1997a, BJC 2006
	Standard deviation	0.037	%	0.037	%	KY 1992a, DOE 1997a, BJC 2006
	Count	38	#	38	#	KY 1992a, DOE 1997a, BJC 2006
	Coefficient of Variation	1.05	%	1.05	%	KY 1992a, DOE 1997a, BJC 2006
	Skew	4.00	-	4.00	-	KY 1992a, DOE 1997a, BJC 2006
	Distribution	Log normal	-	Log normal	-	KY 1992a, DOE 1997a, BJC 2006
	Correlation pair	None	-	None	-	Assumed
	Correlation coefficient	NA	-	NA	-	NA

Table F.2.8. Statistics of variable inputs used in Monte Carlo sampling for AT123D modeling (see Table F.48) (continued)

Input Parameter	Statistics	SWMU 1 and C-720 Building				Remark
		Crystal Ball	Unit	AT123D	Unit	
Degradation Half-Life	Minimum Value	3.2	yr	NA	-	[d] See Attachment F.3
	Likeliest Value	NA	-	NA	-	NA
	Maximum Value	11.3	yr	NA	-	[d] See Attachment F.3
	Standard deviation	NA	-	NA	-	NA
	Count	NA	-	NA	-	NA
	Coefficient of Variation	NA	-	NA	-	NA
	Skew	NA	-	NA	-	NA
	Distribution	Uniform	-	NA	-	[d] See Attachment F.3
	Correlation pair	Hydraulic Gradient and Degradation Rate	-	NA	-	Assumed
	Correlation coefficient	-1.00	-	NA	-	[d] See Attachment F.3
Degradation Rate	Minimum Value	NA	-	7.01E-06	/hr	[d] See Attachment F.3
	Likeliest Value	NA	-	NA	-	NA
	Maximum Value	NA	-	2.45E-05	/hr	[d] See Attachment F.3
	Standard deviation	NA	-	NA	-	NA
	Count	NA	-	NA	-	NA
	Coefficient of Variation	NA	-	NA	-	NA
	Skew	NA	-	NA	-	NA
	Distribution	NA	-	Uniform	-	[d] See Attachment F.3
	Correlation pair	NA	-	Hydraulic Gradient and Degradation Rate	-	Assumed
	Correlation coefficient	NA	-	-1.00	-	[d] See Attachment F.3

[a] Multiple values were noted.
[b] The value selected for probabilistic method.
[c] Field observation was available for porosity. Therefore, effective porosity was estimated from porosity.
[d] Degradation rate was estimated from degradation half-life in units of hours using the formula: rate = [(ln 2)/degradation half-life].
BJC 2001a. C-746-U Solid Waste Landfill Groundwater Monitoring Plan Paducah Gaseous Diffusion Plant Paducah, Kentucky. BJC/PAD-205/R1, December.
BJC 2001b. Groundwater Monitoring Plan for the C-746-S Residential Landfill Paducah Gaseous Diffusion Plant Paducah, Kentucky. BJC/PAD-268/R1, December.

Table F.2.8. Statistics of variable inputs used in Monte Carlo sampling for AT123D modeling (see Table F.48) (continued)

		SWMU 1 and C-720 Building				
Input Parameter	**Statistics**	**Crystal Ball**	**Unit**	**AT123D**	**Unit**	**Remark**

BJC 2006.

DOE 1995. *Northeast Plume Preliminary Characterization Summary Report,* DOE/OR/07-1339/V2 & D2, July.

DOE 1997a. *Data Summary and Interpretation Report for Interim Remedial Design at Solid Waste Management Unit 2 of Waste Area Grouping 22 at the PGDP Paducah, Kentucky,* DOE/OR/07-1549&D1, February.

DOE 1997b. *Ground-Water Conceptual Model for the Paducah Gaseous Diffusion Plant Paducah, Kentucky,* DOE/OR/06-1628&D0, August.

DOE 1999a. *Remedial Investigation Report for Waste Area Grouping 6 at Paducah Gaseous Diffusion Plant Paducah, Kentucky,* DOE/OR/07-1727V1&D2, May.

DOE 1999b. R*emedial Investigation Report for Waste Area Grouping 27 at Paducah Gaseous Diffusion Plant Paducah, Kentucky,* DOE/OR/07-1777V1&D2, June.

DOE 1999c. *Remedial Investigation Report for Waste Area Grouping 6 at Paducah Gaseous Diffusion Plant Paducah, Kentucky,* DOE/OR/07-1727V2&D2, May.

DOE 2000a. *Data Report for the Sitewide Remedial Evaluation for Source Areas Contributing to Off-Site Groundwater Contamination at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/OR/07-1845/D1, January.

DOE 2000b. *Remedial Investigation Report for Waste Area Grouping 3 at the Paducah Gaseous Diffusion Plan, Paducah, Kentucky,* DOE/OR/07-1895/V2&D1, September.

DOE 2004. *Site Investigation Report for the Southwest Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/OR/07-2180&D0, October.

KY 1992a. R*eport of the Paducah Gaseous Diffusion Plan Groundwater Investigation Phase III,* KY/E-150, November 25.

KY 1992b. *Results of the Site Investigation, Phase II, at the Paducah Gaseous Diffusion Plant,* KY/SUB/13B-97777C P-03/1991/1, April.

KY 1997. *Analysis and Interpretation of Water Levels in Observations Wells at the Paducah Gaseous Diffusion Plant 1990-1997,* KY/EM-210, June 30.

Table F.2.9. Statistics of variable inputs used in Monte Carlo runs for Source Term development and AT123D modeling (see Table F.50)

Input Parameter	[c] Statistics	Unit	SWMU 1 and C-720 Building
Aquifer Depth	Minimum	m	3.38
	Median	m	11.30
	Maximum	m	18.50
	Arithmetic Mean	m	10.90
	[c] Standard Deviation	m	3.44
Hydraulic Conductivity	Minimum	m/hr	0.97
	Median	m/hr	3.54
	Maximum	m/hr	17.60
	Arithmetic Mean	m/hr	4.77
	[c] Standard Deviation	m/hr	3.70
Hydraulic Gradient	Minimum	m/m	1.63E-04
	Median	m/m	1.37E-03
	Maximum	m/m	3.98E-03
	Arithmetic Mean	m/m	1.49E-03
	[c] Standard Deviation	m/m	9.20E-04
Porosity	[a] Minimum	%	27.16
	Median	%	38.27
	Maximum	%	53.09
	Arithmetic Mean	%	39.51
	[c] Standard Deviation	%	6.17
Effective Porosity	[a] Minimum	-	0.22
	Median	-	0.31
	Maximum	-	0.43
	Arithmetic Mean	-	0.32
	[c] Standard Deviation	-	0.05
Organic Carbon Content	Minimum	%	0.003
	Median	%	0.024
	Maximum	%	0.228
	Arithmetic Mean	%	0.034
	[c] Standard Deviation	%	0.034
Degradation Half-Life	[b] Minimum	yr	3.2
	Median	yr	4.9
	Maximum	yr	11.3
	Arithmetic Mean	yr	4.9
	[c] Standard Deviation	yr	NA
Degradation Rate	[b] Minimum	/hr	7.20E-06
	Median	/hr	1.62E-05
	Maximum	/hr	2.45E-05
	Arithmetic Mean	/hr	1.61E-05
	[c] Standard Deviation	/hr	NA

Table F.2.9. Statistics of variable inputs used in Monte Carlo runs for AT123D modeling (see Table F.50) (continued)

Input Parameter	[c] Statistics	Unit	SWMU 1 and C-720 Building
Groundwater Concentration in the RGA[c]	Minimum	µg/L	2.92
	Median	µg/L	362.7
	Maximum	µg/L	25311
	Arithmetic Mean	µg/L	2138.6
	[c] Standard Deviation	µg/L	4534.8
Total Soil Concentration Derived from Groundwater Concentrations[c]	Minimum	mg/kg	7.25E-04
	Median	mg/kg	9.73E-02
	Maximum	mg/kg	5.68E+00
	Arithmetic Mean	mg/kg	5.72E-01
	[c] Standard Deviation	mg/kg	1.18E+00

[a] Effective porosity was estimated from porosity (see text).
[b] Degradation rate was estimated from degradation half-life in units of hours using the formula: rate = [(ln 2)/degradation half-life].
[c] This parameter was only used for secondary source term modeling.

Table F.2.10. Qualitative sensitivity of modeling results to input parameters for the Southwest Plume SI Report

Input Parameter	Degree of sensitivity		
	Low	Medium	High
Bulk density	√		
Effective porosity		√	
Horizontal hydraulic conductivity in the RGA		√	
Vertical hydraulic conductivity in the UCRS	√		
Percolation rate		√	
Horizontal hydraulic gradient in the RGA		√	
Aquifer thickness	√		
Longitudinal dispersivity	√		
Soil-water partition coefficient (K_d)			√
Fraction of organic carbon (%)			√
Biodegradation half-life			√
Molecular diffusion	√		
Source Area		√	
Source term in the UCRS			√

Fig. F.2.1. Histogram of Intrinsic Permeability SESOIL inputs for SWMU 1.

Fig. F.2.2. Histogram of Intrinsic Permeability SESOIL inputs for the C-720 Area.

Fig. F.2.3. Histogram of Organic Carbon Content SESOIL inputs for SWMU 1.

Fig. F.2.4. Histogram of Organic Carbon Content SESOIL inputs for the C-720 Area.

Fig. F.2.5. Histogram of Layer 1 TCE concentrations at SWMU 1 used as SESOIL inputs.

Fig. F.2.6. Histogram of Layer 2 TCE concentrations at SWMU 1 used as SESOIL inputs.

Fig. F.2.7. Histogram of Layer 3 TCE concentrations at SWMU 1 used as SESOIL inputs.

Fig. F.2.8. Histogram of Layer 4 TCE concentrations at SWMU 1 used as SESOIL inputs.

Fig. F.2.9. Histogram of Layer 5 TCE concentrations at SWMU 1 used as SESOIL inputs.

Fig. F.2.10. Histogram of Layer 6 TCE concentrations at SWMU 1 used as SESOIL inputs.

Fig. F.2.11. Histogram of Layer 1 TCE concentrations at C-720 Area used as SESOIL inputs.

Fig. F.2.12. Histogram of Layer 2 TCE concentrations at C-720 Area used as SESOIL inputs.

Fig. F.2.13. Histogram of Layer 3 TCE concentrations at C-720 Area used as SESOIL inputs.

Fig. F.2.14. Histogram of Layer 4 TCE concentrations at C-720 Area used as SESOIL inputs.

Fig. F.2.15. Histogram of Layer 5 TCE concentrations at C-720 Area used as SESOIL inputs.

Fig. F.2.16. Histogram of Layer 6 TCE concentrations at C-720 Area used as SESOIL inputs.

Fig. F.2.17. Histogram of Degradation Rate SESOIL inputs for SWMU 1.

Fig. F.2.18. Histogram of Degradation Rate SESOIL inputs for C-720 Area.

Fig. F.2.19. Histogram of Aquifer Thickness AT123D inputs for SWMU 1 and the C-720 Area.

Fig. F.2.20. Histogram of Hydraulic Conductivity AT123D inputs for SWMU 1 and the C-720 Area.

Fig. F.2.21. Histogram of Hydraulic Gradient AT123D inputs for SWMU 1 and the C-720 Area.

Fig. F.2.22. Histogram of Effective Porosity AT123D inputs for SWMU 1 and the C-720 Area.

Fig. F.2.23. Histogram of Organic Carbon Content AT123D inputs for SWMU 1 and the C-720 Area.

Fig. F.2.24. Histogram of Degradation Rate inputs for SWMU 1, and the C-720 Area.

E.6. LEAD-210 AT PGDP

Lead-210 is a radioactive form of lead, having an atomic weight of 210. It is one of the last elements created by the radioactive decay of the isotope uranium-238 (see Figure E.7). Lead-210 forms naturally in the sediments and rocks that contain uranium-238, as well as in the atmosphere, a by-product of radon gas. Within 10 days of its creation from radon, lead-210 falls out of the atmosphere. It accumulates on the surface of the earth where it is stored in soils, lake and ocean sediments, and glacial ice. The lead-210 eventually decays into a non-radioactive form of lead. Lead-210 has a half-life of 22.3 years and is a significant source of beta radiation (USGS 2012; EPA 2012).[1]

Lead-210 is not an easy analysis to perform and typically is not included in a regular gamma radiological scan; it has a peak at 46 KeV and requires a thin window detector and an efficiency curve using a standard with lead-210. Therefore, historical data was reviewed to ensure the analysis was necessary. Because lead-210 is found significantly down the decay chain for uranium-238 through radon-222, activities performed over the past 60 years at PGDP cannot have resulted in PGDP-sourced lead-210.

Figure E.7. Lead-210 Decay Chain

Available PGDP lead-210 data was plotted to estimate an approximate background value. This map is shown in Figure E.8. Because the majority of the available data is historical, data quality is not certain; however, it appears that the higher lead-210 activities within the PGDP boundaries are at background values.

Figure E.8. Lead-210 Soil/Sediment Samples

Figure No. Lead-210_Soil.mxd
DATE 11-01-2012

Data indicate higher levels of lead-210 inside the PGDP boundary at SWMU 222, although radium-226 was not reported for the majority of these samples. The one sample that had radium-226 reported had a significant difference in activity between the radium-226 and its ingrowth radionuclides, lead-214 and bismuth-214. If radium-226 is truly at 11 pCi/g, as reported in that sample, and the analysis was conducted properly (ingrowth for 30 days in a sealed container), the lead-214 and bismuth-214 activity should have equaled the radium-226 activity. Under these analysis conditions the activity of lead-210 would not be in secular equilibrium with radium-226. The fact that the lead-210 is elevated in the samples suggests a possible separate source of lead-210 rather than ingrowth. Lead-210, which has a 22-year half-life, is included in the list of short-lived radionuclides associated with radium-226 for completeness, as this isotope and its short-lived decay products typically are present with radium-226.

After processing, radionuclides with half-lives of less than one year will reestablish equilibrium conditions with their longer-lived parent radionuclides within several years. For this reason, at processing sites what was once a single, long decay series (for example the series for uranium-238) may be present as several smaller decay series headed by the longer-lived decay products of the original series (that is, headed by uranium-238, uranium-234, thorium-230, radium-226, and lead-210 in the case of uranium-238). Each of these sub-series can be considered to represent a new, separate decay series. Understanding the physical and chemical processes associated with materials containing uranium, thorium, and radium is important when addressing associated radiological risks.

Detected lead-210 results available for PGDP were listed alongside radium-226 and uranium-238 results in Table E.4. Lead-210 would be expected to be in equilibrium (i.e., similar activity results) with uranium-238 for instances of natural uranium. Lead-210 would be expected to be in equilibrium with radium-226 for instances of enriched uranium. No split samples are available; however, a surrogate to a “split” could be simply looking at the uranium-238 to lead-210 ratio in samples, where available. For example, if lead-210 is a true contaminant, then it should exceed the uranium-238 level, when the uranium-238 is at background in at least some samples.

A further check of the available data was performed by filtering the activity results against minimum detectable activities and counting uncertainties. The only samples that passed both checks are shown in Table E.5. Recent Soils Operable Unit (OU) soils data passed both checks.

Table E.4. Sample Results for Lead-210, Radium-226, and Uranium-238 in Soil and Sediment

		Depth	Lab	Lead-210 (pCi/g)					Radium-226 (pCi/g)					Uranium-238 (pCi/g)				
Station	Sample ID	(ft bgs)	Code	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?
194-01,02	301043	9	LOCK	20.00	0.02			Yes					No	0.60		0.10		Yes
JP-0092	DOJ1-99-0092		PGDP	14.55	18.18	29.10	29.10	No	0.77	0.31	1.53	1.53	No	4386.00	4.20	89.00	1117.00	Yes
194-01,02	301048	20	LOCK	12.00	0.05			Yes					No	1.30		0.16		Yes
SWMU222-4	2010-53093[a]		KYRAD	10.60	2.05	1.03		Yes					No	27.80	1.62	1.12		Yes
SWMU222-4	2010-53093		KYRAD	10.60	2.05	1.03		Yes					No	27.80	0.03	2.33		Yes
SWMU222-5	2010-53094[b]		KYRAD	8.60	1.47	0.76		Yes					No	32.30	0.04	2.66		Yes
SWMU222-1	2010-53090[b]		KYRAD	8.44	1.71	0.87		Yes					No	23.70	0.13	2.10		Yes
194-01,02	301044	11.33	LOCK	8.00	0.03			Yes					No	0.61		0.11		Yes
SWMU222-2	2010-53091[b]		KYRAD	6.98	1.41	0.71		Yes					No	22.10	0.04	1.94		Yes
SWMU222-3	2010-53092[b]		KYRAD	6.81	1.14	0.61		Yes					No	16.70	0.03	1.51		Yes
SOU195-120A	2010-51253[a]	1	KYRAD	6.57	9.25	3.83		No	2.53	2.08	0.94		Yes	3.94	2.41	1.36		Yes
SOU195-014C	2010-51264[a]	10	KYRAD	6.01	5.28	2.16		Yes	1.44	1.27	0.57		Yes	2.25	0.93	0.84		Yes
194-01,02	301047	18.6	LOCK	5.40	0.00			Yes					No	0.90		0.13		Yes
SWMU222-1	2010-52457[b]		KYRAD	4.92	0.82	0.41		Yes					No	31.30	0.05	3.59		Yes
JP-0160	DOJ1-99-0160		PGDP	4.31	1.79	2.11	2.28	Yes	0.71	1.64	1.42	1.42	No	2.70	0.93	0.52	1.41	Yes
BCBOKYRAD01	2010-50535[a]		KYRAD	4.27	0.46	0.25		Yes	2.35	0.87	0.39		Yes	2.22	0.47	0.22		Yes
LBC2L020	LBCSOSU2S1-04	1	STLMO	4.20	2.00		1.70	Yes	0.80	0.21		0.25	Yes	3.90	1.50		1.40	Yes
RSO3	110013[c]		STLMO	3.90	1.90	1.90		Yes					No					No
JP-0152	DOJ1-99-0152		PGDP	3.76	5.96	7.52	7.52	No	0.84	0.12	1.69	1.69	No	208.00	0.04	3.30	42.00	Yes
H01,05,15	301025	0.7	LOCK	3.70	0.00			Yes					No	0.96		0.10		Yes
SOU195-014A	2010-51258[a]	10	KYRAD	3.56	5.07	2.13		No	1.40	1.10	0.50		Yes	1.54	0.90	0.79		Yes
RSO3	110012[c]		STLMO	3.50	1.40	1.20		Yes					No					No
BC5KYRAD01	2010-50537[a]		KYRAD	3.43	0.36	0.21		Yes	2.06	0.71	0.32		Yes	1.37	0.32	0.15		Yes
C12,18,19	301012[d]	2	LOCK	3.20	0.00			Yes					No	0.97		0.09		Yes
A10	PLDJNSA10-01SO	2.5	PGDP	3.10	5.90	6.20	6.20	No	0.16	0.07	0.01	0.08	Yes	6.60	0.05	0.35	0.89	Yes
LBC2L015	LBCSOSU2S1-03	1	STLMO	3.00	2.90		2.40	Yes	1.21	0.26		0.30	Yes	1.25	0.01		0.18	Yes
JP-0161	DOJ1-99-0161		PGDP	2.92	1.93	2.07	2.10	Yes	0.83	0.17	1.66	1.66	No	2.30	1.02	0.51	3.21	No
SOU200-004	2010-51270[a]	4	KYRAD	2.81	5.18	2.19		No	2.51	1.31	0.61		Yes	1.48	0.88	1.19		Yes
F04,02,29	301005	0.8	LOCK	2.80	0.00			Yes					No	0.82		0.08		Yes
SOU195-120C	2010-51252[a]	1	KYRAD	2.70	0.62	0.32		Yes	1.67	0.90	0.41		Yes	1.02	0.52	0.29		Yes
K008-AIP-RP	030301	0	STLMO	2.70	1.20	1.10		Yes					No	1.71	0.33	0.98		Yes
C07,08,09	301013[d]	0.9	LOCK	2.70	0.00			Yes					No	1.04		0.09		Yes
NST2S04	BJC2041SS	8	PGDP	2.65	2.40	2.50	2.60	Yes	2.43	0.33	4.85	4.85	No	4.11	1.24	0.66	2.11	Yes
SOU222-001	2010-51277[a]	0.5	KYRAD	2.57	0.59	0.76		Yes	11.10	1.30	0.71		Yes	19.62	0.76	0.65		Yes
BCBOKYRAD02	2010-50536[a]		KYRAD	2.51	0.71	0.33		Yes	7.18	1.17	0.56		Yes	10.26	0.87	0.46		Yes
F12,20,22	301004	1.5	LOCK	2.46	0.00			Yes					No	0.90		0.08		Yes
H04,06,09	301023	0.8	LOCK	2.45	0.00			Yes					No	0.84		0.09		Yes
JP-0019	DOJ1-99-0017		PGDP	2.44	16.16	4.87	10.54	No	1.06	0.29	2.11	2.11	No	2270.00	9.14	16.30	609.00	Yes
C12,18,19	301011[d]	0.8	LOCK	2.40	0.00			Yes					No	1.06		0.10		Yes
196-03,04	301038	6.67	LOCK	2.40	0.00			Yes					No	0.80		0.12		Yes
C01,10,24	301017[d]	0.7	LOCK	2.30	0.00			Yes					No	0.95		0.10		Yes
F05,07,17	301008	1.6	LOCK	2.20	0.00			Yes					No	0.86		0.09		Yes
C07,08,09	301015[d]	0.9	LOCK	2.09	0.00			Yes					No	1.00		0.10		Yes

Table E.4. Sample Results for Lead-210, Radium-226, and Uranium-238 in Soil and Sediment (Continued)

		Depth	Lab	Lead-210 (pCi/g)					Radium-226 (pCi/g)					Uranium-238 (pCi/g)				
Station	Sample ID	(ft bgs)	Code	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?
JP-0046	DOJ1-99-0046		PGDP	2.07	1.91	2.03	2.00	Yes	0.70	0.13	1.40	1.40	No	13.90	1.00	1.43	4.00	Yes
A2	PLDJNSA2D-01SO	8.5	PGDP	2.00	6.00	4.10	4.10	No	0.59	0.13	1.10	1.10	No	0.77	0.24	0.39	1.37	No
H04,06,09	301022	2.6	LOCK	1.90	0.00			Yes					No	1.01		0.10		Yes
F12,20,22	301001	0.8	LOCK	1.90	0.00			Yes					No	0.90		0.08		Yes
SOU195-014A	2010-51256 [a]	4	KYRAD	1.89	5.01	2.14		No	1.55	1.16	0.52		Yes	1.12	0.93	1.18		No
F04,02,29	301006	1.5	LOCK	1.85	0.00			Yes					No	0.82		0.08		Yes
JP-0160	DOJ1-99-0177		PGDP	1.84	2.62	3.68	3.68	No	0.65	0.12	1.30	1.30	No	2.01	0.91	1.08	3.57	No
K008-AIP-RP	030303	0	STLMO	1.80	1.10	1.30		Yes	0.80	0.30	0.28		Yes	2.30	0.30	1.10		Yes
C02,03,20	301019 [d]	0.7	LOCK	1.80	0.00			Yes					No	1.03		0.10		Yes
BC5KYRAD02	2010-50538 [a]		KYRAD	1.74	0.90	0.42		Yes	2.01	1.56	0.70		Yes	0.69	0.93	0.55		Yes
194-05,06	301039	9	LOCK	1.72	0.00			Yes					No	0.79		0.12		Yes
194-03,04	301045 [e]	16	LOCK	1.68	0.00			Yes					No	1.06		0.14		Yes
A2	PLDJNSA2-02SO	11.5	PGDP	1.60	6.60	3.30	4.40	No	1.10	0.18	2.20	2.20	No	1.69	0.86	1.03	3.04	No
F01,21,23	301009	0.8	LOCK	1.60	0.00			Yes					No	0.92		0.08		Yes
C02,03,20	301020 [d]	3	LOCK	1.59	0.00			Yes					No	1.00		0.09		Yes
H01,05,15	301026	2.6	LOCK	1.57	0.00			Yes					No	0.87		0.08		Yes
C07,08,09	301014 [d]	2.1	LOCK	1.56	0.00			Yes					No	0.94		0.08		Yes
JP-0157	DOJ1-99-0157		PGDP	1.56	4.07	3.11	3.11	No	0.90	0.16	1.80	1.80	No	108.00	1.80	2.95	29.10	Yes
JP-0113	DOJ1-99-0115		PGDP	1.54	1.60	1.68	1.69	No	0.49	0.12	0.97	0.97	No	6.02	0.88	1.33	3.23	Yes
C07,08,09	301016 [d]	2.1	LOCK	1.51	0.00			Yes					No	0.91		0.08		Yes
H04,06,09	301021	0.8	LOCK	1.50	0.00			Yes					No	0.94		0.10		Yes
F12,20,22	301003	1.5	LOCK	1.50	0.00			Yes					No	0.92		0.09		Yes
K008-AIP-RP	030302	0	STLMO	1.49	1.20	0.82		Yes					No	0.76	0.26	0.56		Yes
BC14KYRAD	2010-50539 [a]		KYRAD	1.49	0.68	0.32		Yes	1.94	1.52	0.67		Yes	1.64	0.70	0.40		Yes
JP-0075	DOJ1-99-0075		PGDP	1.48	4.62	2.97	2.97	No	1.24	0.16	2.48	2.48	No	14.80	1.54	2.05	6.04	Yes
194-03,04	301036 [e]	8	LOCK	1.48	0.00			Yes					No	0.80		0.12		Yes
H02,10,18	301027	0.7	LOCK	1.44	0.00			Yes					No	1.00		0.11		Yes
F12,20,22	301002	0.8	LOCK	1.40	0.00			Yes					No	0.93		0.09		Yes
SOU195-014A	2010-51257 [a]	7	KYRAD	1.38	0.70	0.32		Yes	2.12	1.07	0.49		Yes	1.11	0.58	0.38		Yes
JP-0090	DOJ1-99-0090		PGDP	1.37	2.21	2.74	2.74	No	0.77	0.14	1.55	1.55	No	22.00	0.02	0.75	3.30	Yes
OUTFALL10-1	WC02-242	4	PORTS	1.36	0.67	0.68	0.68	No	0.94	0.32	0.22	0.37	No	0.67	0.05	0.12	0.21	Yes
SOU195-014C	2010-51262 [a]	4	KYRAD	1.31	0.79	0.36		Yes	2.30	1.59	0.71		Yes	0.49	0.97	0.46		Yes
JP-0062	DOJ1-99-0062		PGDP	1.31	2.95	2.61	2.61	No	0.71	0.13	1.41	1.41	No	4.01	1.17	1.62	3.02	Yes
F01,21,23	301010	1.6	LOCK	1.26	0.00			Yes					No	0.82		0.08		Yes
SWMU222-4	2010-52458 [a]		KYRAD	1.25	0.48	0.22		Yes					No	1.52	0.44	0.29		Yes
JP-0163	DOJ1-99-0163		PGDP	1.22	2.94	2.45	2.45	No	0.97	0.23	1.93	1.93	No	3.23	1.36	0.78	1.76	Yes
NST2S02	BJC2021SS	3	PGDP	1.20	2.87	2.41	2.41	No	0.64	0.18	1.28	1.28	No	104.00	0.31	3.50	21.00	Yes
194-01,02	301040	6.75	LOCK	1.20	0.00			Yes					No	0.79		0.12		Yes
194-05,06	301050	17.5	LOCK	1.20	0.00			Yes					No	0.71		0.11		Yes
SOU195-014	2010-51255 [a]	10	KYRAD	1.20	0.88	0.36		Yes	1.89	1.50	0.67		Yes	0.74	0.97	0.51		Yes
SOU195-014B	2010-51260 [a]	7	KYRAD	1.17	0.64	0.30		Yes	2.25	0.91	0.43		Yes	0.79	0.56	0.35		Yes
194-05,06	301042	11.5	LOCK	1.17	0.00			Yes					No	0.72		0.11		Yes
H03,07,13	301029	0.7	LOCK	1.10	0.00			Yes					No	1.10		0.12		Yes

Table E.4. Sample Results for Lead-210, Radium-226, and Uranium-238 in Soil and Sediment (Continued)

		Depth	Lab	Lead-210 (pCi/g)					Radium-226 (pCi/g)					Uranium-238 (pCi/g)				
Station	Sample ID	(ft bgs)	Code	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?
H03,07,13	301029	0.7	LOCK	1.10	0.00			Yes					No	1.10				Yes
SOU195-006	2010-51265 [a]	7	KYRAD	1.09	0.73	0.33		Yes	2.13	1.16	0.53		Yes	0.86	0.57	0.34		Yes
SOU195-025	2010-51250 [a]	7	KYRAD	1.09	0.84	0.38		Yes	2.41	1.65	0.73		Yes	1.05	0.72	0.52		Yes
SOU195-014B	2010-51261 [a]	10	KYRAD	1.08	0.96	0.43		Yes	1.46	1.45	0.64		Yes	0.77	0.69	0.44		Yes
SOU200-009	2010-51275 [a]	4	KYRAD	1.08	5.15	2.23		No	1.87	1.32	0.60		Yes	1.08	0.93	0.88		Yes
H02,10,18	301028	3	LOCK	1.07	0.00			Yes					No	0.92		0.08		Yes
JP-0162	DOJ1-99-0162		PGDP	1.05	1.94	2.10	2.10	No	0.84	0.16	1.67	1.67	No	1.63	0.91	0.47	2.29	No
194-03,04	301041 [e]	12	LOCK	1.04	0.00			Yes					No	0.81		0.12		Yes
SOU200-005	2010-51271 [a]	4	KYRAD	1.04	0.89	0.40		Yes	2.15	1.57	0.70		Yes	1.64	0.99	0.64		Yes
SOU195-014C	2010-51263 [a]	7	KYRAD	1.03	1.04	0.46		No	1.73	1.32	0.59		Yes	0.90	0.75	0.45		Yes
SOU195-025	2010-51251 [a]	10	KYRAD	1.02	0.77	0.35		Yes	1.91	1.46	0.66		Yes	1.17	1.07	0.62		Yes
JP-0091	DOJ1-99-0091		PGDP	1.01	2.08	2.02	2.02	No	0.82	0.14	1.64	1.64	No	12.70	1.24	1.72	3.82	Yes
NST1S01	BJC1011SS	2.5	PGDP	1.01	3.31	2.02	2.02	No	0.65	0.19	1.29	1.29	No	65.90	1.87	2.87	18.00	Yes
SOU200-008	2010-51274 [a]	4	KYRAD	1.01	0.70	0.32		Yes	1.88	1.18	0.53		Yes	1.01	0.56	0.32		Yes
H04,06,09	301024	2.6	LOCK	1.00	0.00			Yes					No	0.94		0.09		Yes
OUTFALL10-1	WC02-242D	4	PORTS	0.99	0.63	0.64	0.65	No	0.87	0.29	0.25	0.31	No	0.68	0.07	0.13	0.46	Yes
SOU195-014B	2010-51259 [a]	4	KYRAD	0.99	0.92	0.41		Yes	1.62	1.32	0.59		Yes	0.93	0.99	0.56		Yes
JP-0018	DOJ1-99-0016		PGDP	0.96	4.68	1.92	2.81	No	0.64	0.14	1.28	1.28	No	188.00	0.05	2.30	32.00	Yes
OUTFALL10-2	WC02-243	4	PORTS	0.96	0.68	0.63	0.64	No	0.82	0.31	0.28	0.31	No	0.63	0.02	0.13	0.21	Yes
SOU200-006	2010-51272 [a]	4	KYRAD	0.95	0.66	0.30		Yes	2.67	1.09	0.51		Yes	0.94	0.57	0.38		Yes
SOU200-001	2010-51267 [a]	4	KYRAD	0.94	0.83	0.37		Yes	2.73	1.33	0.61		Yes	1.06	0.70	0.39		Yes
SOU200-010	2010-51276 [a]	4	KYRAD	0.89	0.94	0.42		No	1.75	1.47	0.65		Yes	0.76	0.69	0.36		Yes
SOU195-006	2010-51266 [a]	10	KYRAD	0.88	0.78	0.35		Yes	1.98	1.52	0.68		Yes	1.51	0.98	0.63		Yes
JP-0081	DOJ1-99-0081		PGDP	0.87	1.43	1.75	1.75	No	0.61	0.11	1.22	1.22	No	3.60	0.01	0.17	0.47	Yes
SOU200-003	2010-51269 [a]	4	KYRAD	0.86	0.92	0.41		No	2.22	1.27	0.57		Yes	0.74	0.69	0.50		Yes
JP-0015	DOJ1-99-0013		PGDP	0.81	1.66	1.62	1.62	No	0.62	0.13	1.23	1.23	No	3.16	0.82	1.25	1.99	Yes
H03,07,13	301030	3	LOCK	0.80	0.00			Yes					No	0.83		0.08		Yes
NST1S03	BJC1031SS	12	PGDP	0.79	1.55	1.59	1.59	No	0.80	0.18	1.60	1.60	No	0.66	0.04	0.11	0.13	Yes
JP-0080	DOJ1-99-0080		PGDP	0.73	1.91	1.46	1.46	No	0.82	0.15	1.64	1.64	No	2.39	0.94	0.47	3.33	No
SOU195-014	2010-51254 [a]	7	KYRAD	0.71	0.74	0.33		No	1.72	1.50	0.66		Yes	0.54	0.70	0.44		Yes
LBC2L005	LBCSOSU2S1-01	1	STLMO	0.70	2.20		1.30	No	1.40	0.15		0.30	Yes	3.12	16.80	9.24		No
SOU200-007	2010-51273 [a]	4	KYRAD	0.69	0.78	0.35		No	2.12	1.68	0.75		Yes	1.16	0.90	0.41		Yes
JP-0110	DOJ1-99-0110		PGDP	0.67	8.67	1.34	5.33	No	0.81	0.19	1.61	1.61	No	626.00	4.72	8.10	168.00	Yes
SOU200-002	2010-51268 [a]	4	KYRAD	0.65	0.62	0.28		Yes	2.10	0.94	0.44		Yes	1.08	0.56	0.33		Yes
JP-0057	DOJ1-99-0057		PGDP	0.65	1.60	1.30	1.30	No	0.28	0.09	0.56	0.56	No	7.97	0.78	1.14	4.06	Yes
JP-0097	DOJ1-99-0097		PGDP	0.62	1.70	1.25	1.25	No	0.76	0.13	1.52	1.52	No	2.58	0.77	1.04	3.71	No
JP-0066	DOJ1-99-0066		PGDP	0.60	2.87	1.21	1.85	No	0.85	0.14	1.70	1.70	No	4.81	1.22	1.63	3.47	Yes
JP-0082	DOJ1-99-0082		PGDP	0.60	2.74	1.20	1.67	No	1.29	0.18	2.58	2.58	No	20.00	0.02	0.75	3.30	Yes
194-03,04	301046 [e]	21	LOCK	0.60	0.00			Yes					No	1.18		0.16		Yes
JP-0061	DOJ1-99-0061		PGDP	0.60	2.19	1.20	1.41	No	0.33	0.08	0.66	0.66	No	6.32	0.76	1.00	0.16	Yes
JP-0013	DOJ1-99-0011		PGDP	0.55	2.26	1.11	1.36	No	0.83	0.15	1.66	1.66	No	17.30	0.97	1.38	4.86	Yes
JP-0063	DOJ1-99-0063		PGDP	0.54	2.50	1.09	1.64	No	0.65	0.12	1.29	1.29	No	1.00	0.01	0.10	0.16	Yes
JP-0087	DOJ1-99-0088		PGDP	0.47	5.67	0.94	3.46	No	0.77	0.13	1.54	1.54	No	138.00	2.54	4.19	53.00	Yes

Table E.4. Sample Results for Lead-210, Radium-226, and Uranium-238 in Soil and Sediment (Continued)

		Depth	Lab	Lead-210 (pCi/g)					Radium-226 (pCi/g)					Uranium-238 (pCi/g)				
Station	Sample ID	(ft bgs)	Code	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?	Results	MDA	Rad Error	TPU	Detect?
A10	PLDJNSA10-02SO	8.5	PGDP	0.34	5.70	0.69	3.60	No	0.49	0.12	0.98	0.98	No	1.91	0.79	0.42	3.26	No
ISOCSOFFST	ISOCSBKGR08-01	0	PGDP	0.34	1.04	0.68	0.68	No					No	1.58	0.47	0.25	0.33	Yes
NST2S03	BJC2031SS	15	PGDP	0.31	2.30	0.61	1.39	No	0.99	0.19	1.98	1.98	No	19.80	0.08	0.79	3.00	Yes
JP-0112	DOJ1-99-0114		PGDP	0.27	1.38	0.54	0.85	No	0.67	0.11	1.34	1.34	No	7.50	0.01	0.37	1.10	Yes
JP-0060	DOJ1-99-0060		PGDP	0.22	2.13	0.44	1.40	No	0.13	0.04	0.16	0.26	No	8.24	0.85	1.26	3.40	Yes
C01,10,24	301018 [d]	2.8	LOCK	0.20	0.00			Yes					No	1.03		0.09		Yes
NST2S05	BJC2052SS	12.5	PGDP	0.17	1.28	0.35	0.78	No	0.52	0.14	1.03	1.03	No	1.21	0.20	0.32	1.70	No
JP-0100	DOJ1-99-0100		PGDP	0.09	1.44	0.18	0.89	No	0.72	0.12	1.44	1.44	No	1.48	0.67	0.39	2.08	No
NST1S02	BJC1021SS	2.5	PGDP	0.06	2.53	0.13	1.54	No	0.57	0.19	1.15	1.15	No	29.70	1.38	2.18	8.27	Yes
JP-0016	DOJ1-99-0014		PGDP	0.00	1.81	0.01	1.10	No	0.57	0.12	1.13	1.13	No	8.80	0.04	0.35	1.20	Yes
196-01,02	301037	7	LOCK	0.00 [f]	0.00			No					No	0.82		0.12		Yes
JP-0164	DOJ1-99-0164		PGDP	-0.01	1.86	0.01	1.15	No	0.69	0.15	1.38	1.38	No	1.84	0.92	0.45	2.57	No
NST2S01	BJC2011SS	2	PGDP	-0.13	1.73	0.25	1.06	No	0.57	0.16	1.14	1.14	No	8.11	0.91	1.35	2.56	Yes
JP-0045	DOJ1-99-0045		PGDP	-0.29	2.68	0.58	1.76	No	0.58	0.12	1.15	1.15	No	6.00	0.01	0.23	0.77	Yes
JP-0016	DOJ1-99-0014DUP		PGDP	-0.29	1.76	0.59	1.08	No	0.52	0.12	1.05	1.05	No	11.00	0.02	0.37	1.40	Yes
JP-0087	DOJ1-99-0087		PGDP	-0.43	5.27	0.86	3.23	No	0.65	0.12	1.30	1.30	No	126.00	2.33	3.83	48.30	Yes
JP-0071	DOJ1-99-0071		PGDP	-0.75	5.45	1.50	3.40	No	2.78	0.26	5.56	5.56	No	19.00	1.98	2.46	7.68	Yes
BGS194-04	301049	24	LOCK	-0.80	0.01			No					No	0.76		0.12		Yes
JP-0085	DOJ1-99-0085		PGDP	-0.86 [f]	6.72	1.72	4.14	No	0.80	0.15	1.60	1.60	No	160.00	3.01	5.07	61.80	Yes
F05,07,17	301007	1	LOCK	-1.10 [f]	0.00			No					No	0.93		0.08		Yes
A10	PLDJNSA10-03SO	9	PGDP	-1.20	31.00	2.50	18.00	No	0.14	0.20	0.00	0.06	No	326.00	4.61	7.56	125.00	Yes
JP-0072	DOJ1-99-0072		PGDP	-1.31	9.10	2.62	5.58	No	6.88	0.41	13.75	13.75	No	87.00	0.24	2.80	21.00	Yes
JP-0111	DOJ1-99-0112		PGDP	-1.99	6.10	3.99	3.99	No	0.84	0.17	1.69	1.69	No	317.00	0.67	11.00	68.00	Yes
JP-0076	DOJ1-99-0076		PGDP	-2.04	6.16	4.07	4.07	No	2.19	0.23	4.38	4.38	No	69.00	2.28	3.26	26.70	Yes
NST2S05	BJC2051SS	12.5	PGDP	-2.12	12.77	4.25	7.90	No	5.15	1.39	10.30	10.30	No	11.10	1.90	3.14	4.33	Yes
JP-0077	DOJ1-99-0077		PGDP	-2.71	5.02	5.42	5.42	No	1.47	0.17	2.94	2.94	No	56.00	0.21	1.80	11.00	Yes
A2	PLDJNSA2-01SO	8.5	PGDP	-2.90	6.20	5.80	5.80	No	0.65	0.14	1.30	1.30	No	1.24	0.26	0.44	2.14	No
JP-0152	DOJ1-99-DUP1		PGDP	-2.91	6.47	5.83	5.83	No	0.87	0.13	1.73	1.73	No	393.00	0.69	12.00	120.00	Yes
JP-0111	DOJ1-99-0111		PGDP	-2.99	6.03	5.98	5.98	No	0.91	0.17	1.81	1.81	No	365.00	0.13	4.50	63.00	Yes
JP-0151	DOJ1-99-0151		PGDP	-4.78	8.89	9.57	9.57	No	0.54	0.13	1.07	1.07	No	365.00	3.25	5.42	140.00	Yes
JP-0150	DOJ1-99-0150		PGDP	-10.07	12.75	20.14	20.14	No	0.79	0.18	1.58	1.58	No	599.00	4.88	8.14	230.00	Yes
JP-0153	DOJ1-99-0153		PGDP	-19.47	14.31	38.93	38.93	No	0.32	0.17	0.64	0.64	No	1921.00	3.50	50.00	617.00	Yes

Yellow shading indicates sample analysis by the Kentucky Radiation Health Branch Laboratory.
Blue shading indicates a detected lead-210 result for samples other than those analyzed by the Kentucky Radiation Health Branch.
TPU = total propagated uncertainty
Lab Codes are the following: LOCK = Lockheed Engineering & Science Co., Las Vegas, NV; KYRAD = Kentucky Radiation Health Branch; PGDP = USEC-Paducah Gaseous Diffusion Plant; PORTS = USEC-Portsmouth Plant; STLMO = Severn Trent, Earth City, Missouri
[a] The uranium-238 results was reported by the lab as thorium-234/uranium-238.
[b] The maximum uranium-238 result was used for comparison.
[c] This sample is not plotted in Figure 2, the coordinates place the sample in Illinois. The available coordinates are likely incorrect.
[d] This sample is not plotted in Figure 2, no coordinates are available.
[e] This sample is not plotted in Figure 2, the coordinates place the sample in Ballard County, which is outside the scale of the map.
[f] This results is set as a nondetect because the reported result is less than the minimum detectable activity (MDA).

Table E.5. Results of Filtering

Method	Chemical	Date Collected	MDA	Lab Code	Lab Sample ID	Media	Rad Error	Result	Lab Qualifier	Station	Units	Val Qualifier	Greater Than DL	Less Than DL	Pass cut
DNT	Lead-210	7/31/2006	152.1	KYRAD	2006-51812	SW	133.1	529.9		A-Composite	pCi/L	X	529.9		529.9
DNT	Lead-210	7/21/2004	139	KYRAD	2004-51807	SW	120.4	557.4		A-Composite	pCi/L	=	557.4		557.4
DNT	Lead-210	7/9/2003	86.13	KYRAD	2003-06373	SW	77.85	213.2		A-Composite	pCi/L	=	213.2		213.2
DNT	Lead-210	12/8/2006	141.6	KYRAD	2006-53149	SW	156.5	1469		A-Composite	pCi/L	X	1469		1469
DNT	Lead-210	7/18/2005	96.2	KYRAD	2005-51647	SW	176.1	661.4		A-Composite	pCi/L	X	661.4		661.4
DNT	Lead-210	5/26/2006	116	KYRAD	2006-51119	SW	126.8	1605		A-Composite	pCi/L	X	1605		1605
Gamma Spec	Lead-210	2/2/2007	159.2	KYRAD	2007-50161	SW	276.5	692.8	U	A-Composite	pCi/L	U	692.8		692.8
DNT	Lead-210	10/27/2005	105.5	KYRAD	2005-52609	SW	124.9	1707		A-Composite	pCi/L	X	1707		1707
Gamma Spec	Lead-210	6/4/2007	174.2	KYRAD	2007-51252	SW	107	1284		A-Composite	pCi/L	=	1284		1284
DNT	Lead-210	10/13/2004	99.77	KYRAD	2004-52643	SW	143.4	309.4		C-Composite	pCi/L	=	309.4		309.4
DNT	Lead-210	3/9/2005	173.9	KYRAD	2005-50440	SW	189.5	2593		C-Composite	pCi/L	=	2593		2593
DNT	Lead-210	5/11/2005	144.7	KYRAD	2005-51034	SW	82.96	514		A-Composite	pCi/L	X	514		514
DNT	Lead-210	6/9/2004	147.5	KYRAD	2004-51367	SW	77.57	1714		A-Composite	pCi/L	=	1714		1714
Gamma Spec	Lead-210	4/3/2007	180.9	KYRAD	2007-50606	SW	97.97	1719	U	A-Composite	pCi/L	U	1719		1719
Gamma Spec	Lead-210	11/19/2007	168	KYRAD	2007-52795	SW	123.9	274.7	J	A-Composite	pCi/L	J	274.7		274.7
DNT	Lead-210	1/10/2005	138.2	KYRAD	2005-50023	SW	147.8	1210		C-Composite	pCi/L	X	1210		1210
Gamma Spec	Lead-210	2/22/2007	275.7	KYRAD	2007-50293	SW	160.8	2222	U	C-Composite	pCi/L	U	2222		2222
DNT	Lead-210	1/3/2006	299	KYRAD	2005-53157	SW	285.5	881.4		C-Composite	pCi/L	X	881.4		881.4
DNT	Lead-210	3/9/2005	173.9	KYRAD	2005-50440	SW	189.5	2593		C-Composite	pCi/L	X	2593		2593
DNT	Lead-210	12/20/2004	173.3	KYRAD	2004-53235	SW	237	832.2		C-Composite	pCi/L	=	832.2		832.2
Gamma Spec	Lead-210	4/25/2007	128.9	KYRAD	2007-50839	SW	138.1	1185		C-Composite	pCi/L	=	1185		1185
DNT	Lead-210	12/14/2006	533.1	KYRAD	2006-53330	SW	283.4	3222	U	ATC746K	pCi/L	X	3222		3222
DNT	Lead-210	9/11/2006	149.7	KYRAD	2006-52207	SW	130.7	594		B-Composite	pCi/L	X	594		594
Gamma Spec	Lead-210	6/25/2007	154.2	KYRAD	2007-51454	SW	85.39	1936	U	B-Composite	pCi/L	U	1936		1936
DNT	Lead-210	9/22/2004	112.7	KYRAD	2004-52430	SW	121.2	368.1		B-Composite	pCi/L	=	368.1		368.1
DNT	Lead-210	10/13/2004	146.1	KYRAD	2004-52679	SW	126.1	664.9		D2-Composite2	pCi/L	=	664.9		664.9
DNT	Lead-210	12/24/2003	80.3	KYRAD	2003-08104	SW	79.66	233		D2-Composite2	pCi/L	=	233		233
DNT	Lead-210	3/2/2006	67	KYRAD	2006-50341	SW	43.39	102.5		B-Composite	pCi/L	X	102.5		102.5
Gamma Spec	Lead-210	4/3/2007	183.7	KYRAD	2007-50628	SW	95.3	2502	U	B-Composite	pCi/L	U	2502		2502
DNT	Lead-210	7/18/2005	129.3	KYRAD	2005-51670	SW	96.29	1306		B-Composite	pCi/L	X	1306		1306
DNT	Lead-210	1/10/2005	225.3	KYRAD	2005-50022	SW	113.8	3492		B-Composite	pCi/L	X	3492		3492
DNT	Lead-210	8/31/2004	106.9	KYRAD	2004-52253	SW	92.05	604.6		D-Composite	pCi/L	=	604.6		604.6
DNT	Lead-210	6/30/2004	138.7	KYRAD	2004-51697	SW	127.6	575.8		D2-Composite2	pCi/L	=	575.8		575.8
DNT	Lead-210	10/27/2005	115.4	KYRAD	2005-52720	SW	122.4	1419		F-Composite	pCi/L	X	1419		1419
Gamma Spec	Lead-210	11/29/2010	1.61	KYRAD	2010-53281	SW	0.894	974	U	C-613	pCi/L	U	974		974
DNT	Lead-210	11/17/2005	152.4	KYRAD	2005-52866	SW	106.8	1269		D-Composite	pCi/L	X	1269		1269
Gamma Spec	Lead-210	2/2/2007	126.9	KYRAD	2007-50240	SW	224.8	490.7	U	F-Composite	pCi/L	U	490.7		490.7
DNT	Lead-210	12/13/2006	532.5	KYRAD	2006-53325	SW	282.9	3226	U	BBCDG	pCi/L	X	3226		3226
DNT	Lead-210	10/27/2005	2017	KYRAD	2005-52676	SW	2740	9532		D1-Composite	pCi/L	X	9532		9532
DNT	Lead-210	9/14/2005	130.7	KYRAD	2005-52307	SW	55.96	169.4		D1-Composite	pCi/L	X	169.4		169.4
DNT	Lead-210	12/13/2006	5867	KYRAD	2006-53326	SW	3802	7905	U	BBCROSS	pCi/L	X	7905		7905
DNT	Lead-210	7/5/2006	315.2	KYRAD	2006-51734	SW	293.3	612.9	R	BBCUG	pCi/L	X	612.9		612.9
DNT	Lead-210	8/25/2005	592.4	KYRAD	2005-52201	SW	312.6	3755		BBCUG	pCi/L	X	3755		3755

Table E.5. Results of Filtering (Continued)

Method	Chemical	Date Collected	MDA	Lab Code	Lab Sample ID	Media	Rad Error	Result	Lab Qualifier	Station	Units	Val Qualifier	Greater Than DL	Less Than DL	Pass cut
DNT	Lead-210	12/8/2006	141.1	KYRAD	2006-53231	SW	155.1	1554		D1-Composite	pCi/L	X	1554		1554
Gamma Spec	Lead-210	6/4/2007	171.1	KYRAD	2007-51333	SW	99.26	406.2		D1-Composite	pCi/L	=	406.2		406.2
DNT	Lead-210	8/13/2004	135.7	KYRAD	2004-52111	SW	137.5	621.3		F-Composite	pCi/L	=	621.3		621.3
Gamma Spec	Lead-210	11/29/2010	51.1	KYRAD	2010-53280	SW	23.7	230	U	K001	pCi/L	U	230		230
DNT	Lead-210	1/26/2005	152	KYRAD	2005-50163	SW	150	482.9		F-Composite	pCi/L	X	482.9		482.9
DNT	Lead-210	1/26/2005	152	KYRAD	2005-50163	SW	150	482.9		F-Composite	pCi/L	=	482.9		482.9
DNT	Lead-210	7/16/2002	437.6	KYRAD	2002-06663	SW	256.7	27660		D2-Composite	pCi/L	=	27660		27660
DNT	Lead-210	9/14/2005	110.6	KYRAD	2005-52329	SW	55.95	146.3		D2-Composite	pCi/L	X	146.3		146.3
DNT	Lead-210	11/20/2006	267.2	KYRAD	2006-53106	SW	283.2	843		G-Composite	pCi/L	X	843		843
DNT	Lead-210	12/22/2006	230.8	KYRAD	2006-53421	SW	148.8	2500		G-Composite	pCi/L	X	2500		2500
DNT	Lead-210	8/31/2004	107.1	KYRAD	2004-52318	SW	90.23	526		G-Composite	pCi/L	=	526		526
DNT	Lead-210	7/31/2006	150.7	KYRAD	2006-51871	SW	132.9	446.9		D2-Composite	pCi/L	X	446.9		446.9
DNT	Lead-210	11/20/2006	113.4	KYRAD	2006-53074	SW	73.27	265.4		D2-Composite	pCi/L	X	265.4		265.4
DNT	Lead-210	7/21/2004	137.2	KYRAD	2004-51947	SW	144	342.6		G-Composite	pCi/L	=	342.6		342.6
DNT	Lead-210	5/26/2006	159.3	KYRAD	2006-51229	SW	79.65	2701		D2-Composite	pCi/L	X	2701		2701
DNT	Lead-210	8/25/2005	599	KYRAD	2005-52191	SW	424.1	1900		K010	pCi/L	X	1900		1900
DNT	Lead-210	6/1/2005	237.4	KYRAD	2005-51358	SW	260.6	1634		G-Composite	pCi/L	X	1634		1634
Gamma Spec	Lead-210	4/3/2007	182	KYRAD	2007-50729	SW	96.81	2054	U	G-Composite	pCi/L	U	2054		2054
DNT	Lead-210	12/14/2006	537.4	KYRAD	2006-53312	SW	285.4	3298	U	K011	pCi/L	X	3298		3298
DNT	Lead-210	6/16/2005	539.3	KYRAD	2005-51401	SW	366.8	865.9		K012	pCi/L	X	865.9		865.9
DNT	Lead-210	8/23/2005	589.5	KYRAD	2005-52186	SW	491.7	2210		L14	pCi/L	X	2210		2210
DNT	Lead-210	12/14/2006	539.1	KYRAD	2006-53316	SW	286.2	3332	U	K015	pCi/L	X	3332		3332
Gamma Spec	Lead-210	11/29/2010	685	KYRAD	2010-53280	SW	274	4070	U	L4	pCi/L	U	4070		4070
DNT	Lead-210	12/14/2006	7379	KYRAD	2006-53321	SW	4801	11210	U	LBC@McCaw	pCi/L	X	11210		11210
Gamma Spec	Lead-210	5/11/2010	0.838952	KYRAD	2010-51250	SO	0.375929	1.0877436		SOU195-025	pCi/g	=			
Gamma Spec	Lead-210	5/11/2010	0.774856	KYRAD	2010-51251	SO	0.352924	1.0153096		SOU195-025	pCi/g	=			
Gamma Spec	Lead-210	5/11/2010	0.622129	KYRAD	2010-51252	SO	0.323104	2.7034682		SOU195-120C	pCi/g	=			
Gamma Spec	Lead-210	5/11/2010	9.25275	KYRAD	2010-51253	SO	3.831	6.5693666	U	SOU195-120A	pCi/g	U			
Gamma Spec	Lead-210	5/12/2010	0.738264	KYRAD	2010-51254	SO	0.327648	0.7087367	U	SOU195-014	pCi/g	U			
Gamma Spec	Lead-210	5/12/2010	0.87614	KYRAD	2010-51255	SO	0.357205	1.1963452		SOU195-014	pCi/g	=			
Gamma Spec	Lead-210	5/12/2010	5.00644	KYRAD	2010-51256	SO	2.14186	1.8868582	U	SOU195-014A	pCi/g	U			
Gamma Spec	Lead-210	5/12/2010	0.69731	KYRAD	2010-51257	SO	0.323468	1.3837602		SOU195-014A	pCi/g	=			
Gamma Spec	Lead-210	5/12/2010	5.07442	KYRAD	2010-51258	SO	2.12668	3.5576405	U	SOU195-014A	pCi/g	U			
Gamma Spec	Lead-210	5/12/2010	0.919572	KYRAD	2010-51259	SO	0.410998	0.9908741		SOU195-014B	pCi/g	=			
Gamma Spec	Lead-210	5/12/2010	0.643217	KYRAD	2010-51260	SO	0.297765	1.1705553		SOU195-014B	pCi/g	=			
Gamma Spec	Lead-210	5/12/2010	0.963233	KYRAD	2010-51261	SO	0.42696	1.0807067		SOU195-014B	pCi/g	=			
Gamma Spec	Lead-210	5/12/2010	0.786643	KYRAD	2010-51262	SO	0.364651	1.3145335		SOU195-014C	pCi/g	=			
Gamma Spec	Lead-210	5/12/2010	1.03762	KYRAD	2010-51263	SO	0.457097	1.0294589	U	SOU195-014C	pCi/g	U			
Gamma Spec	Lead-210	5/12/2010	5.28305	KYRAD	2010-51264	SO	2.15693	6.0068083	J	SOU195-014C	pCi/g	J			
Gamma Spec	Lead-210	5/12/2010	0.727831	KYRAD	2010-51265	SO	0.330025	1.0930592		SOU195-006	pCi/g	=			
Gamma Spec	Lead-210	5/12/2010	0.779156	KYRAD	2010-51266	SO	0.351511	0.8835402		SOU195-006	pCi/g	=			
Gamma Spec	Lead-210	5/5/2010	0.832552	KYRAD	2010-51267	SO	0.370699	0.9368339		SOU200-001	pCi/g	=			
Gamma Spec	Lead-210	5/5/2010	0.616779	KYRAD	2010-51268	SO	0.276128	0.6544536		SOU200-002	pCi/g	=			

Table E.5. Results of Filtering (Continued)

Method	Chemical	Date Collected	MDA	Lab Code	Lab Sample ID	Media	Rad Error	Result	Lab Qualifier	Station	Units	Val Qualifier	Greater Than DL	Less Than DL	Pass cut
Gamma Spec	Lead-210	5/5/2010	0.918867	KYRAD	2010-51269	SO	0.405092	0.8584913	U	SOU200-003	pCi/g	U			
Gamma Spec	Lead-210	5/5/2010	0.894012	KYRAD	2010-51271	SO	0.401519	1.0366496		SOU200-005	pCi/g	=			
Gamma Spec	Lead-210	5/5/2010	0.662666	KYRAD	2010-51272	SO	0.300982	0.9515829		SOU200-006	pCi/g	=			
Gamma Spec	Lead-210	5/5/2010	0.777267	KYRAD	2010-51273	SO	0.346092	0.6884684	U	SOU200-007	pCi/g	U			
Gamma Spec	Lead-210	5/5/2010	0.695554	KYRAD	2010-51274	SO	0.31533	1.0058769		SOU200-008	pCi/g	=			
Gamma Spec	Lead-210	5/5/2010	5.14907	KYRAD	2010-51275	SO	2.22839	1.0775268	U	SOU200-009	pCi/g	U			
Gamma Spec	Lead-210	5/5/2010	0.942465	KYRAD	2010-51276	SO	0.415427	0.8905683	U	SOU200-010	pCi/g	U			
Gamma Spec	Lead-210	4/27/2010	0.590492	KYRAD	2010-51277	SO	0.763757	2.571285		SOU222-001	pCi/g	=			
Gamma Spec	Lead-210	9/2/2010	0.816	KYRAD	2010-52457	SO	0.406	4.92		SWMU222-1	pCi/g	=			
Gamma Spec	Lead-210	9/2/2010	0.475	KYRAD	2010-52458	SO	0.221	1.25		SWMU222-4	pCi/g	=			
Gamma Spec	Lead-210	11/4/2010	1.71	KYRAD	2010-53090	SO	0.869	8.44		SWMU222-1	pCi/g	=			
Gamma Spec	Lead-210	11/4/2010	1.41	KYRAD	2010-53091	SO	0.709	6.98		SWMU222-2	pCi/g	=			
Gamma Spec	Lead-210	11/4/2010	1.14	KYRAD	2010-53092	SO	0.607	6.81		SWMU222-3	pCi/g	=			
Gamma Spec	Lead-210	11/4/2010	2.05	KYRAD	2010-53093	SO	1.03	10.6		SWMU222-4	pCi/g	=			
Gamma Spec	Lead-210	11/4/2010	1.47	KYRAD	2010-53094	SO	0.757	8.6		SWMU222-5	pCi/g	=			
Gamma Spec	Lead-210	5/11/2010	0.838952	KYRAD	2010-51250	SO	0.375929	1.0877436		SOU195-025	pCi/g	=			
Gamma Spec	Lead-210	5/11/2010	0.774856	KYRAD	2010-51251	SO	0.352924	1.0153096		SOU195-025	pCi/g	=			
Gamma Spec	Lead-210	5/11/2010	0.622129	KYRAD	2010-51252	SO	0.323104	2.7034682		SOU195-120C	pCi/g	=			

DNT = Analytical methods was not transmitted.
Gamma Spec = Gamma Spec
KYRAD = Kentucky Radiation Health Branch Laboratory
SW = surface water
X = no 3rd party validation was performed
U = not detected above the MDA
R = result rejected
"=" = result accepted by 3rd party validation

Lead-210 is the daughter of polonium-214 that is a member of the uranium-238 decay chain. Lead-210 is reported at background levels of 1-2 pCi/g in at least one facility (http://www.lrb.usace.army.mil/Portals/45/docs/FUSRAP/DaytonIII/day3-si-2004-12.pdf, Table 2). Please see Tables E.4 and E.5 for the Kentucky Radiation Health Branch (RHB) lead-210 analysis. Only data with a sample specific minimum detectable concentration (MDC) of less than 1 pCi/g were included in the analysis. Based on the data provided by the RHB for lead-210, the background would be in the 1-2 pCi/g range for lead-210 at PGDP.

The no action levels [i.e., 1E-6 values calculated using Risk Assessment Information System (RAIS) and Paducah-specific parameters] are as follows:

- Resident—0.661 pCi/g,
- Industrial worker—7.62 pCi/g, and
- Outdoor worker—1.08 pCi/g.

Based on information provided by TestAmerica to LATA Environmental Services of Kentucky, LLC, the MDC obtained by liquid scintillation (LS) is approximately 5 pCi/g. TestAmerica indicates this is the target MDC by LS; however, this MDC can be lower, if necessary. TestAmerica's target MDC by gamma spectroscopy is the same, 5 pCi/g, but it could vary. TestAmerica indicates that "Lead-210 is a low energy radionuclide on the gamma spec and there could be interferences from other radionuclides and samples with sufficient activity. This could raise the MDA."

Soil analysis by the Kentucky RHB using gamma spectroscopy and a thin window high purity germanium (HPGe) detector, however, achieved an MDC of approximately 1 pCi/g for lead-210 (employing the 46 KeV line for lead-210). Using gamma spectroscopy with the appropriate thin window HPGe detector an MDC of 1 pCi/g is achievable without interference from other radionuclides. In fact, lead-210 is used in calibration standards for thin window HPGe detectors. Gamma spectroscopy, using these thin window HPGe detectors and incorporation of lead-210 into the calibration standard, provides a significant improvement in efficiency in the region less than 59 KeV. Because the analysis of lead-210 by gamma spectroscopy uses the 46 KeV line energy, thin window HPGe detectors are the preferred detectors for analysis of lead-210 by gamma spectroscopy. Achieving a 1 pCi/g MDC for soil analysis is fully supported by the Kentucky RHB data for lead-210 analysis. Because there is no requirement for sample dissolution and separation from other radionuclides, gamma spectroscopy using a thin window HPGe detector would be the preferred method for analysis of lead-210 in soil.

Because analysis of lead-210 by LS requires dissolution of the media in this case soil, it would be preferable to use gamma spectroscopy in order to eliminate concerns regarding complete dissolution of the sample.

With the equipment used by the United States Enrichment Corporation (USEC) laboratory, gamma spectroscopy analysis for lead-210 was not possible because the two primary energy lines are below the analytical laboratory normal energy calibration range. It would require the purchase of a new calibration mixture to include the Pb-210 lines at 46 KeV. The analytical laboratory only has one manual detector that can measure in the x-ray region, so output would be limited.

Lead-210 was included as part of the standard gamma scan for radiological analysis by TestAmerica during the Soils OU project. The MDC for lead-210 was approximately 30 pCi/g. This MDC is protective of a worker at a risk of 1E-5.

The ingrowth of lead-210 from uranium-238 is blocked at uranium-234. Due to the long ingrowth period from uranium-234 to lead-210, it is unlikely that, at the present time, ingrowth of lead-210 from the uranium used in the uranium enrichment processes at PGDP contributes to presence of lead-210 as a potential contaminant/risk at PGDP.

Independent analysis of lead-210 is not necessary on a routine basis. The need for the analysis of radionuclides, such as lead-210, not related to natural uranium and recycled uranium enrichment by the gaseous diffusion process at PGDP should be assessed on project by project basis.

[1] EPA 2012. *Lead-210*, accessed from http://www.epa.gov/radiation/glossary/termjklm.html in 2012.

USGS 2012. *^{210}Pb (lead 210) Dating*, accessed from http://gec.cr.usgs.gov/archive/lacs/lead.htm in 2012.

E.7. PAH CONTAMINATION AND ESTABLISHMENT OF REMEDIAL GOALS

E.7.1. IDENTIFICATION OF THE PROBLEM

Due to the nature of polycyclic aromatic hydrocarbons (PAHs), as described in the Toxicological Profile for PAHs,[1] the presence of PAHs in PGDP in some soils and sediments (e.g., along roads, including roadside ditches, and around buildings) may not be directly related to PGDP releases, but rather from other on- or off-site site activities, including airborne deposition of PAHs that result from the incomplete burning of oil, gas, wood, garbage, or other organic substances or deposition due to the use of rubber, asphalt, crude oil, coal tar, creosote, and roofing tar. The most common source of PAHs in the environment currently is deposition of automobile exhaust.[2] Thus, in evaluating risk/hazard at PGDP SWMUs/areas of concern under the FFA, there is a potential for PAHs not associated with PGDP releases to be identified as a risk driver, potentially leading to the development of disagreements on appropriate cleanup decisions.[3]

The on-site Surface Water Operable Unit (SWOU) contaminated sediment project provides an example of the aforementioned problems. As discussed in the SWOU (on-site) contaminated sediment Engineering Evaluation/Cost Analysis (EE/CA), [9] PAHs were determined not to be good candidates to verify cleanup because PAHs were detected above cleanup criteria at random locations due to their sources. To address PAH contamination in on-site sediments, other contaminants of concern (COCs) found to be co-located with PAHs [i.e., polychlorinated biphenyls (PCBs) and uranium] were used to verify cleanup.

E.7.2. DISCUSSION

Varying approaches have been used to address the presence of PAHs as risk drivers by DOE. At the Oak Ridge Reservation, an early document proposed that DOE manage PAHs as if they were wholly associated with background;[4] however, currently at the Oak Ridge Reservation, PAHs are being addressed on a case-by-case basis and anthropogenic sources are considered. At the Portsmouth Gaseous Diffusion Plant,[2] DOE proposed remediation of PAHs in areas where (1) the source has been determined to be contributed to by past plant operations or treatment, storage, and disposal activities; and (2) concentrations are sufficiently high that the acceptable risk range of 1E-4 to 1E-6 is exceeded.[5]

Commonwealth of Kentucky guidance indicates that parking lots, paved areas, areas within 3 ft of a roadway, railroad tracks, railway areas, storm drains, or ditches presently or historically receiving industrial or urban runoff should not be sampled when determining background, in part due to the potential for PAHs to be present in these areas.[3,6] Kentucky Revised Statutes exclude emissions from the engine exhaust of a motor vehicle from the definition of a release;[7] therefore, remediation of the widespread low concentrations of PAHs, when linked to such sources (e.g., automobile exhaust and asphalt), should not be considered.

As part of the baseline human health risk assessment (BHHRA) process at PGDP, the potential risks posed by PAHs are included in the quantitative BHHRA. In evaluating methods to address unacceptable risk/hazard, the nature of the PAHs and the potential non-PGDP sources will be considered as uncertainties when identifying risk drivers requiring action and when analyzing alternatives to manage site risk. This evaluation will include consideration of the following:

- PAHs are a group of chemicals formed during the incomplete burning of coal, oil, gas, wood, garbage, or other organic substances. PAHs are constituents of rubber, asphalt, coal, crude oil, coal tar, creosote, and roofing tar.

- PAH media concentrations in some areas (e.g., along roads and in roadside ditches) may increase over time in the absence of identifiable releases from PGDP processes.

- PAHs currently in the environment will degrade over time; however, the rate of degradation is unknown and depends upon the site conditions, including the medium in which PAHs are present and the location of the environmental medium.

Of the PAH chemicals considered to be carcinogenic, benzo(a)pyrene is believed to be the most potent. In a database search at PGDP in October 2017, there were 563 detected benzo(a)pyrene results, out of 5,224 analyzed environmental soil and sediment samples. Table E.6 summarizes these benzo(a)pyrene results and indicates that the highest concentrations of the PAH are in surface soils.

Table E.6. Maximum Benzo(a)pyrene Concentrations by Sample Depth

Sample Depth (ft)	Maximum Benzo(a)pyrene Concentration (mg/kg)
0-1	6,100
2-4	3.9
4-8	8.6
8-12	0.95
>12	0.98

Toxicity equivalence factors (TEFs) are used to calculate Total PAHs.[8] The method to calculate Total PAHs using TEFs is described in Section 3.3.3.2 (Step 8) of the Paducah Risk Methods Document. As described there, detected concentrations of each carcinogenic PAH in each sample are multiplied by the carcinogenic PAH's TEF. Also, for carcinogenic PAHs not detected in a sample, the minimum detection limit for the PAH is multiplied by the carcinogenic PAH's TEF. The products for detected and non-detected PAHs are then summed to derive Total PAHs. The carcinogenic PAHs considered in these calculations are benzo(a)pyrene; benz(a)anthracene; benzo(b)fluoranthene; benzo(k)fluoranthene; chrysene; dibenz(a,h)anthracene; and indeno(1,2,3-cd)pyrene.

Table E.7 summarizes the maximum concentrations of Total PAHs detected in surface (0–1 ft), subsurface (1–10 ft), and deep subsurface soils (> 10 ft) at PGDP (as defined by the Paducah Risk Methods Document).[8] Figure E.9 summarizes the range of concentrations of Total PAHs detected in soil at the PGDP as found in PEGASIS. This figure provides a comparison to the no action level (ELCR = 1E-06) and action level (ELCR = 1E-04) for the industrial worker. These values are 0.643 mg/kg and 64.3 mg/kg, respectively. Figures E.10 through E.12 illustrate the location of these Total PAHs by depth.

Table E.7. Maximum Total PAHs by Depth

Sample Depth (ft)	Maximum Total PAH Concentration (mg/kg)
Surface (0–1)	8,750
Subsurface (1–10)	11.4
Deep Subsurface (> 10)	1.46

Figure E.9. Total PAH Concentrations by Depth

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Figure E.10. Total PAH in Surface (0-1 ft bgs) Soil/Sediment Samples

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Figure E.11. Total PAH Subsurface (1-10 ft bgs) Soil/Sediment Samples

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Figure E.12. Total PAH Deep Subsurface (>10 ft bgs) Soil/Sediment Samples

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The Observations section of BHHRAs address uncertainties associated with the presence of PAHs, and the feasibility study (FS) includes discussions ensuring that remedial actions appropriately address the uncertainties associated with the presence of residual concentrations of PAHs.

E.7.3. SUMMARY

In evaluating risk/hazard at PGDP, the need to sample for PAHs and the evaluations of PAH sampling results will be determined on a case-by-case basis to incorporate uncertainties concerning the presence of PAHs into the risk management process. This will include ***quantitative*** evaluation of the risk/hazard presented by PAHs in the BHHRA when PAHs are sampled for, consistent with the Paducah Risk Methods Document.[8] Subsequently, the BHHRA will discuss the uncertainties associated with the presence of PAHs, and these uncertainties will be combined with risk characterization in the Observations section. The FS will manage these uncertainties and incorporate regulatory requirements to ensure that potential exposure to residual PAHs in environmental media is addressed appropriately.

[1]Agency for Toxic Substances and Disease Registry [ATSDR 1995] (see http://www.atsdr.cdc.gov/toxprofiles/tp69.pdf).

[2]*Risk Management Considerations for Polycyclic Aromatic Hydrocarbon Contamination at the Portsmouth Gaseous Diffusion Plant*, POEF-ER-4616&D1, January 27, 1995.

[3]E-mail correspondence among FFA parties.

[4]*Final Report on the Background Soil Characterization Project at the Oak Ridge Reservation, Oak Ridge, Tennessee; Volume 1, Results of Field Sampling Program*, DOE/OR/01-1175/V1, October 1993.

[5]"Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions" (OSWER Directive 9355.0-30) April 22, 1991.

[6]Kentucky Guidance for Ambient Background Assessment, January 8, 2004, Natural Resources and Environmental Protection Cabinet.

[7]Kentucky Revised Statute 224.01-400 (1) (b).

[8]Draft *Risk Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0107&D2/R9, December 2017.

[9]*Engineering Evaluation/Cost Analysis for Contaminated Sediment Associated with the Surface Water Operable Unit (On-Site) at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0012&D2, August 2008.

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E.8. SITE-SPECIFIC SOIL SCREENING LEVELS AND SITE-SPECIFIC DILUTION ATTENUATION FACTORS AT THE PADUCAH GASEOUS DIFFUSION PLANT

E.8.1. IDENTIFICATION OF THE PROBLEM

U.S. Environmental Protection Agency (EPA) provides guidance for calculating risk-based, site-specific, soil screening levels (SSLs) for contaminants in soil that may be used to identify areas needing further investigation at National Priorities List sites (EPA 1996a; EPA 1996b; EPA 2002). SSLs are risk-based concentrations derived from equations combining exposure information assumptions with EPA toxicity data. SSLs may be developed for the direct exposure pathways (e.g., incidental ingestion, dermal contact, particulate inhalation, and inhalation of volatiles) based on excess lifetime cancer risk for carcinogens or on hazard quotients for noncarcinogens; or. SSLs may be developed for the indirect exposure pathway of soil to groundwater migration and subsequent ingestion of contaminated groundwater. This paper looks only at these SSLs for soil to groundwater migration.

Contaminant concentrations are attenuated by adsorption and degradation as soil leachate moves through soil and groundwater. In the aquifer, dilution by groundwater further reduces concentrations before contaminants reach receptor points (i.e., drinking water wells). This reduction through dilution in concentration can be expressed as a dilution attenuation factor (DAF), defined as the ratio of soil leachate concentration to receptor point concentration. A DAF of 1 corresponds to a situation where there is no dilution or attenuation of a contaminant (i.e., when the concentration in the receptor well is equal to the soil leachate concentration). On the other hand, higher DAF values correspond to a large reduction in contaminant concentration from the contaminated soil to the receptor well (EPA 1996a).

In order to facilitate agreement with respect to use of SSLs and DAFs at Paducah Gaseous Diffusion Plant (PGDP), the Federal Facility Agreement (FFA) Managers decided that the Groundwater Modeling Working Group (MWG) would develop a white paper for inclusion in the Risk Methods Document to provide guidance on development of site-specific SSLs and site-specific DAFs to be implemented when scoping projects.

E.8.2. BACKGROUND

E.8.2.1 HYDROGEOLOGY OF THE PADUCAH SITE

PGDP is located in the Jackson Purchase region of western Kentucky, approximately 10 miles west of Paducah, Kentucky, and 3.5 miles south of the Ohio River. Buried Pleistocene fluvial deposits of the ancestral Tennessee River unconformably overlie Cretaceous marine sediments at a depth of approximately 100 ft directly beneath and north of the Paducah Site. The bottom Pleistocene fluvial deposits consist of a gravel unit that ranges in thickness from 30 ft to 50 ft, with the top of the unit encountered at a general depth of 60 ft below ground surface (bgs) at the Site. This gravel unit is the primary member of the uppermost aquifer beneath the Paducah Site and north to the Ohio River—the Regional Gravel Aquifer (RGA). The RGA is the main conduit for groundwater flow to the north, where groundwater discharges to the Ohio River, and the main pathway for off-site contaminant plume migration. A thick sequence of silts and fine sands, comprising the Upper Continental Recharge System (UCRS), overlies the RGA.

E.8.2.2 USE OF SSLS AND DAF AT THE PADUCAH SITE

The maximum UCRS soil concentrations that are protective of RGA groundwater quality, SSLs, are determined by combining the DAF (unitless) calculations with contaminant-specific distribution coefficients (K_d) (units of volume/mass).

RGA groundwater flows are much higher relative to UCRS groundwater flows; thus, mixing the two waters will result in much lower RGA groundwater contaminant concentrations relative to the initial UCRS groundwater contaminant concentrations. The reduction in groundwater concentrations in the RGA is proportional to the ratio of the volume of RGA groundwater to contaminated UCRS groundwater. The DAF calculates the impact on the concentration from the relative rates of vertical migration of contaminated UCRS water and horizontal migration of RGA groundwater to yield a concentration of the blended water.

To complete the evaluation, the K_d of the constituent must be factored into the analysis. K_d represents the ratio of contamination adhered to soil particles (the source zone) relative to that dissolved in groundwater (as the soil leachate).

Starting with a target-acceptable RGA groundwater contaminant concentration [i.e., maximum contaminant levels (MCLs) or site-specific risk based concentrations, etc.] and assuming that the receptor point concentration is below the source area in the RGA, the maximum acceptable UCRS groundwater contaminant concentration can be calculated using a DAF value. When this result is combined with the applicable K_d for the UCRS and for the contaminant, this calculation will yield the SSL, the maximum-acceptable UCRS soil contaminant concentration that is protective of RGA groundwater quality at the target concentration.

E.8.3. HISTORICAL USE OF SSLS AT THE PADUCAH GASEOUS DIFFUSION PLANT

E.8.3.1 EARLY PROJECTS

Prior to the use of site-specific soil-to-groundwater SSLs, projects used background and risk-based screening levels from the site Risk Methods Document. The following are example projects.

- SWMU 2 Data Summary Interpretation Report (DOE 1997)
- WAG 6 Remedial Investigation (RI) (DOE 1998a)
- WAG 27 RI (DOE 1999a)

Other site RIs screened media analyses against EPA-derived SSLs using a DAF of 20. The following projects used this approach.

- WAGs 9 & 11 Site Evaluation (DOE 1999b)
- WAG 28 RI (DOE 2000a)
- WAG 3 RI (DOE 2000b)

The SWMUs 7 and 30 RI used EPA SSLs at a DAF of 1 to screen chemicals or radionuclides of potential concern (COPCs) prior to fate and transport modeling using Seasonal Soil Model (SESOIL) (DOE 1998b). The Southwest Plume Site Investigation (SI) Report provided SSLs at DAFs of 1 and 20 for volatile organic compounds (DOE 2007).

E.8.3.2 SOUTHWEST PLUME FFS

Following the Southwest Plume SI Report, the Southwest Plume Focused Feasibility Study (FFS) (DOE 2011) used deterministic modeling [SESOIL/Analytical Transient 1-, 2-, 3-Dimensional Simulation of Waste Transport in the Aquifer System (AT123D)] and site-specific values of attenuation and migration factors to evaluate remediation goals for protection of groundwater for trichloroethene (TCE) and its break-down products for the Oil Landfarm (SWMU 1) and the C-720 area.

The Southwest Plume FFS calculated a DAF of 59. Cleanup goals of 0.073 and 0.075 mg/kg for TCE at SWMU 1 and C-720, respectively, were calculated (using an MCL of 5 µg/L as a target-acceptable RGA groundwater contaminant concentration). Site-specific values used in the calculations are shown in Tables C.9 and C.10 of the FFS (DOE 2011).

E.8.3.3 SOILS OU RI

Based on expected minimum and maximum RGA hydraulic conductivity (K) (0.03 to 1.09 cm/s), RGA gradient (i) (1.84E-04 to 2.98E-03 m/m), and UCRS infiltration (I) (0.0679 to 0.1964 m/yr) values, DAF values for the Soils Operable Unit (OU) ranged between 5 and 139 (DOE 2013). The parameter distributions, with the exception of I, were developed for probabilistic evaluation of soil cleanup remediation goals for SWMU 1 and the C-720 Building (DOE 2007; DOE 2011). For the soil remediation goal probabilistic evaluation, I was held constant. For this probabilistic evaluation, I was assumed to range linearly between 2.64 inches/yr and 7.64 inches/yr (0.067 m/yr and 0.194 m/yr) (DOE 2013).

Limiting the maximum hydraulic conductivity value to 1,500 ft/d, to reflect the expected lower hydraulic conductivity values found beneath the PGDP, the maximum DAF was calculated at 68. To develop a better understanding of the potential DAF distribution, a probabilistic evaluation was performed. The evaluation predicted mean, median, minimum, and maximum DAF values of 52, 33, 3, and 366, respectively. Evaluation of the probabilistic DAF distribution (Figure E.13) shows that lower DAF values occur more frequently than higher DAF values with the most frequently occurring DAF being between 11 and 20.

DAF values for the Soils OU ranged between 5 and 139 (DOE 2013).

Figure E.13. Probabilistic DAF Distribution

Deterministic evaluation of typical PGDP site conditions predicted a DAF of 58 for the Soils OU RI. Minimum and maximum deterministic predicted DAF values were 5 and 139, respectively. The DAF of 58 derived with the expected values for hydraulic parameters was used to support screening of the Soils OU results to identify those SWMUs/AOCs where constituents might present an impact to groundwater.

E.8.4. DISCUSSION

E.8.4.1 RISK METHODS DOCUMENT MODELING MATRIX

Based on guidance presented in Section 3.3.4.3 "Quantification of Exposure" of the Risk Methods Document (DOE 2017a), to determine if fate and transport modeling is needed, the maximum soil concentrations (or activities for radionuclides) at the source (over all depths) for each analyte are compared to the appropriate groundwater protection preliminary remediation goal (PRG). If the maximum soil concentration exceeds the groundwater protection PRG, then future concentrations in groundwater will be modeled. Models to be used to determine future concentrations and activities at the source and in groundwater will be based on the modeling matrix presented in Table E.8 (from Table 1 DOE 2017a). Tier 1 values are existing sets of screening levels used for the initial screening of a site. Tier 2 values also are used for scoping, but account for more specific estimates of model parameters than the default Tier 1 values. Tiers 3 and 4 values are derived by models used primarily with site–specific values for site decision making.

Table E.8. Modeling Matrix for Groundwater

	Values for Soil to Protect Groundwater	Model	Point of Exposure	Notes
INVESTIGATION DOCUMENTS	Tier 1 (Used for scoping)	SSLs and/or RESidual RADioactivity (RESRAD) Vapor intrusion model	At source unit At source unit	Value to be used for initial scoping, use DAF of 1 for SSLs, unless site-specific values are available. Groundwater protection value based on residential use and targets of 1E-6, 0.1, and 1 for risk, hazard, and radiological dose, respectively. If site-specific DAF values are used, then need to justify these values. The depth of water needs to be considered in the calculation. Initial vapor intrusion model will use default values.
	Tier 2 (Used for scoping)	SESOIL and/or RESRAD	At source unit	Includes source delimitation. Recognize SESOIL limitations when modeling inorganic COPCs—refine K_ds.
DECISION DOCUMENTS	Tier 3 (Enhanced modeling used in decision documents if needed)	SESOIL and RESRAD suite of codes (including RESRAD-OFFSITE) with AT123D	At source unit and at downgradient points (Industrialized area, DOE property boundary, creek, river)	Uses source delimitation and refined K_ds from above. Use values from this effort to set initial cleanup levels. On the Terrace (southern portion of PGDP), different points of exposure will apply.
	Tier 4 (Enhanced modeling used in decision and design documents if needed)	Source modeling and three-dimensional finite-difference groundwater model (MODFLOW/MT3D/ RT3D)	At source unit and at downgradient points appropriate to the selected remedy	To be used to refine cleanup levels (if needed). May be especially important to set monitoring goals. On the Terrace (southern portion of PGDP), different points of exposure will apply.

(Table from DOE 2017a)

E.8.4.2 METHODOLOGY FOR DEVELOPMENT OF TIER 1 SSLS FOR GROUNDWATER PROTECTION

SSLs[1] will be calculated using EPA guidance (i.e., EPA 1996a; EPA 1996b; EPA 2002). EPA guidance is appropriate for calculating SSLs corresponding to target leachate contaminant concentrations in the zone of contamination. Inputs to the calculations will use project-specific data, when available, to guide selection of values for variables of the SSL and DAF calculations, as appropriate. If necessary, additional data may be collected if determined during project scoping.

For nonradionuclides, soil to groundwater SSLs in the Risk Methods Document are calculated from the equation below. This methodology follows EPA guidance in EPA 1996b.

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

Where:

Variable	Explanation	Recommended Input
C_w	Target groundwater concentration (mg/L)	MCLs or resident/child resident no action level.
DAF	dilution attenuation factor (unitless)	See equation below.
K_d	soil-water partition coefficient (L/kg)	For inorganics: Chemical-specific (RAIS default, unless project-specific value is available). For organics: $K_d = K_{oc} \times f_{oc}$
K_{oc}	soil organic carbon-water partition coefficient (L/kg) K_{oc} is the determinant for each organic chemical's effective distribution coefficient	Chemical-specific (RAIS default, unless project-specific value is available). See also equation shown for K_d.
f_{oc}	fraction organic carbon in soil (unitless)	0.002 (RAIS default), unless project-specific value is available. (NOTE: Paducah-specific values range 0.0002 to 0.005. Most projects have location-specific values available.[a])
θ_w	water-filled soil porosity (Lwater/Lsoil)	0.3 (RAIS default), unless project-specific value is available. [NOTE: Paducah-specific values of total porosity are from the WAG 6 RI data set (DOE 1998a). Water filled soil porosity ranges between 0.37 for shallow water table settings and 0.30 for deep water table settings.[b]]
θ_a	air-filled soil porosity (Lair/Lsoil)	0.13[c] (EPA 1996b), unless project-specific value is available. (NOTE: Paducah-specific values are 0.0 for shallow water table settings and 0.07 for deep water table settings.[d])
ρ_b	dry soil bulk density (kg/L)	1.5 (RAIS default), unless project-specific value is available. (NOTE: Paducah-specific value is 1.7.[e])
H'	dimensionless Henry's law constant	Chemical-specific (RAIS default).

[a] Fraction organic carbon in soil typically can be found on the Paducah Site's Environmental Geographic Analytical Spatial Information System as Total Organic Carbon (TOC).
[b] The water-filled soil porosity 0.37 value represents 100 % water saturation and the 0.30 value represents 80% water saturation.
[c] Although the default value for air-fill soil porosity is 0.13, much lower values are representative of the near-saturated, fine-grained soils of the Paducah Site.
[d] The air-filled soil porosity 0.0 value represents 100 % water saturation and the 0.07 value represents 80% water saturation.
[e] $\rho_b = [1.00-0.37\ (\theta_{total})] \times 2.65$ kg/L (soil particle specific gravity)

[1] These SSLs are developed as Tier 1 values. Using more sophisticated modeling (e.g., SESOIL) to develop Tier 2 values also is consistent with EPA guidance.

For radionuclides, soil to groundwater SSLs are calculated from the equation below. This methodology also follows EPA guidance in EPA 1996b, since Henry's law constant is not applicable.

$$SSL = C_w \times DAF \times \frac{\left(K_d + \left(\frac{\theta_w}{\rho_b}\right)\right)}{1{,}000}$$

Where:

Variable	Explanation	Recommended Input
C_w	Target groundwater concentration (pCi/L)	MCLs or resident/child resident no action level.
DAF	dilution attenuation factor (unitless)	See equation below.
K_d	soil-water partition coefficient (L/kg)	Radionuclides: values are from DOE 2003 and DOE 2012.
θ_w	water-filled soil porosity (L/L)	0.3 (RAIS default), unless project-specific value is available. (NOTE: Paducah-specific value is 0.37.)
ρ_b	dry soil bulk density (kg/L)	1.5 (RAIS default), unless project-specific value is available. (NOTE: Paducah-specific value is 1.7.)

DAF calculation utilizes EPA guidance and the following equations (EPA 1996a).

$$DAF = 1 + \frac{Kid}{IL}$$

Where:

Variable	Explanation	Recommended Input
i	horizontal hydraulic gradient (m/m)	Project-specific value.
d	mixing zone depth (m)	See equation below.
I	infiltration rate (m/yr)	Range of values taken from DOE 2017b.
L	length of source area parallel to groundwater flow (m)	Project-specific value (maximum distance across the source area in a direction parallel to RGA groundwater flow).
K	aquifer hydraulic conductivity (m/yr)	Project-specific value taken from within range of values in DOE 2017b.

The equation for calculating the aquifer mixing zone depth, d:

$$d = \left(0.0112L^2\right)^{0.5} + d_a\left\{1 - e^{\left[\frac{(-LI)}{(Kid_a)}\right]}\right\}$$

Where:

Variable	Explanation	Recommended Input
i	horizontal hydraulic gradient (m/m)	Project-specific value.
d_a	aquifer thickness (m)	Average of values for project-specific area taken from most recent KRCEE database.
I	infiltration rate (m/yr)	Range of values taken from DOE 2017b.
L	length of source area parallel to groundwater flow (m)	Project-specific value.
K	aquifer hydraulic conductivity (m/yr)	Project-specific value taken from within range of values in DOE 2017b.

An example comparison of site-specific and default inputs for key COPCs is shown in Table E.9.

Table E.9. Example Site-Specific and Default Inputs for Key COPCs

Key COPC	Site-Specific			Default		
	DAF	K_d L/kg	SSL mg/kg or pCi/g	DAF	K_d L/kg	SSL[a] mg/kg or pCi/g
TCE	59[b]	7.52E-02[b]	7.30E-02[b]	20[e]	1.21E-01[f]	3.58E-02[e]
1,1-DCE	59[b]	5.20E-02[b]	1.30E-01[b]	20[e]	6.36E-02[f]	5.02E-02[e]
cis-1,2-DCE	59[b]	2.88E-02[b]	6.00E-01[b]	20[e]	7.92E-02[f]	4.12E-01[e]
trans-1,2-DCE	59[b]	3.04E-02[b]	1.08E+00[b]	20[e]	7.92E-02[f]	6.26E-01[e]
Vinyl chloride	59[b]	1.52E-02[b]	3.40E-02[b]	20[e]	4.34E-02[f]	1.38E-02[e]
Tc-99	58[c]	2.00E-01[d]	2.12E+01[c]	20[e]	2.00E-01[e]	1.52E-01[e]
U-238	58[c]	6.68E+01[d]	2.64E+02[c]	20[e]	6.68E+01[e]	8.04E-01[e]

[a] SSL is based on MCL for the organics and resident NAL for the radionuclides.
[b] DOE 2011, for SWMU 1 area, using site-specific foc.
[c] DOE 2013.
[d] DOE 2003.
[e] DOE 2017a.
[f] RAIS 2017. https://rais.ornl.gov/, accessed November 27, using K_{oc} × foc where foc is 0.002.

E.8.5. SUMMARY

Site-specific SSLs and site-specific DAFs will be developed collaboratively during project scoping by the FFA parties. If adequate site-specific data (of known and sufficient quality and quantity) are not available to support these calculations, SSLs developed using DAFs of 1 and 20 will be used for screening, consistent with EPA guidance (EPA 1996a). For the purposes of this paper, it is the intent of the FFA parties that "site" is a project-level term and does not refer to larger areas of consideration such as the facility, the plant, the Superfund Site or site-wide.

The method to be used in developing site-specific SSLs and site-specific DAFs is presented in the attachment to this paper and will follow Section 4.2, "Methodology for Development of Tier 1 SSLs for Groundwater Protection."

E.8.6. REFERENCES

DOE 1997. *Data Summary Interpretation Report for Interim Remedial Design at Solid Waste Management Unit 2 of Waste Area Grouping 22 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-1549&D1, February.

DOE 1998a. *Remedial Investigation Report for Waste Area Grouping 6 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-1727&D2, May.

DOE 1998b. *Remedial Investigation Report for Solid Waste Management Units 7 and 30 of Waste Area Grouping 22 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-1604&D2, January.

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

DOE 1999b. *WAGs 9 and 11 Site Evaluation Report at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-l 785&D2, June.

DOE 2000a. *Remedial Investigation Report for Waste Area Grouping 28 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-1846&D2, August.

DOE 2000b. *Remedial Investigation Report for Waste Area Grouping 3 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-1895&D1, September.

DOE 2003. *Risk and Performance Evaluation of the C-746-U Landfill at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-2041&D2/R1, September.

DOE 2007. *Southwest Plume Site Investigation Report at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/OR/07-2180&D2/R1, June.

DOE 2011. *Revised Focused Feasibility Study for Solid Waste Management Units 1, 211A, and 211B Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/LX/07-0362&D2, May.

DOE 2012. *Remedial Investigation/Feasibility Study Report for the CERCLA Waste Disposal Alternatives Evaluation at the Paducah Gaseous Diffusion Plant*, *Paducah, Kentucky*, U.S. Department of Energy, Paducah, KY, DOE/LX/07-0244&D1, May.

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.

DOE 2017a. *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, KY, DOE/LX/07-0107&D2/R8/V1, July.

DOE 2017b. *2016 Update of the Paducah Gaseous Diffusion Plant Sitewide Groundwater Flow Model*, U.S. Department of Energy, Paducah, KY, DOE/LX/07-2415&D2, July.

EPA (U.S. Environmental Protection Agency) 1996a. *Soil Screening Guidance: User's Guide*. OSWER 9355.4-23, Office of Solid Waste and Emergency Response, July.

EPA 1996b. *Soil Screening Guidance: Technical Background Document*. EPA/540/R95/128, Office of Solid Waste and Emergency Response, May.

EPA 2002. *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*. OSWER 9355.4-24, Office of Solid Waste and Emergency Response, December.

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ATTACHMENT

METHOD TO BE USED IN DEVELOPING SITE-SPECIFIC SSLS AND SITE-SPECIFIC DAFS

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SITE-SPECIFIC SSL AND SITE-SPECIFIC DAF

OBJECTIVE

The methodology will serve as a standard for determining site-specific soil screening levels (SSLs) for soil to groundwater migration and site-specific dilution attenuation factors (DAFs). While this guidance presents a standard method for determining site-specific SSLs and DAFs, deviations from this guidance are likely, and these deviations will be discussed on a case-by-case basis.

BASIS

In order to facilitate agreement with respect to use of SSLs and DAFs at the Paducah Site, the Federal Facility Agreement Managers decided that the Groundwater Modeling Working Group would develop a white paper for inclusion in the Risk Methods Document providing guidance on development of site-specific SSLs and site-specific DAFs to be implemented when scoping projects.

SITE-SPECIFIC SSL AND SITE-SPECIFIC DAF DEVELOPMENT GUIDANCE

This guidance applies to determining maximum Upper Continental Recharge System soil concentrations that are protective of Regional Gravel Aquifer groundwater quality, SSLs, by combining the DAF (unitless) calculations with contaminant-specific distribution coefficients (K_d) (units of volume/mass).

Requirements for this determination are inputs to the equations identified in Section 4.2, "Methodology for Development of Tier 1 SSLs for Groundwater Protection." Each variable will be documented as to its source. An assessment of each of these variables for use as project-specific inputs will be included. These parameters will be agreed to by all parties during scoping. Derivation using the equations will be clearly documented.

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E.9. HUMAN HEALTH INFORMATION FOR THE PADUCAH VAPOR INTRUSION EVALUATION

Information provided in Table E.10 is taken from several sources. It should be noted that according to the Occupational Safety & Health Administration (OSHA) website (https://www.osha.gov/dsg/annotated-pels/, accessed in January 2022), "OSHA recognizes that many of its permissible exposure limits (PELs) are outdated and inadequate for ensuring protection of worker health. Most of OSHA's PELs were issued shortly after adoption of the Occupational Safety and Health (OSH) Act in 1970, and have not been updated since that time. Since 1970, OSHA promulgated … new PELs for 16 agents, and standards without PELs for 13 carcinogens. Industrial experience, new developments in technology, and scientific data clearly indicate that in many instances these adopted limits are [also] not sufficiently protective of worker health. This has been demonstrated by the reduction in allowable exposure limits recommended by many technical, professional, industrial, and government organizations, both inside and outside the United States."

Additionally, the following information has been provided in this section:

- Information provided by EPA Region 4 for cis-1,2-DCE and trans-1,2-DCE screening levels.
- Information provided by EPA Region 4 regarding the basis of their use of the Agency for Toxic Substances and Disease Registry intermediate minimal risk levels.
- Excerpt of Agency for Toxic Substances and Disease Registry minimal risk levels updated March 2016.
- Excerpt of information from the Region 4 Scientific Support Section Vapor Intrusion Screening Tool.
- Information provided by Kentucky Risk Assessment Branch to support a project discussion on June 20, 2017.
- Archived Provisional Peer Reviewed Toxicity Values for *trans*-1,2-Dichloroethylene (withdrawn by EPA).

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Table E.10. Vapor Intrusion Screening Levels (VISLs) for Analytes of Interest for PGDP—Commercial

Chemical	Is Chemical Sufficiently Volatile and Toxic to Pose Inhalation Risk via VI from Soil Source?	Is Chemical Sufficiently Volatile and Toxic to Pose Inhalation Risk via VI from Groundwater Sources?	Indoor Air VISL (µg/m³) at TCR = 1E-06 or THQ = 1[a]	Toxicity Basis	Soil Gas VISL (µg/m³) at TCR = 1E-06 or THQ = 1[a]	Target Groundwater Concentration (µg/L) at TCR = 1E-06 or THQ = 1[a]	Occupational Exposure Limits[b]		
							OSHA PEL/TWA (µg/m³)	NIOSH REL/TWA (µg/m³)	ACGIH TLV/TWA (µg/m³)
	Cvp > Cia, target?	Chc > Cia, target?	Min (Cia, c; Cia, nc)	C or NC	Csg	Chc			
Chloroform	Yes	Yes	5.33E-01	C	1.78E+01	3.55E+00[c]	No PEL/TWA[d]	No REL/TWA[e]	4.88E+01
Dichloroethane, 1,1- (1,1-DCA)	Yes	Yes	7.67E+00	C	2.56E+02	3.34E+01	4.00E+05	4.00E+05	4.00E+05
Dichloroethylene, 1-1- (1,2-DCE)	Yes	Yes	8.76E+02	NC	2.92E+04	8.21E+02	No PEL/TWA	No PEL/TWA	2.00E+04
Dichloroethylene, 1,2-cis- (cis-1,2-DCE)	No Inhalation Toxicological Information	No Inhalation Toxicological Information	NVA[f,g], 3.50E+03	NC	N/A	N/A	7.93E+05	7.93E+05	7.93E+05
Dichloroethylene, 1,2-trans- (trans-1,2-DCE)	Yes	Yes	NVA[g], 3.50E+03	NC	N/A	N/A			
Mercury (elemental)[h]	Yes	Yes	1.31E+00	NC	4.38E+01	3.73E+00	1.00E+02	5.00E+01	2.5E+01
Trichloroethane, 1,1,1- (1,1,1-TCA)[i]	Yes	Yes	2.19E+04	NC	7.30E+05	3.11E+04	1.91E+06	No REL/TWA[j]	1.91E+06
Trichloroethylene (TCE)	Yes	Yes	2.99E+00	C	9.97E+01	7.43E+00	5.37E+05	1.34E+05[k]	5.37E+04
Vinyl Chloride (VC)	Yes	Yes	2.79E+00	C	9.29E+01	2.45E+00	2.56E+03	No REL/TWA	2.56E+03

ACGIH = American Conference of Governmental Industrial Hygienists
C = carcinogenic
Cia = concentration, indoor air
Chc = concentration, groundwater vapor
Csg = concentration, subslab and exterior soil gas concentration
Cvp = concentration, pure phase vapor
µg/m³ = micrograms per cubic meter

Table E.10. Vapor Intrusion Screening Levels (VISLs) for Analytes of Interest for PGDP—Commercial (Continued)

N/A = no value available
NC = noncarcinogenic
NIOSH = National Institute for Occupational Safety and Health
NVA = no VISL value available
REL = recommended exposure limit
STEL = short-term exposure limit
TCR = target risk for carcinogens
THQ = target hazard quotient for noncarcinogens
TWA = time-weighted average
VI = vapor intrusion
VISL = vapor intrusion screening level

[a] The agreed upon VISLs in the Paducah Gaseous Diffusion Plant Industrial Area Vapor Intrusion Preliminary Risk Assessment Report (DOE/LX/07-2471&D2) were calculated at a hazard quotient of 1 because this was a preliminary assessment and was not intended to be used for human health risk assessment. Projects should consider using reporting limits targeted to meet the hazard quotient of 0.1 to ensure usability for future risk assessment.
[b] Occupational exposure limits obtained from the OSHA Occupational Chemical Database (https://www.osha.gov/chemicaldata), accessed February 7, 2022. Values provided in units of parts per million were converted to units of $\mu g/m^3$ using the NIOSH online conversion calculator (https://wwwn.cdc.gov/niosh-oeb/resource/calculator), accessed February 7, 2022; based on 25°C and 1 atmosphere, and using molecular weight obtained from the OSHA Occupational Chemical Database.
[c] The maximum contaminant level (MCL) for total trihalomethanes in drinking water, of which, chloroform is a key component, is 80 µg/L.
[d] There is no OSHA PEL/TWA for chloroform; a ceiling peak PEL of 240,000 $\mu g/m^3$ has been established.
[e] There is no NIOSH REL/TWA for chloroform; a 60-minute STEL of 9,780 $\mu g/m^3$ has been established.
[f] The reference concentration for *trans*-1,2-DCE, was used as a surrogate to calculate the screening levels for *cis*-1,2,-DCE.
[g] Provisional value provided by EPA, as documented in Section E.9, because VISL value is not available.
[h] For an analyte to be considered a contaminant of potential concern for VI, the analyte must be toxic and sufficiently volatile to migrate from a subsurface source into a building at a concentration greater than its indoor air screening level. Elemental mercury is toxic and can be sufficiently volatile to exist in vapors at levels potentially harmful to human receptors; therefore, mercury must be present in subsurface media in elemental form to pose a VI risk. The majority of mercury, which is a common industrial contaminant and by-product of coal combustion, detected in groundwater or soils at PGDP is expected to be in the form of salts—not elemental mercury. Mercury has not been detected in site monitoring wells at concentrations greater than its groundwater VISL; therefore, mercury is not expected to be present in vapor form above trace concentrations. Indoor air in each building identified for VI sampling, however, was screened for mercury using a field meter as a protective measure based on its widespread detection in site soil.
[i] 1,1,1-TCA was included to be considered only when there is documented use within a facility.
[j] There is no NIOSH REL/TWA for 1,1,1-TCA; a 15-minute STEL of 1.90E+06 $\mu g/m^3$ has been established.
[k] Recommendation listed in *NIOSH Pocket Guide to Chemical Hazards*, Appendix C, Supplementary Exposure Limits, (https://www.cdc.gov/niosh/npg/nengapdxc.html), accessed February 2022.

Note:
The VISL values are taken from the VISL calculator (results generated, April 5, 2022, https://epa-visl.ornl.gov/cgi-bin/visl_search) derived for a commercial exposure scenario at a target excess cancer risk of 1.0E-06 and a target hazard quotient of 1.0. Per the VISL calculator, the commercial exposure scenario has a 70-year averaging time for carcinogens, a 25-year averaging time for noncarcinogens, an exposure duration of 25 years, an exposure frequency of 250 days/year, and an exposure time of 8 hours/day.

-----Original Message-----
From: Koporec, Kevin
Sent: Thursday, June 15, 2017 10:04 AM
To: Bentkowski, Ben <Bentkowski.Ben@epa.gov>
Subject: VI/air screening levels

Here is the table of screening values Ben.
In case you want the DCE values handy before you can open the table, here's the SLs (ug/m3).

1,2-Dichloroethylene (both isomers):
residential indoor air SL = 800; subsurface soil vapor SL = 27,000.
Industrial indoor air SL = 3500; subsurface soil vapor SL = 120,000.

From: Koporec, Kevin <Koporec.Kevin@epa.gov>
Sent: Tuesday, June 20, 2017 1:46 PM
To: White, Jana; Bentkowski, Ben; Duncan, Tracey; Rich Bonczek; Corkran, Julie; 'Begley, Brian (EEC)'; Brewer, Gaye (EEC); Jeri.Higginbotham@ky.gov; Towarnicky, Joseph M; Overby, Teresa; Nourse, Bobette (PPPO/CONTR); Jung, Christopher H (EEC); Kim Knerr; Frederick, Tim
Subject: RE: C-400 VI Work Plan - Follow-up Technical Discussion
Attachments: 12DCE May2016.pdf

Re: DCE inhalation tox value.
Here is the basis for region 4's use of the ATSDR Intermediate MRL as an interim value for assessment of inhalation to 1,2-DCE. ATSDR is on the list of sources of Toxicity values on our (EPA Superfund risk assessment) hierarchy. I would note that we have recently requested an expedited assessment of this chemical by the EPA IRIS program.

Kevin Koporec
Toxicologist
USEPA Region 4

-----Original Appointment-----
From: White, Jana [mailto:Jana.White@FFSPaducah.Com]
Sent: Tuesday, June 20, 2017 1:23 PM
To: White, Jana; Koporec, Kevin; Bentkowski, Ben; Duncan, Tracey; Rich Bonczek; Corkran, Julie; 'Begley, Brian (EEC)'; Brewer, Gaye (EEC); Jeri.Higginbotham@ky.gov; Towarnicky, Joseph M; Overby, Teresa; Nourse, Bobette (PPPO/CONTR); Jung, Christopher H (EEC); Kim Knerr; Frederick, Tim
Subject: FW: C-400 VI Work Plan - Follow-up Technical Discussion
When: Tuesday, June 20, 2017 2:00 PM-3:00 PM (UTC-06:00) Central Time (US & Canada).
Where: DOE Large Conference Room Conference Call 1-800-454-9043 Participant Code: 4415861

-----Original Appointment-----
From: White, Jana [mailto:Jana.White@FFSPaducah.Com]
Sent: Friday, June 16, 2017 9:37 AM
To: White, Jana; Duncan, Tracey; Rich Bonczek; Corkran, Julie; Bentkowski, Ben; 'Begley, Brian (EEC)'; Brewer, Gaye (EEC); Jeri.Higginbotham@ky.gov; Towarnicky, Joseph M; Overby, Teresa; Nourse, Bobette (PPPO/CONTR); Jung, Christopher H (EEC); Kim Knerr; Frederick, Tim
Subject: C-400 VI Work Plan - Follow-up Technical Discussion
When: Tuesday, June 20, 2017 2:00 PM-3:00 PM (UTC-06:00) Central Time (US & Canada).
Where: DOE Large Conference Room Conference Call 1-800-454-9043 Participant Code: 4415861

The purpose of the meeting is to continue discussions on language for Condition 4; review remaining actions associated with Worksheet #15 of QAPP; and to discuss the schedule associated with C-400 VI.
The current deadline for the informal dispute is July 1st and the parties have agreed to meet prior to July 1st to continue resolution of the remaining technical issues.

If you have any questions, please let me know.
Thanks,
Jana

Superfund Technical Support Center
National Center for Environmental Assessment
U.S. Environmental Protection Agency
26 West Martin Luther King Drive, MS-AG41
Cincinnati, Ohio 45268

Phillip Kaiser/Hotline Director, Teresa Shannon/Administrator
Hotline 513-569-7300, FAX 513-569-7159, E-Mail: Superfund_STSC@epa.gov

May 25, 2016

Kevin Koporec
EPA Region 4

ASSISTANCE REQUESTED: Inhalation toxicity value (RfC) for 1,2-dichloroethylene and its cis- and trans- isomers.

ENCLOSED INFORMATION: Attachment 1: 1,2-DCE Frederick, Tim Response_Final.pdf

If you have any questions regarding this transmission, please contact the STSC at (513) 569-7300.

Attachments (1)

cc: STSC files

RESPONSE MESSAGE:

The STSC understands your urgent need for PPRTV assessments for 1,2-dichloroethylene and its cis- and trans- isomers. Our PTV document development queue is currently set through FY18, however NCEA/STSC representatives are currently working collaboratively on a standard operating procedure with OLEM to outline a formal chemical nomination process that might facilitate 'fast-tracking' specific PTV development requests for Regions. This process, while not currently enacted, may serve as the conduit for requests such as for 1,2-dichloroethylene and its cis- and trans- isomers. In the interim, the STSC suggests that you contact Michele Burgess (Burgess.Michele@epa.gov or 703-603-9003) of OLEM directly to discuss a path forward for PTV development for the chemicals of interest. Furthermore, please note that the ATSDR derived a Minimal Risk Level of 0.2 ppm in 1996 for acute-duration inhalation exposure and intermediate-duration inhalation exposure to trans-1,2-dichloroethylene that could be referred to when assessing the health risks associated with the inhalation of this chemical.

Supported by Highlight Technologies, LLC, under
U.S. Environmental Protection Agency Contract No. EP-C-13-007

Agency for Toxic Substances and Disease Registry
MINIMAL RISK LEVELS (MRLs)
March 2016

Name	Route	Duration	MRL	Uncertainty Factors	Endpoint	Status	Cover Date	CAS Number
1,2-DICHLOROETHENE, CIS-	Oral	Acute	1 mg/kg/day	100	Hemato.	Final	08/96	156-59-2
		Int.	0.3 mg/kg/day	100	Hemato.			
1,2-DICHLOROETHENE, TRANS-	Inh.	Acute	0.2 ppm	1000	Hepatic	Final	08/96	156-60-5
		Int.	0.2 ppm	1000	Hepatic			
	Oral	Int.	0.2 mg/kg/day	100	Hepatic			

For Duration, Acute = 1 to 14 days, Intermediate = 15 to 364 days, and Chronic = 1 year or longer.

For general information on ATSDR Minimal Risk Levels, see www.atsdr.cdc.gov/MRLs.

For more information on a specific MRL, please refer to our Toxicological Profiles, particularly Appendix A of Profiles released after 1995. The Toxicological Profiles can be found online at www.atsdr.cdc.gov/ToxProfiles, where you can also find a contact form. Or call 1-800-CDC-INFO.

Region 4 Scientific Support Section
Vapor Intrusion Screening Tool

Last updated 06/26/2017

Internal Use Only: Air Screening Table for Industrial Sites										
	RSL(3)		RSL(3)		RML(2)		RML(2)		RSL Sub-slab(1)	RSL Sub-slab(1)
	ug/m^3		ppbv		ug/m^3		ppbv		ug/m^3 [c]	ppbv [c]
Acetone	14,000	n	5,900	n	420,000	n	180,000	n	4,500,000 n	1,900,000 n
Benzene	1.6	c	0.5	c	160	c	500	c	52 c	16 c
Carbon Tetrachloride	2	c	0.32	c	200	c	32	c	68 c	11 c
Chloroethane	4,400	n	1,700	n	130,000	n	50,000	n	1,500,000 n	57,000 n
Chloroform[a]	43	n	8.8	n	430	n	88	n	1400 n	300 n
1,1-Dichloroethane	7.7	c	1.9	c	770	c	190	c	260 c	64 c
1,2-Dichloroethane	0.47	c	0.12	c	47	c	12	c	16 c	4 c
1,1-Dichloroethylene	88	n	22	n	2600	n	670	n	29,000 n	7300 n
***cis* -1,2-Dichloroethylene[b]**	3500	n	880	n	10,000	n	2600	n	120,000 n	300,000 n
***trans* -1,2-Dichloroethylene[b]**	3500	n	880	n	10,000	n	2600	n	120,000 n	300,000 n
Ethylbenzene	4.9	c	1.1	c	490	c	110	c	160 c	37 c
Methylene Chloride	260	n	75	n	7800	n	2200	n	41,000 n	12,000 n
Naphthalene	0.36	c	0.07	c	36	c	7	c	12 c	2.3 c
1,1,1,2-Tetrachloroethane	1.7	c	0.25	c	170	c	25	c	55 c	8 c
1,1,2,2-Tetrachloroethane	0.21	c	0.03	c	21	c	3	c	7 c	1 c
Tetrachloroethylene (PCE)	18	n	2.7	n	540	n	80	n	1600 n	240 n
Toluene	2,200	n	580	n	66,000	n	17,500	n	730,000 n	190,000 n
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon)	2,200	n	290	n	390,000	n	51,000	n	4,400,000 n	57,000 n
1,1,1-Trichloroethane	2,200	n	400	n	66,000	n	12,000	n	730,000 n	130,000 n
1,1,2-Trichloroethane	0.088	n	0.016	n	SSV				26 n	5 n
Trichloroethylene (TCE)	0.88	n	0.16	n	8.8[d]/26[e]	n	1.6[d]/4.8[e]	n	100 n	19 n
1,2,3-Trimethylbenzene	26	n	5.3	n	66	n	13	n	730 n	150 n
1,2,4-Trimethylbenzene	26	n	5.3	n	93	n	19	n	1000 n	200 n
Vinyl Chloride	2.8	c	1.1	c	280	c	110	c	93 c	36 c
Xylene	44	n	10	n	1300	n	300	n	15,000 n	3500 n

(1) based on lower of HI=1 or 1x10e-6, except 1,2-Dichloroethylene & chloroform
(2) based on lower of HI=3 or 1x10e-4, except 1,2-Dichloroethylene & chloroform
(3) based on lower of HI=0.1 or 1x10e-6, except 1,2-Dichloroethylene, chloroform, & TCE
(a) RSL based on HI=0.1 & RML based on HI=1 because of chloroform being a threshold carcinogen (USEPA IRIS file)
(b) based on ATSDR MRL for trans-1,2-Dichloroethylene: http://www.atsdr.cdc.gov/mrls/pdfs/atsdr_mrls.pdf
(c) Values were calculated using the default sub-slab attenuation factor of 0.03
(d) based on HI=1 to be protective of sensitive sub-populations
(e) based on HI=3 to be protective of non-sensitive populations
SSV - Site Specific Value should be calculated
n = non carcinogen; c = carcinogen

*This table is not for rule making or specific guidance. It is a Region 4 screening tool only.

Internal Use Only: Air Screening Table for Residential Sites											
	RSL(3)		RSL(3)		RML(2)		RML(2)		RSL Sub-slab(1)		RSL Sub-slab(1)
	ug/m^3		ppbv		ug/m^3		ppbv		ug/m^3 [c]		ppbv [c]
Acetone	3,200	n	1,350	n	96,000	n	40,400	n	1,100,000	n	463,000	n
Benzene	0.36	c	0.11	c	36	c	11	c	12	c	3.8	c
Carbon Tetrachloride	0.47	c	0.08	c	47	c	7.5	c	16	c	2.5	c
Chloroethane	1,000	n	380	n	30,000	n	11,000	n	350,000	n	133,000	n
Chloroform[a]	10	n	2	n	100	n	20	n	330	n	68	n
1,1-Dichloroethane	1.8	c	0.44	c	180	c	45	c	58	c	14	c
1,2-Dichloroethane	0.11	c	0.03	c	11	c	2.7	c	3.6	c	0.9	c
1,1-Dichloroethene	21	c	5.3	n	630	n	160	n	7000	c	1800	c
***cis* -1,2-Dichloroethylene[b]**	800	n	200	n	2400	n	600	n	27,000	n	6,800	n
***trans* -1,2-Dichloroethylene[b]**	800	n	200	n	2400	n	600	n	27,000	n	6,800	n
Ethylbenzene	1.1	c	0.25	c	110	c	25	c	37	c	8.5	c
Methylene Chloride	63	n	18	n	1,900	n	540	n	3400	n	980	n
Naphthalene	0.083	c	0.02	c	8.3	c	1.6	c	2.8	c	0.53	c
1,1,1,2-Tetrachloroethane	0.38	c	0.06	c	38	c	5.5	c	13	c	1.9	c
1,1,2,2-Tetrachloroethane	0.048	c	0.007	c	4.8	c	0.7	c	1.6	c	0.23	c
Tetrachloroethylene (PCE)	4.2	n	0.6	n	130	n	19	n	360	n	53	n
Toluene	520	n	140	n	16,000	n	4100	n	170,000	n	45,000	n
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon)	520	n	70	n	93,000	n	12,000	n	1,000,000	n	131,000	n
1,1,1-Trichloroethane	520	n	95	n	16,000	n	3000	n	170,000	n	31,000	n
1,1,2-Trichloroethane	0.021	n	0.004	n	SSV		0		6	n	1	n
Trichloroethylene (TCE)	0.21	n	0.04	n	2.1[d]/6.3[e]	n	0.4[d]/1.2[e]	n	16	n	3	n
1,2,3-Trimethylbenzene	6.3	n	1.3	n	16	n	100	n	170	n	35	n
1,2,4-Trimethylbenzene	6.3	n	1.3	n	22	n	150	n	240	n	49	n
Vinyl Chloride	0.17	c	0.07	c	17	c	6.7	c	6	c	2	c
Xylene	10	n	2.3	n	300	n	69	n	3500	n	800	n

(1) based on lower of HI=1 or 1x10e-6, except 1,2-Dichloroethylene, chloroform, & TCE
(2) based on lower of HI=3 or 1x10e-4, except 1,2-Dichloroethylene, chloroform, & TCE
(3) based on lower of HI=0.1 or 1x10e-6, except 1,2-Dichloroethylene, chloroform, & TCE
(a) RSL based on HI=0.1 & RML based on HI=1 because of chloroform being a threshold carcinogen (USEPA IRIS file)
(b) based on ATSDR MRL for trans-1,2-Dichloroethylene: http://www.atsdr.cdc.gov/mrls/pdfs/atsdr_mrls.pdf
(c) Values were calculated using the default sub-slab attenuation factor of 0.03
(d) based on HI=1 to be protective of sensitive sub-populations
(e) based on HI=3 to be protective of non-sensitive populations
SSV - Site Specific Value should be calculated
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*This table is not for rule making or specific guidance. It is a Region 4 screening tool only.

MEMORANDUM

DATE: June 17, 2014

SUBJECT: Removal of the *trans*-1,2-Dichloroethylene (CASRN 156-60-5) Provisional Peer-Reviewed Toxicity Value (PPRTV) assessment from the Electronic Library

FROM: Scott Wesselkamper
Director, Superfund Health Risk Technical Support Center (STSC)
EPA/ORD/NCEA

TO: Michele Burgess (OSWER/OSRTI)
Lynn Flowers (NCEA)
Teresa Shannon (NCEA)
The File

It was brought to the attention of the STSC that there is an inconsistency in the conclusions regarding the derivation of a reference concentration (RfC) for *trans*-1,2-Dichloroethylene (DCE) between the 2006 PPRTV assessment and the 2010 IRIS assessment (http://www.epa.gov/iris/toxreviews/0418tr.pdf) for this chemical. The 2006 PPRTV assessment derived a chronic p-RfC of 0.06 mg/m^3 based on pulmonary and liver effects observed in the principal study by Freundt et al. (1977). No subchronic p-RfC was derived. The 2010 IRIS assessment found Freundt et al. (1977), a study by the National Toxicology Program (NTP, 2002), and an unpublished study by DuPont (1998) to be insufficient to support derivation of an RfC value for *trans*-1,2-DCE. Thus, there appears to be a fundamental difference in how the principal study and critical effect(s) used to derive the chronic p-RfC in the 2006 PPRTV assessment were evaluated compared to what was more recently done by IRIS. It is important to note that there are some differences in the respective decision-making processes for developing PPRTV and IRIS assessments, specifically with the IRIS Program having a more extensive review process (e.g., agency and interagency review steps, a public comment period, etc.) than that utilized for developing PPRTV assessments.

Pertinent information from the 2010 IRIS Toxicological Review on *trans*-1,2-DCE that outlines why the Freundt et al. (1977) study was discounted and no RfC value was derived is excerpted and italicized below:

"The finding of lung effects in the Freundt et al. (1977) study is difficult to interpret as this study is the only report of lung pathology in animals exposed to trans-1,2-DCE, a small number of animals were examined, several of the controls also developed this effect, and the upper respiratory tract was not examined for pathology."

"For each of the exposure durations, there was no statistically significant difference between the controls and the exposed groups with respect to the incidence of liver effects (fat accumulation). In general, however, the incidence and severity of fat accumulation increased with increasing exposure duration. Although Freundt et al. (1977) reported histopathologic changes in the liver of rats, the DuPont (1998) study did not corroborate the Freundt et al. (1977) study findings. DuPont (1998) reported relatively small increases in relative and absolute liver weight (1–8%) and no gross or microscopic changes of the liver attributable to trans-1,2-DCE at an exposure concentration 20-fold higher than that

used in the Freundt et al. (1977) study. NTP (2002a) similarly found no histopathologic changes in the liver when trans-1,2-DCE was administered for 90 days by the oral route at dietary concentrations as high as 50,000 ppm. In light of the results of DuPont (1998) and NTP (2002a), it is difficult to explain the liver findings in the single-exposure concentration study by Freundt et al. (1977). Given the limitations of the Freundt et al. (1977) study (i.e., small sample size, use of only one exposure concentration, and observation of fatty accumulation in the liver lobules and Kupffer cells in control animals at some exposure durations) and lack of corroboration from other studies, the Freundt et al. (1977) study was not used as the basis for deriving an RfC for trans-1,2-DCE."

"In summary, the available inhalation data from DuPont (1998) and Freundt et al. (1977) were considered insufficient to support reference value derivation and, therefore, an RfC for trans-1,2-DCE was not derived."

Current practice by the PPRTV Program states that once an IRIS assessment becomes available for any given chemical, the PPRTV assessment for that chemical is removed from the PPRTV electronic library. Thus, based on this practice and the rationale outlined above, it is recommended that the conclusions presented in the IRIS assessment for *trans*-1,2-DCE be presently adhered to, and the *trans*-1,2-DCE PPRTV assessment has been removed from the electronic library. Any additional questions regarding *trans*-1,2-DCE should be directed to the IRIS Hotline at (202) 566-1676 or http://www.epa.gov/iris/contact_hotline.htm.

References:

Freundt, K.J., G.P. Liebaldt and E. Lieberwirth. 1977. Toxicity studies on trans-1,2-dichloroethylene. Toxicology. 7: 141-153.

NTP (2002). NTP technical report on the toxicity studies of trans-1,2-dichloroethylene (CAS No. 156-60-5) administered in microcapsules in feed to F344/N rats and B6C3F1 mice. Public Health Service, U.S. Department of Health and Human Services; NTP TR 55. Available from the National Institute of Environmental Health Sciences, Research Triangle Park, NC and online at http://ntp.niehs.nih.gov/ntp/htdocs/ST_rpts/tox055.pdf

10-31-2002

Provisional Peer Reviewed Toxicity Values for

trans-1,2-Dichloroethylene
(CASRN 156-60-5)

Derivation of a Chronic Inhalation RfC

Superfund Health Risk Technical Support Center
National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

Acronyms and Abbreviations

bw	body weight
cc	cubic centimeters
CD	Caesarean Delivered
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act of 1980
CNS	central nervous system
cu.m	cubic meter
DWEL	Drinking Water Equivalent Level
FEL	frank-effect level
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
g	grams
GI	gastrointestinal
HEC	human equivalent concentration
Hgb	hemoglobin
i.m.	intramuscular
i.p.	intraperitoneal
i.v.	intravenous
IRIS	Integrated Risk Information System
IUR	inhalation unit risk
kg	kilogram
L	liter
LEL	lowest-effect level
LOAEL	lowest-observed-adverse-effect level
LOAEL(ADJ)	LOAEL adjusted to continuous exposure duration
LOAEL(HEC)	LOAEL adjusted for dosimetric differences across species to a human
m	meter
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF	modifying factor
mg	milligram
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
MRL	minimal risk level
MTD	maximum tolerated dose
MTL	median threshold limit

NAAQS	National Ambient Air Quality Standards
NOAEL	no-observed-adverse-effect level
NOAEL(ADJ)	NOAEL adjusted to continuous exposure duration
NOAEL(HEC)	NOAEL adjusted for dosimetric differences across species to a human
NOEL	no-observed-effect level
OSF	oral slope factor
p-IUR	**provisional inhalation unit risk**
p-OSF	**provisional oral slope factor**
p-RfC	**provisional inhalation reference concentration**
p-RfD	**provisional oral reference dose**
PBPK	physiologically based pharmacokinetic
ppb	parts per billion
ppm	parts per million
PPRTV	**Provisional Peer Reviewed Toxicity Value**
RBC	red blood cell(s)
RCRA	Resource Conservation and Recovery Act
RDDR	Regional deposited dose ratio (for the indicated lung region)
REL	relative exposure level
RfC	inhalation reference concentration
RfD	oral reference dose
RGDR	Regional gas dose ratio (for the indicated lung region)
s.c.	subcutaneous
SCE	sister chromatid exchange
SDWA	Safe Drinking Water Act
sq.cm.	square centimeters
TSCA	Toxic Substances Control Act
UF	uncertainty factor
μg	microgram
μmol	micromoles
VOC	volatile organic compound

PROVISIONAL PEER REVIEWED TOXICITY VALUES FOR *trans*-1,2-DICHLOROETHYLENE
Derivation of a Chronic Inhalation RfC

Background

On December 5, 2003, the U.S. Environmental Protection Agency's (EPA's) Office of Superfund Remediation and Technology Innovation (OSRTI) revised its hierarchy of human health toxicity values for Superfund risk assessments, establishing the following three tiers as the new hierarchy:

1. EPA's Integrated Risk Information System (IRIS).

2. Provisional Peer-Reviewed Toxicity Values (PPRTV) used in EPA's Superfund Program.

3. Other (peer-reviewed) toxicity values, including:

   - Minimal Risk Levels produced by the Agency for Toxic Substances and Disease Registry (ATSDR),
   - California Environmental Protection Agency (CalEPA) values, and
   - EPA Health Effects Assessment Summary Table (HEAST) values.

A PPRTV is defined as a toxicity value derived for use in the Superfund Program when such a value is not available in EPA's Integrated Risk Information System (IRIS). PPRTVs are developed according to a Standard Operating Procedure (SOP) and are derived after a review of the relevant scientific literature using the same methods, sources of data, and Agency guidance for value derivation generally used by the EPA IRIS Program. All provisional toxicity values receive internal review by two EPA scientists and external peer review by three independently selected scientific experts. PPRTVs differ from IRIS values in that PPRTVs do not receive the multi-program consensus review provided for IRIS values. This is because IRIS values are generally intended to be used in all EPA programs, while PPRTVs are developed specifically for the Superfund Program.

Because science and available information evolve, PPRTVs are initially derived with a three-year life-cycle. However, EPA Regions or the EPA Headquarters Superfund Program sometimes request that a frequently used PPRTV be reassessed. Once an IRIS value for a specific chemical becomes available for Agency review, the analogous PPRTV for that same chemical is retired. It should also be noted that some PPRTV manuscripts conclude that a PPRTV cannot be derived based on inadequate data.

Disclaimers

Users of this document should first check to see if any IRIS values exist for the chemical of concern before proceeding to use a PPRTV. If no IRIS value is available, staff in the regional Superfund and RCRA program offices are advised to carefully review the information provided in this document to ensure that the PPRTVs used are appropriate for the types of exposures and circumstances at the Superfund site or RCRA facility in question. PPRTVs are periodically updated; therefore, users should ensure that the values contained in the PPRTV are current at the time of use.

It is important to remember that a provisional value alone tells very little about the adverse effects of a chemical or the quality of evidence on which the value is based. Therefore, users are strongly encouraged to read the entire PPRTV manuscript and understand the strengths and limitations of the derived provisional values. PPRTVs are developed by the EPA Office of Research and Development's National Center for Environmental Assessment, Superfund Health Risk Technical Support Center for OSRTI. Other EPA programs or external parties who may choose of their own initiative to use these PPRTVs are advised that Superfund resources will not generally be used to respond to challenges of PPRTVs used in a context outside of the Superfund Program.

Questions Regarding PPRTVs

Questions regarding the contents of the PPRTVs and their appropriate use (e.g., on chemicals not covered, or whether chemicals have pending IRIS toxicity values) may be directed to the EPA Office of Research and Development's National Center for Environmental Assessment, Superfund Health Risk Technical Support Center (513-569-7300), or OSRTI.

INTRODUCTION

An RfC for *trans*-1,2-dichloroethylene is not available on IRIS (U.S. EPA, 2002) or in the HEAST (U.S. EPA, 1997). The CARA list (U.S. EPA, 1991, 1994a) includes a Health Effects Assessment (HEA) for *trans*-1,2-dichloroethylene (U.S. EPA, 1984) and a Health and Environmental Effects Profile (HEEP) on dichloroethylenes (U.S. EPA, 1986) that reported no data regarding inhalation toxicity in humans and inconsistent results in two subchronic inhalation assays in animals. ATSDR (1996) established an intermediate inhalation MRL of 0.2 ppm (0.8 mg/m^3) based on a LOAEL of 200 ppm (790 mg/m^3) in a 16-week subchronic inhalation study in rats by Freundt et al. (1977) to protect against hepatic effects. ACGIH (1991, 2001) assigned a TLV-TWA of 200 ppm (790 mg/m^3) for all isomers of 1,2-dichloroethylene based on a no-effect level of 1000 ppm following exposure to mixed isomers in a study by Torkelson (ACGIH, 1991). However, the value was under review, since liver effects had been reported in rats repeatedly exposed to 200 ppm of the *trans* isomer (Freundt et al., 1977). The NIOSH (1981, 2001) REL-TWA and OSHA (1999, 2000) PEL for isomers of 1,2-dichloroethylene were both established at

200 ppm (790 mg/m^3) to protect against irritation of the eyes and respiratory system and depression of the central nervous system. Neither IARC (2001) nor the WHO (2001) have written a toxicological review document on *trans*-1,2-dichloroethylene. A toxicity review on unsaturated halogenated hydrocarbons (Lemen, 2001) and the NTP (2001a,b) management status report and health and safety report for *trans*-1,2-dichloroethylene were consulted for relevant information. Literature searches were conducted from 1994 to June 2001 for studies relevant to the derivation of a provisional RfC for *trans*-1,2-dichloroethylene. The databases searched were: TOXLINE, MEDLINE, CANCERLIT, TOXLIT/BIOSIS, RTECS, HSDB, GENETOX, CCRIS, TSCATS, EMIC/EMICBACK, and DART/ETICBACK.

REVIEW OF THE PERTINENT LITERATURE

Human Studies

Acute exposures to high concentrations (>1000 ppm) of *trans*-1,2-dichloroethylene have been reported to cause eye irritation, nausea, vertigo, and narcosis in humans (ACGIH, 1991; OSHA, 1999). Due to its narcotic effects, *trans*-1,2-dichloroethylene has been used as an anesthetic in humans (ACGIH, 1991). One human fatality, presumably from depression of the central nervous system, was reported following exposure to an unknown quantity of 1,2-dichloroethylene vapor (isomer composition unreported) in an enclosed area (ATSDR, 1996). No data regarding chronic or subchronic inhalation toxicity of *trans*-1,2-dichloroethylene in humans were found in the available review documents (U.S. EPA, 1984, 1986; Lemen, 2001) or in the literature search.

Animal Studies

1,2-Dichloroethylene has been used as an anesthetic in animals (ACGIH, 1991; Lemen, 2001). Inhalation toxicity studies of *trans*-1,2-dichloroethylene in animals include a subchronic rat study by Freundt et al. (1977) and a developmental rat study by Hurtt et al. (1993). No chronic duration animal study was located in the literature search.

Other Studies

Freundt et al. (1977) exposed groups of six female Wistar rats by inhalation to 0 or 200 ppm (0 or 794 mg/m^3) of *trans*-1,2-dichloroethylene for 8 hours/day for 1 day only and for 8 hours/day, 5 days/week for prolonged durations of 1, 2, 8 and 16 weeks. Additional studies were done at higher concentrations (1000 and 3000 ppm) for 8 hours/day for a single day. All concentrations were given as mean values with a variability of ±3% (S.E.M.) based on monitoring the chambers using gas chromatography.

Subsequent to single and repeated exposures at 200 ppm, the rats were examined for gross pathology and histological pathology of selected organs (brain, sciatic nerve, lung, heart,

liver, kidney, spleen, brain, and muscle). No signs of narcosis were observed during exposure, and no mortality was reported. Histopathological effects were observed only in the liver(fatty accumulation in liver lobule and Kupffer cells) and lungs (capillary hyperemia and alveolar septum distension).

Repeated exposures of 200 ppm for 1 and 2 weeks produced only slight histopathological changes for liver and lungs in contrast to the studies of 8 and 16 weeks where slight to severe changes were noted. Therefore, these latter studies of longer duration will only be addressed in this report.

In the group exposed for 8 weeks, fatty degeneration was observed in the liver lobule of 3/6 treated rats (versus 0/6 controls) and in the Kupffer cells of 3/6 treated rats (versus 1/6 controls). In the group exposed for 16 weeks, fatty degeneration both in the liver lobule and in Kupffer cells was observed in 5/6 treated rats and 2/6 controls. The observed liver lesions were graded as slight changes, except for Kupffer cell fat accumulation in the 8-week exposure group (all 3 treated and 1 control rats showing the lesion) and liver lobule fat accumulation in the 16-week exposure group (3 of the 5 treated rats with the lesion), which were graded as severe changes. Lung lesions were all graded as slight changes. In the 8-week exposure group, pulmonary capillary hyperemia and distension of the alveolar septum were observed in 6/6 treated rats (3 with severe pneumonic infiltration) and 0/6 controls. Identical findings were reported in the16-week exposure group. This study identified a free standing LOAEL of 200 ppm (794 mg/m^3) for hepatic and pulmonary lesions in rats subchronically exposed to *trans*-1,2-dichloroethylene.

These findings are supported by shorter-term experiments described in the same paper. Freundt et al. (1977) observed the same hepatic and pulmonary effects (hepatic fatty infiltration, pulmonary capillary hyperemia, and alveolar septal distension) in rats exposed to 200 ppm for as short as 8 hours. With the exception of one rat in a single exposure for 8 hours only), the incidence and/or severity was lower . Eight-hour exposure to higher concentrations produced no additional effects, except that histopathology of the cardiac muscle was observed in rats given a single 8-hour exposure to 3000 ppm. Additional studies showed that pulmonary lesions similar to those observed by inhalation exposure were also produced by intraperitoneal exposure. Based on this finding and the absence of histological evidence (transudates or exudates) for irritation of the bronchial epithelium, the investigators suggested that irritation can be discounted as the causal agent for the observed lesions and that the pulmonary lesions may be, at least in part, systemic in origin.

An overview of all the brief and prolonged studies demonstrates that both dose (200, 1000 and 3000 ppm for 8 hours) and time (200 ppm for 8 hours, 1, 2, 8 and 16 weeks) do appear to make a difference in the severity of fat accumulation in the liver lobule and of cardiotoxicity.

A developmental study by Hurtt et al. (1993) showed that the developing organism is not a sensitive target for *trans*-1,2-dichloroethylene. Hurtt et al. (1993) exposed groups of 24

presumed pregnant female CRL:CD BR rats by inhalation to concentrations of 0, 2000, 6000, or 12,000 ppm (0, 7940, 23,820, or 47,640 mg/m^3) of *trans*-1,2-dichloroethylene (99.64% purity) for 6 hours/day on gestational days (GD) 7-16. Rats were observed daily (twice daily on exposure days) for clinical signs. During exposure, the response of the dams to a sound stimulus (rapping on the side of the exposure chamber) was recorded; because of the design of the chamber, not all animals in each group could be observed. Maternal body weight was recorded on GD 1, 7-17, and 22; feed consumption was measured on alternate days from GD 1-19 and on GD 22. Dams were sacrificed on GD 22 and examined for gross pathology; the weights of liver, gravid uterus and empty uterus were recorded. Other endpoints included the number of uterine resorptions (revealed by ammonium sulfide staining in apparently 'nonpregnant' dams), fetal mortality, weight and sex of live fetuses, and the number of stunted live fetuses. All fetuses were examined for external malformations and variations, and subsequently analyzed for either skeletal or visceral changes. Two control females were found to be not pregnant and were excluded from most analyses.

No maternal mortality was observed (Hurtt et al., 1993). Significantly reduced body weight gain was observed at 6000 ppm on GD 11-13 and at 12,000 ppm on GD 7-17 (actual loss of weight on GD 7-9). Significantly reduced feed consumption occurred at 2000 ppm on GD 13-15, and at both higher doses during the exposure period. Body weight and food consumption reverted to normal values during the post-exposure period. Ocular irritation (lacrimation and stained periocular hair) was observed in all exposed groups. Narcotizing effects of treatment and alopecia were observed at 6000 and 12,000 ppm, and lethargy and salivation at 12,000 ppm. Of these clinical signs, only alopecia was observed in exposed rats in the post-exposure period. No other compound-related effects were observed in dams. Significant trends and increases in the mean number of total and early resorptions per litter were found in dams exposed to 6000 or 12,000 ppm. However, the researchers considered this finding to be not biologically significant, but rather an artifact of the unusually low resorption rate in the concurrent control group; rates in exposed groups were within the limits of historical control data from the same laboratory during the previous 2 years. The pregnancy rate, corpora lutea, fetuses per litter, and number of stunted fetuses were unaffected by treatment. At 12,000 ppm, mean fetal weight was significantly reduced and there was a small, statistically nonsignificant increase in the incidence of hydrocephalus. Otherwise, treatment had no significant effect on the incidence of fetal malformations or variations. In this study, fetal effects were found only at high concentrations producing overt maternal toxicity, indicating that the developing organism is not a sensitive target of *trans*-1,2-dichloroethylene toxicity.

In a briefly-described range-finding experiment for the developmental study, Hurtt et al. (1993) exposed groups of pregnant female Crl:CD BR rats by inhalation to 0, 6000, 9000, or 12,000 ppm (0, 23,820, 35,730, or 47,640 mg/m^3) of *trans*-1,2-dichloroethylene for 6 hours/day on gestational days 7-16. Narcosis [central nervous system (CNS) depression] was observed in all test groups during exposure and was evident as incoordination immediately following exposure. Maternal body weight gain and food consumption were decreased at the two highest exposure levels, and fetal body weight was decreased at the highest level.

DERIVATION OF A PROVISIONAL RfC FOR *trans*-1,2-DICHLOROETHYLENE

No pertinent data were located regarding the chronic or subchronic inhalation toxicity of *trans*-1,2-dichloroethylene in humans. No chronic inhalation toxicity study in animals was located in the literature search. The 16-week subchronic rat inhalation toxicity study by Freundt et al. (1977) was cited on IRIS (U.S. EPA, 2002) in support of the oral RfD, but was not used to derive a p-RfC. The U.S. EPA (1986) concluded that there was an unresolvable conflict between the adverse level of 200 ppm for the *trans* isomer in the Freundt study and results of an unpublished study on the mixed isomers by Torkelson that was submitted in 1965 to the ACGIH (1991). As reported in secondary sources (Torkelson and Rowe, 1981; ACGIH, 1991), no adverse effects were observed in rats, guinea pigs, rabbits, or dogs exposed by inhalation to the equivalent of 200 or 400 ppm of *trans*-1,2-dichloroethylene (500 or 1000 ppm of 1,2-dichloroethylene containing 40% *trans* isomer) for 7 hours/day, 5 days/week for 6 months. However, as indicated in a report of this study submitted to the EPA in 1994 (Dow, 1962), statistically significant increases in organ weights relative to body weight were observed in the liver of female rats and the kidney of male rats at both exposure levels, and in kidney of female rats at the high exposure level; in addition, average relative liver weight was also increased in a small group of male and female rabbits. The reported organ weight changes observed for the mixed isomers in the Dow (1962) study would appear to provide support for the *trans*-isomer-related hepatic toxicity reported by Freundt et al. (1977). However, absolute organ weights and histopathology results were not reported for the Dow (1962) study.

The critical study of Freundt et al. (1977) reported adverse effects in the liver (fatty degeneration) and lung (pulmonary capillary hyperemia and distension of the alveolar septum) in female Wistar rats exposed to atmospheres containing 200 ppm (794 mg/m^3) of *trans*-1,2-dichloroethylene 8 hours/day, 5 days/week for 16 weeks. As mentioned above, the pulmonary effects were considered to be not only local, but systemic, since they occurred in rats exposed by other routes and were not accompanied by signs of irritation in the lungs (Freundt et al., 1977). Although these same lesions were also observed in rats exposed to the same free standing LOAEL of 200 ppm for only 8 hours, a p-RfC based on this LOAEL is expected to be protective for systemic effects from chronic exposure. The minimal nature of the effects in the 8-hour study suggests that the LOAEL of 200 ppm is very close to the threshold for acute effects. Exposure to 200 ppm for longer durations (up to 16 weeks) or higher concentrations (up to 3000 ppm) for acute durations produced increases in incidence and/or severity of the lesions, but no differences in the types of lesions observed or target organs (with the exception of cardiac histopathology after 3000 ppm for 8 hours). This suggests that the concentration- and duration-response curves for *trans*-1,2-dichloroethylene are shallow, and therefore, that the LOAEL of 200 ppm is a reasonable basis for a chronic p-RfC (i.e., uncertainty factors applied during derivation of the p-RfC are likely to encompass the chronic NOAEL).

The developmental study of Hurtt et al. (1993) was conducted at much higher concentrations (2000-12000 ppm) than the Freundt et al. (1977) study. At these levels, *trans*-1,2-dichloroethylene produced overt clinical signs of toxicity in the dams. Fetal effects were

observed, but only at levels that also produced overt maternal toxicity. Therefore, a p-RfC based on the LOAEL of 200 ppm (794 mg/m^3) is expected to provide adequate protection of the fetus in case of maternal exposure.

To calculate the provisional RfC, the LOAEL of 200 ppm (794 mg/m^3) in rats (Freundt et al., 1977) is first adjusted for intermittent exposure, as follows (U.S. EPA, 1994b):

$$\begin{aligned} LOAEL_{ADJ} &= (LOAEL_{RAT})\ (\text{hours}/24\ \text{hours})\ (\text{days}/7\ \text{days}) \\ &= (794\ \text{mg/m}^3)\ (8/24)\ (5/7) \\ &= 189\ \text{mg/m}^3 \end{aligned}$$

For purposes of calculating the p-RfC, *trans*-1,2-dichloroethylene was treated as a category 3 gas. Lesions in the lung, as well as the liver, were considered extrarespiratory effects for this derivation, because the evidence (discussed above) suggests that the lung lesions were, at least partly, systemic in origin. The human equivalent concentration (HEC) for extrarespiratory effects produced by a category 3 gas is calculated by multiplying the duration-adjusted LOAEL by the ratio of blood:gas partition coefficients ($H_{b/g}$) in animals and humans (U.S. EPA, 1994b). Since the value of $H_{b/g}$ for *trans*-1,2-dichloroethylene in rats (9.58; Gargas et al., 1989) is larger than $H_{b/g}$ in humans (6.04), a default value of 1 is used for the ratio of partition coefficients, and the $LOAEL_{HEC}$ becomes 189 mg/m^3:

$$LOAEL_{HEC} = (LOAEL_{ADJ}) \times [(H_{b/g})_{RAT} / (H_{b/g})_{HUMAN}],$$

If $(H_{b/g})_{RAT} > (H_{b/g})_{HUMAN}$, then $(H_{b/g})_{RAT} / (H_{b/g})_{HUMAN} = 1$

$$\begin{aligned} &\text{Since } 9.58 > 6.04, \\ &= 189\ \text{mg/m}^3 \times [1] = 189\ \text{mg/m}^3 \end{aligned}$$

A composite uncertainty factor of 3000 was used, reflecting the following areas of uncertainty: use of a LOAEL, use of a less than chronic study, extrapolation from rats to humans using the dosimetric adjustments, protection of sensitive individuals, and database deficiencies (including lack of a multigeneration reproduction study). The modifying factor was set to 1. The provisional RfC for *trans*-1,2-dichloroethylene was derived as follows:

$$\begin{aligned} \text{p-RfC} &= LOAEL_{HEC} \div (UF \times MF) \\ &= 189\ \text{mg/m}^3 \div (3000 \times 1) \\ &= 0.06 \text{ or } 6E\text{-}2\ \text{mg/m}^3 \end{aligned}$$

Although based on the same critical study, the provisional RfC for *trans*-1,2-dichloroethylene (6E-2 mg/m^3) is 13-fold lower than the intermediate inhalation MRL (8E-1 mg/m^3) calculated by ATSDR (1996). This difference stems from lack of duration adjustment and an alternative application of uncertainty factors in the ATSDR (1996) assessment.

STATEMENT OF CONFIDENCE

Confidence in the critical study is low because, although methods and results were adequately designed, conducted and reported, certain inadequacies remain, namely, small sample size, use of a single sex, the use of a single exposure level, the relatively short exposure duration, and the lack of analysis of body and organs weights, nasal histology, clinical chemistry, and hematology. Confidence in the database is low because of the lack of data for exposures longer than 16 weeks, or for species other than rat, and the lack of a multigeneration reproduction study. Low confidence in the p-RfC results.

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E.10. PERTINENT TOXICITY VALUES AND INFORMATION

The "BAF_{fish}" is the bioaccumulation factor for fish. EPA's "Waste and Cleanup Risk Assessment Glossary" defines it as the ratio of the concentration of a contaminant in an organism to the concentration in the ambient environment at steady state, where the organism can take in the contaminant through ingestion with its food as well as through direct contact. BAF_{fish} is not used in PRG derivation, but is presented in this table for reference only. The BAF_{fish} is in units of L/kg. Bioaccumulation factors for other organisms are available on the RAIS Web site and in *Risk Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, DOE/LX/07-0107&D2/R1, February 2011.

Chemical Abstract Number	Analyte	BAF_{fish}	BAF_{fish} Ref.
7429-90-5	Aluminum	5.00E+02	NCRP
7440-36-0	Antimony (metallic)	1.00E+02	NCRP
7440-38-2	Arsenic, Inorganic	3.00E+02	Wang
7440-39-3	Barium	4.00E+00	IAEA
7440-41-7	Beryllium and compounds	1.00E+02	NCRP
7440-42-8	Boron And Borates Only		
7440-43-9	Cadmium (Diet)	2.00E+02	NCRP
7440-43-9	Cadmium (Water)	2.00E+02	NCRP
7440-47-3	Chromium (Total)		
16065-83-1	Chromium(III), Insoluble Salts	2.00E+02	IAEA
18540-29-9	Chromium(VI)	2.00E+02	IAEA
7440-48-4	Cobalt	3.00E+02	IAEA
7440-50-8	Copper	2.00E+02	NCRP
16984-48-8	Fluoride		
7439-89-6	Iron	2.00E+02	NCRP
7439-92-1	Lead	3.00E+02	IAEA
7439-96-5	Manganese (Diet)	4.00E+02	IAEA
7439-96-5	Manganese (Non-diet)	4.00E+02	IAEA
7439-97-6	Mercury, Inorganic Salts	1.00E+03	NCRP
7439-98-7	Molybdenum	1.00E+01	NCRP
7440-02-0	Nickel Soluble Salts	1.00E+02	IAEA
7782-49-2	Selenium	2.00E+02	NCRP
7440-22-4	Silver	5.00E+00	IAEA94
7440-28-0	Thallium (Soluble Salts)	1.00E+04	NCRP
N/A	Uranium (Soluble Salts)	1.00E+01	IAEA
N/A	Vanadium and Compounds		
7440-66-6	Zinc and Compounds	1.00E+03	IAEA
83-32-9	Acenaphthene	7.55E+02	EPI
208-96-8	Acenaphthylene[a]	2.71E+02	EPI
107-13-1	Acrylonitrile	3.16E+00	EPI
120-12-7	Anthracene	1.80E+03	EPI
71-43-2	Benzene	4.27E+00	EPI
117-81-7	Bis(2-ethylhexyl)phthalate[b]	5.88E+02	EPI
75-27-4	Bromodichloromethane	9.70E+00	EPI
86-74-8	Carbazole	1.70E+02	EPI
56-23-5	Carbon Tetrachloride	7.40E+00	EPI
67-66-3	Chloroform	1.30E+01	EPI
75-71-8	Dichlorodifluoromethane (Freon-12)[b]	6.15E+00	EPI

Chemical Abstract Number	Analyte	BAF_{fish}	BAF_{fish} Ref.
75-34-3	Dichloroethane, 1,1- [b]	7.05E+00	EPI
107-06-2	Dichloroethane, 1,2-	4.40E+00	EPI
75-35-4	Dichloroethylene, 1,1-	1.30E+01	EPI
540-59-0	Dichloroethylene, 1,2- (Mixed Isomers)	1.11E+01	EPI
156-59-2	Dichloroethylene, 1,2-*cis*-	1.11E+01	EPI
156-60-5	Dichloroethylene, 1,2-*trans*-	1.11E+01	EPI
60-57-1	Dieldrin	7.48E+03	EPI
1746-01-6	Dioxins/Furans, Total		
37871-00-4	~HpCDD		
38998-75-3	~HpCDF, 2,3,7,8-		
34465-46-8	~HxCDD, 2,3,7,8-		
55684-94-1	~HxCDF, 2,3,7,8-		
3268-87-9	~OCDD	1.31E+03	EPI
39001-02-0	~OCDF		
36088-22-9	~PeCDD, 2,3,7,8-		
57117-41-6	~PeCDF, 1,2,3,7,8-		
57117-31-4	~PeCDF, 2,3,4,7,8-		
1746-01-6	~TCDD, 2,3,7,8-	9.70E+04	EPI
51207-31-9	~TCDF, 2,3,7,8-	4.06E+03	EPI
100-41-4	Ethylbenzene	5.56E+01	EPI
206-44-0	Fluoranthene	3.63E+03	EPI
86-73-7	Fluorene	5.25E+02	EPI
118-74-1	Hexachlorobenzene	2.14E+04	EPI
91-20-3	Naphthalene	8.45E+01	EPI
88-74-4	Nitroaniline, 2-	1.00E+01	EPI
621-64-7	Nitroso-di-N-propylamine, N-	3.67E+00	EPI
87-86-5	Pentachlorophenol	5.96E+02	EPI
85-01-8	Phenanthrene[a]	2.51E+03	EPI
1336-36-3	Polychlorinated Biphenyls (high risk)	2.53E+04	EPI
1336-36-3	Polychlorinated Biphenyls (low risk)	2.53E+04	EPI
12674-11-2	~Aroclor 1016	9.14E+03	EPI
11104-28-2	~Aroclor 1221		
11141-16-5	~Aroclor 1232		
53469-21-9	~Aroclor 1242		
12672-29-6	~Aroclor 1248		
11097-69-1	~Aroclor 1254		
11096-82-5	~Aroclor 1260		
50-32-8	Polycyclic aromatic hydrocarbons (cPAH), Total Carcinogenic		
56-55-3	~Benz[a]anthracene	2.60E+02	EPI
50-32-8	~Benzo[a]pyrene	5.15E+03	EPI
205-99-2	~Benzo[b]fluoranthene	3.02E+03	EPI
207-08-9	~Benzo[k]fluoranthene	4.99E+03	EPI
218-01-9	~Chrysene	3.17E+03	EPI
53-70-3	~Dibenz[a,h]anthracene	9.60E+03	EPI
193-39-5	~Indeno[1,2,3-cd]pyrene	1.22E+04	EPI
129-00-0	Pyrene	1.51E+03	EPI
127-18-4	Tetrachloroethylene	5.20E+01	EPI
108-88-3	Toluene[b]	8.32E+00	EPI
71-55-6	Trichloroethane, 1,1,1-	5.00E+00	EPI
79-00-5	Trichloroethane, 1,1,2-	5.00E+00	EPI
79-01-6	Trichloroethylene	1.60E+01	EPI
76-13-1	Trichloro-1,2,2-trifluoroethane, 1,1,2- (Freon-113)[b]	4.96E+01	EPI
75-01-4	Vinyl Chloride	5.47E+00	EPI
1330-20-7	Xylene, Mixture		
108-38-3	Xylene, m-	1.48E+01	EPI
95-47-6	Xylene, o-	1.41E+01	EPI
106-42-3	Xylene, P-	1.48E+01	EPI

Chemical Abstract Number	Analyte	BAF_{fish}	BAF_{fish} Ref.
14596-10-2	Americium-241	3.00E+01	IAEA
10045-97-3	Cesium-137	2.00E+03	IAEA
13994-20-2	Neptunium-237	1.00E+01	IAEA
13981-16-3	Plutonium-238	4.00E+00	IAEA
15117-48-3	Plutonium-239	4.00E+00	IAEA
14119-33-6	Plutonium-240	4.00E+00	IAEA
14133-76-7	Tcchnetium-99	2.00E+01	IAEA
14269-63-7	Thorium-230	3.00E+01	IAEA
13966-29-5	Uranium-234	1.00E+01	IAEA
15117-96-1	Uranium-235	1.00E+01	IAEA
7440-61-1	Uranium-238	1.00E+01	IAEA

Information compiled from RAIS October 2016.
[a] Values for Acenaphthylene and Phenanthrene, if not available use toxicity factors for Acenaphthene.
[b] Analytes are not PGDP significant COPCs (Table 2.1), but are provided for project support.

Reference Codes:

EPI EPA's Estimation Programs Interface Suite.

IAEA International Atomic Energy Agency (IAEA) 1982, *Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases. Exposures of Critical Groups*, Safety Series No. 57.

IAEA94 IAEA 1994, *Handbook of Parameter Values for the Prediction of Radionuclide Transfer in Temperate Environments*, Technical Reports Series No. 364.

NCRP National Council on Radiation Protection and Measurements, *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground.* Report No. 123, 1996.

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E.11. MEETING MINUTES FROM PADUCAH RISK ASSESSMENT WORKING GROUP

Notes from RAWG meetings held in 2000 through 2007 and minutes from RAWG quarterly meetings held from June 2012 through December 2016 are presented in Appendix E of *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/R8/V1 (DOE 2017). Meeting summaries from RAWG quarterly meetings held in 2017 are presented in Appendix E of *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/R9/V1 (DOE 2018). Meeting summaries from RAWG quarterly meetings held in 2018 are presented in Appendix E of *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/R10/V1 (DOE 2019). Meeting summaries from RAWG quarterly meetings held in 2019 are presented in Appendix E of *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/R11/V1 (DOE 2020). Meeting summaries from RAWG quarterly meetings held in 2020 are presented in Appendix E of *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/R12/V1 (DOE 2021). Meeting summaries from RAWG quarterly meetings held in 2021 are presented in Appendix E of *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/R13/V1 (DOE 2022). Meeting summaries from RAWG quarterly meetings held in 2022 are presented in Appendix E of *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/R14/V1 (DOE 2023). Meeting summaries from RAWG quarterly meetings held in 2023 are presented herein.

The meeting summaries presented herein, and within the annual updates to the Risk Methods Document since 2017, are provided for historical information to promote program consistency over time and facilitate succession planning. Meeting summaries may reflect document locations (e.g., table numbers) that have since been updated. The meeting summaries may not reflect information that currently is in the document.

Risk Assessment Working Group
Meeting Summary—March 1, 2023

DOE	EPA	Kentucky	FRNP
Rich Bonczek ✓	Shanna Alexander ✓	Brian Begley	Stefanie Fountain ✓
	Kristen Avedikian	Stephanie Brock	Bruce Ford
ETAS	Mac McRae	Nathan Garner ✓	LeAnne Garner
Martin Clauberg ✓	Ann Schnitz ✓	Will Grasch ✓	Christine Julias ✓
	Brett Thomas	Brian Lainhart	Chris Saranko ✓
	Victor Weeks ✓	Todd Mullins ✓	Grant Walter ✓
		Bart Shaffer ✓	
		Chris Travis	

✓ Indicates member was present

Original meeting agenda items are provided followed by meeting notes; the meeting notes are provided in *italics* with action items noted in *green*.

1. Call for Issues from Risk Assessment Working Group (RAWG) Members

No items were brought forward for discussion by the group.

2. Notes from 12/7/2022 Meeting

No comments were received on the December 7, 2022 meeting summary (provided to the group on December 21, 2022). If there are no additional comments, the meeting summary will be considered final and will appear in Appendix E of the 2023 Risk Methods Document (RMD).

No additional comments were received from the group on the December 7, 2022 meeting summary and the summary is now final.

3. FY 2023 Schedule/Work Plan

Activity	Target Finish
~~Submit Work Plan (FY2023) to RAWG~~	~~8/31/2022~~
~~Quarterly Meeting (September/FY22Q4)~~	~~9/7/2022~~
~~RAWG Concurs with FY2023 Work Plan~~	~~10/7/2022~~
~~RAWG Provide Additional Suggested Revisions/Corrections to Human Health (HH) Risk Methods Document (RMD) for FY22~~	~~10/21/2022~~
~~Quarterly Meeting (December/FY23Q1)~~	~~12/7/2022 (Moved from 12/14/2022)~~
~~Submit Draft FY2023 HH RMD Appendix A [i.e., Preliminary Remediation Goals (PRGs)] to RAWG for Review~~	~~12/8/2022~~
~~Provide Draft FY2023 HH RMD Main Text and Appendix B and D to RAWG for Review~~	~~12/20/2022~~
~~RAWG Comments Due for Draft FY2023 HH RMD Appendix A~~	~~1/20/2023~~

Activity	Target Finish
~~RAWG Comments Due for Draft FY2023 HH RMD Main Text and HH Appendix B and D~~	~~1/27/2023~~
~~Provide Draft FY2023 HH RMD Appendix E to RAWG for Review~~	~~2/16/2023 (Deleted)~~
Quarterly Meeting (March/FY23Q2)	3/1/2023
RAWG concurs with Draft FY2023 HH RMD Appendix A	3/3/2023 (was 2/17/2023)
RAWG Concurs with Draft FY2023 HH RMD Main Text and HH Appendix B and D	3/3/2023
~~RAWG Comments Due for Draft FY2023 HH RMD Appendix E~~	~~3/17/2023 (Deleted)~~
~~RAWG Concurs with Draft FY2023 HH RMD Appendix E~~	~~3/31/2023 (Deleted)~~
Provide Complete Draft FY2023 HH RMD to RAWG for Review	4/6/2023
RAWG Comments Due for Entire Revised HH RMD	5/5/2023
Quarterly Meeting (June/FY23Q3)	6/7/2023
Submit FY2023 HH RMD to FFA Managers (DOE/LX/07-0107&D2/R13/V1)	6/29/2023
FFA Managers Acknowledge Receipt of FY2023 HH RMD	7/28/2023
Submit Work Plan (FY2024) to RAWG	9/6/2023
Quarterly Meeting (September/FY23Q4)	9/13/2023
RAWG Concurs with FY2024 Work Plan	10/6/2023

Color code for schedule:

Due date	Quarterly meeting
Submittal date	Concurrence/acknowledgement date

Comments received on the FY 2023 RMD update to date (see Agenda Item 8 for discussion):

- Appendix A: EPA comments 1/17/2023; KY comments 1/18/2023
- Main Text, Appendix B, Appendix D: EPA comments 1/17/2023; KY no comments 1/24/2023
- Appendix E: DOE, EPA, and KY have agreed to forego separate review of draft Appendix E and instead review Appendix E when the complete draft document is provided on 4/6/2023.

The group did not have any comments on the FY 2023 schedule/work plan.

4. C-400 Data

The C-400 Remedial Investigation/Feasibility Study (RI/FS) report was submitted for FFA party review on January 5, 2023.

- An email request for specific discussion topics related to C-400 and risk methods or risk assessment was sent to the RAWG on February 13, 2023.
- The groundwater modeling values used for the project will be reviewed against the values in the probabilistic modeling discussion included in Appendix E of the Risk Methods Document.
- Question from T. Mullins 2/13/2023: I have been reviewing the C-400 screening level risk assessment. Do you know why the surface soil arsenic result from boring SOU047-001 wasn't used in the sector EPC calculation for the industrial worker? It looks like the result from boring 400S6-01 was used instead. The SOU047-001 result isn't that old and doesn't appear to be qualified in a way that would lead to its rejection. None of the arsenic levels are screaming high in this sector. I was just wondering why that data point was dropped.

No updates or comments on this topic were provided or brought forward by the group.

5. Anthropogenic Background

As discussed during December 7, 2022 meeting the group has agreed by consensus to develop a white paper on anthropogenic background in FY 2023.

Activity	Planning Date
Provide Draft Anthropogenic Background White Paper to RAWG	3/23/2023
RAWG Provide Comments on Draft Anthropogenic Background White Paper	4/14/2023
Submit Final Anthropogenic Background White Paper to EPA and KY	5/4/2023

The group discussed that the white paper is planned to be included in Appendix E of this year's update to the RMD.

6. Chemical Surrogates

The next chemical surrogates list review will be as part of the FY 2023 Q4 or FY 2024 Q1 meeting.

No updates or comments on this topic were provided or brought forward by the group during this portion of the meeting. As part of the discussion on comments to the RMD draft sections, ***EPA commented that fluorine should be considered as a surrogate for carbazole. Shanna will check the status of the fluorine report and Todd will check with his team on use of fluorine as a surrogate for carbazole.***

7. Emerging Contaminants

- PFAS
  - PFAS is discussed as part this working group and has ties to the Groundwater Modeling Working Group (MWG) as well.
  - The Paducah Site continues to participate in the DOE HQ PFAS Working Group Meetings. Rich is a member of the DOE PFAS Coordinating Committee and plans to coordinate Paducah information and actions with Oak Ridge and Portsmouth.
    - The PFAS Coordinating Committee last met on January 10, 2023.
    - The DOE HQ PFAS Working Group last met on January 12, 2023.
  - The Paducah Implementation Plan was provided to DOE HQ by December 31, 2022.
  - There are multiple DOE guidance documents in development:
    - The DOE Preliminary Assessment was released in late November and the template for the annual update has been reviewed and is pending finalization.
    - The preliminary assessment (PA) guidance is anticipated to be released in February 2023; the Paducah Site is already beyond the PA stage. Currently the draft refers sites to the EPA guidance. The group acknowledged that action levels currently are guidance and are not regulatory requirements.
    - The final DOE PFAS Investigation Guide was reviewed by Paducah and is expected to be available in January 2023.
    - The draft DOE PFAS Environmental Sampling Guide is in review. This guide is expected to be final in late spring 2023.

        - The DOE disposal guidance is has been internally reviewed by the DOE sites and is being finalized.
    - For Paducah, the main PFAS activity for 2023 is the in-progress PFAS screening assessment project. The final scope for the Site-wide PFAS Screening Assessment was included in the FY 2023 Environmental Monitoring Plan.
        - Drinking water samples were collected in November 2022 (Round 1) and a second set of samples was collected in January 2023 (Round 2). Round 1 samples were collected using standard procedures and method specific sample containers (consistent with the screening assessment project QAPP). The Round 2 samples were collected based on a question on the potential for cross-contamination of samples derived from clothing or products worn by the samplers and PFAS-specific collection procedures, including special sampler PPE, were developed, and an experienced PFAS sampler was mobilized for the sample collection; method specific sample containers were used.
            - During the December 2022 meeting, the group discussed the use of standard sampling procedures and the potential for cross-contamination of samples. DOE relayed that the potential for cross-contamination from the samplers themselves is thought to be minimal based on newer literature. For drinking water samples, the only equipment are the sample containers, which were obtained from the lab and are specific for the analytical method.
        - FRNP and DOE are putting the 2023 schedule of sampling together for the PFAS screening assessment project and will share that with EPA/KY once finalized. Sampling is planned to be completed this fiscal year with a Performance Assessment (PA)-type report or technical report that could form the basis of a PA to be written in the fall of 2023.
    - There is study on PFAS in fish tissue available, including an interactive map: (https://www.ewg.org/interactive-maps/pfas_in_US_fish/map/).
    - Interactions with FFA parties is being managed at the site level as opposed to the HQ level.
    - PFAS volatility is a subtopic being tracked by the group.
- 1,4-Dioxane
    - The site is responding to a DOE HQ survey on 1,4-dioxane, with responses provided by February 15, 2023.
    - 1,4-dioxane was historically used as a stabilizer in 1,1,1-trichloroethane and dichloroethane. The group plans to discuss fate & transport characteristics of 1,4-dioxane (compared to TCE) during the April 2023 Groundwater MWG meeting.

- *DOE-PPPO shared the implementation plan submitted to DOE HQ:*
    - *Results from the drinking water PFAS sampling are with management.*
    - *Historical research on PFAS use at the site is due to DOE HQ in the second quarter of FY 2023. This is largely done for PGDP. DOE HQ has completed their complex-wide research.*

- *The site field assessment annual survey form has been reviewed and comments were provided to DOE HQ. PFAS results as of last July will be in last year's ASER. This year's data will be in next year's ASER.*
- *The publication for PFAS Updated Status Report is planned for FY25.*
- *Bottled water has been provided on-site for many years, which satisfies the DOE requirement to provide an alternate drinking water supply if PFAS detected above regulatory limits. Review of the drinking water PFAS results is in progress.*
- *AFFF has been addressed at PGDP. Some AFFF materials are in storage, and some have been disposed of.*
- *DOE-PPPO has requested additional guidance from DOE HQ regarding disposal of PFAS-containing/contaminated wastes in Subtitle C landfills and the C-746-U Landfill.*
- *Interagency partners include PNNL (TRAC) and laboratories.*
- *DOE-PPPO management is working on a Communication Plan.*

The 2023 sample schedule is pending. Procedures for the sampling event have been revised for sampler precautions to address concerns raised by DOE management including potential cross-contamination from sampler personal hygiene products, clothing, PPE, etc. There has been no evidence of cross-contamination between Round 1 and Round 2 drinking water results, with a roughly 50-50 split between higher concentrations per analyte and lower concentrations between the two rounds. To understand potential bias from the monitoring wells samples (e.g., bias related to use of existing pumps, tubing, etc.) locations upgradient or cross-gradient from the plant industrial area will be used to compare plant industrial area location results. After the procedures are revised, the PFAS QAPP worksheets will be reissued.

The group is awaiting information from FFA Managers to understand if there will be a future PFAS project.

DOE-PPPO noted that PFAS volatility will be pertinent at the Paducah site and will be considered in DQOs if there is an RI-type project. Jeff Ryan (EPA) presented findings on PFAS air emissions at EPA national laboratory and noted air emissions can be a significant source of PFAS. ***Shanna (EPA) will track the publication and share when available. DOE will advise as to when they can share the DW results during the weekly GW call so the invite can be forwarded.***

A high 1,4-dioxane result from one well at C-400 cannot be replicated or confirmed as the MW has been dry since that sampling event. The group discussed that there are two methods that could be used to analyze for 1,4-dioxane and that the SVOC method tends to bias results low and the VOC method tends to bias results high. The 1,4-dioxane results are typically isolated detections and are not indicative of a plume. The group discussed that a lesson learned from PORTS is that if there is no air stripper on a groundwater/leachate treatment system, a special vessel would be needed for treatment of 1,4-dioxane. This may be relevant to the CERCLA cell project.

8. 2023 Update Comments

See Attachment 1.

9. Watch Topics:

- **Derivation of Risk-based Surface Water Effluent Limits**
  As discussed during the September 7, 2022 meeting, DOE has developed DOE Order 458.1 compliant ALARA-based standards for possible C-400 effluents. The results indicate that the limiting pathway is fish consumption and that these ALARA-based values will be below current Tc-99 and uranium MCLs and result in less than a 1 mrem/year dose to a maximally exposed individual. The ALARA values are within the EPA risk range and are currently planned to be included in the C-400 project Record of Decision and should be able to be used for other projects at Paducah. DOE presented the approach to EPA and KY during the Routine Paducah Groundwater Update call on February 9, 2023.

  DOE shared a presentation from a prior February 2023 discussion and outlined the proposed C-400 treatment system and its likely design efficiency (99%). An efficiency of 90% was used in the evaluation and an additional column for redundancy in case of system shutdown was assumed. DOE went through the calculated concentrations, the risk scenarios evaluated, and the resultant calculated risks. DOE also compared calculated project remedial goals (PRGs) to the no action levels (NALs) in the RMD and a calculated value for fish consumption. Risk was calculated for Tc-99: 4.0E-06 for the residential drinking water scenario, 4E-06 for the recreational swimming scenario, and 2.0E-06 for the fish consumption scenario. An increased rate of fish consumption was considered (the fish consumption rate of 29 g/d was increased to 54 g/d), resulting in a calculated risk of 3.0E-06. When mixing was considered, the calculated risk drops from 3.0E-06 to 7.0E-07. Each of these calculated risks are within or below the EPA risk range. If taken to the next step, DOE will review options for inclusion in a project document. DOE noted that ALARA itself is a DOE function only.

- **Status of EPA's Policy for Lead in Blood**
  - Shanna is tracking this item and will keep the team posted on any developments.
  - As part of the FY 2023 RMD update, the RAWG agreed that the no action level for lead should remain at 400 mg/kg until EPA releases additional information.
  - EPA relayed to the group during the September 7, 2022 meeting that a new EPA working group in this topic has been formed and the draft policy is in EPA internal review.

  No updates or comments on this topic were provided or brought forward by the group.

10. Poll RAWG Members/Open Discussion

The group discussed that the ecological volume of the RMD should be reviewed for potential update in FY 2024. A recommendation will be provided to the group at the September 2023 meeting.

Attachment 1

FY 2023 Risk Methods Document Comments Discussion

Main Text, Appendix B, Appendix D

KY Comments - KY did not have comments on the Main Text, Appendix B or Appendix D

USEPA Comments - Comments from Shanna Alexander transmitted via email from Victor Weeks on 1/25/2023

Comment	Response	Discussion/ Agreements
EPA previously discussed with the Risk Assessment Working Group (RAWG) the possible usefulness of the Exposure Factors Handbook (2011) and other relevant sources embedded in the Radionuclide PRG Calculator when selecting exposure factors for the various consumption scenarios (e.g., potentially contaminated homegrown vegetables and/or game animals). While it is not necessary to update the exposure factors provided in Table B.5, Section 3.3.7.2 of the text should identify these documents as potential sources of information for high-end (90th percentile and greater) RME (reasonable maximum exposure) estimates, including consumption rates. Further, while the weblink to the EPA's Radionuclide PRG calculator and User's Guide is provided in Appendix B.1, please also insert a reference in Section 5 of the main document.	Site-specific information is included in the RMD (Appendix E, Section E.2 and Attachments E1 and E2). A footnote has been added to Section 3.3.7.2 and a reference for the EPA's Radionuclide PRG calculator has been added to the RMD. This topic will be included as part of a future meeting agenda and a table comparing exposure factors for the consumption scenarios from the RMD, the Exposure Factors Handbook, and the Radionuclide PRG calculator will be prepared.	*The group discussed that the exposure factors were just updated and include new plant uptake factors. This topic will be included in a future meeting agenda.*
Section 3.3.7.2 new footnote: In addition to the exposure parameters presented in the RMD, the Exposure Factors Handbook (EPA, 2011) and EPA's online Radionuclide PRG calculator (EPA, 2022c) also contain information on this subject. Section 5 reference addition: EPA 2022b. *Preliminary Remediation Goals for Radionuclide Contaminants at Superfund Sites Calculator and User's Guide*. Available at: https://epa-prgs.ornl.gov/radionuclides/		*The group agreed to this revision by consensus.*

Comment	Response	Discussion/ Agreements
In Section 3.3.7.2 (page 3-46), it states, "Consideration of scenarios that involve livestock, dairy, and/or game animals that are potentially exposed to contaminated feed, soil, or groundwater. Please change "groundwater" to "water" since wild game and farm animals may also consume surface water as drinking water.	The text in Section 3.3.7.2 has been revised as suggested in the comment.	*No other discussion or agreements brought forward by the group.*
Section 3.3.7.2 revised text: • Consideration of scenarios that involve livestock, dairy, and/or game animals that are potentially exposed to contaminated feed, soil, or ~~groundwater~~ water.		*The group agreed to this revision by consensus.*
None of the direct contact dose-based PRGs for radionuclides could be replicated using the updated toxicity values in Table B.6b and the information described in Section B.2. As requested during review of Appendix A, please provide the Radionuclide PRG calculator inputs/output and example calculations to support the PRG calculations.	Neither the EPA Radionuclide PRG Calculator nor the toxicity values in Table B.6b are used in the calculation of the dose-based PRGs. The dose-based PRGs are calculated in an Excel spreadsheet. DOE recommends that text describing the calculation of the dose-based screening levels be added to Appendix B. A draft copy of the new Appendix B text will be provided to the RAWG.	*The revisions will be provided to the group as part of the complete draft of the FY 2023 RMD update.*

Attachment 1

Appendix A

USEPA Comments - Comments from Shanna Alexander transmitted via email from Victor Weeks on 1/17/2023

Comment	Response	Discussion/ Agreements
General Comment – It is understood that we have a meeting scheduled to discuss the rad ALARA calculations, which may (or may not) affect the text and tables as currently presented. However, it may help if we had some discussion in the RMD for how to handle rad effluent values for surface water. Further, for transparency and reproducibility, including the EPA rad secular equilibrium PRG inputs and output for at least one of the primary radionuclides of potential concern per media and exposure scenario is recommended. This may include insertion of the peak risk graph to illustrate secular equilibrium for parent and daughter activity.	DOE recommends deferring action on this comment until the C-400 Complex OU documents have been approved. The derivation of risk-based radiological effluent limits is a project-specific approach developed to utilize the DOE Order/ALARA process, as applied to effluent treatment system conceptual design based on best available technology (BAT), and results in projected effluent discharges that are compliant with CERCLA. No change to the document is proposed at this time.	*The group discussed that once the C-400 RI/FS report is finalized, that information from report will be incorporated into Appendix E of the RMD (or a reference may be added to the RMD). The group agreed by consensus that adding the information now would be premature.*
Item (9)(h) (Page A-6) – Given the release of DOE's Initial Assessment of Per- and Polyfluoroalkyl Substances at Department of Energy Sites (October 2022) and PFAS Strategic Roadmap: DOE Commitments to Action 2022-2025 (August 2022) coupled with the RMD objective, it seems reasonable to include the media-specific Regional Screening Levels (RSLs) for PFAS that are currently available in the RSL tables. These values will only aid in the initial screening assessment.	DOE recommends deferring action on this comment until the PFAS Screening Assessment project is completed (scheduled for Q1 of FY24). PFAS is a RAWG watch topic and discussion of the RSLs can be included on the next meeting agenda. No change to the document is proposed at this time.	*DOE discussed that the plan is to have PFAS results next year to support this discussion and to inform use of RSLs or site-specific values (NALs). The RAWG will discuss and collectively decide on values to use for screening at a future meeting.*

Comment	Response	Discussion/ Agreements
Item (9)(i) (Page A-6) – It is not evident from Item (9)(i) what chemical surrogates were obtained from the EPA CompTox database and the identity of these surrogates. For instance, what surrogate was used for carbazole and was it obtained from the EPA CompTox database. Also, how was the final selection made if multiple suitable surrogates were provided?	Note (9)(i) lists the only chemical surrogates used in the calculation of the ALs and NALs presented in the RMD. This list of surrogates was discussed and agreed to by the RAWG. With respect to carbazole, it is listed in the RAIS Chemical PRG Calculator, which uses an oral cancer slope factor from HEAST. Carbazole is not included the EPA RSL Calculator. No changes have been made to the document based on this comment.	*The group discussed the differences between the RSL calculator and RAIS calculator. RAIS uses an older HEAST value for carbazole. EPA noted that they would have used fluorine as a surrogate and that HEAST values are only used where there is no other information. Carbazole is not in the RSL table. This is a one-off and will be revisited during a future meeting.* *EPA recommended adding fluorine as a surrogate for carbazole and to also add a footnote that although this is listed as a surrogate this year, that the AL/NAL were calculated using a value out of HEAST. The group agreed by consensus that carbazole is not a risk driver for the site and to table revision of the AL/NAL to next year.* *KY to check on fluorine as surrogate for carbazole. Shanna will share information on this topic (next several weeks/month).*
Table A.1a (Page A-16) – Similar to cadmium, please specify that the soil/sediment Action Levels (ALs) for manganese were based on the toxicity values available for manganese (diet).	The entries for manganese in Tables A.1a A.2a, A.3a, A.4a, A.5a, A.6a, and B.6a have been revised to "Manganese (Non-Diet)" to be consistent with the toxicity values used to calculate the ALs/NALs.	*No other discussion or agreements brought forward by the group.*
Table A.1 as an example of the revisions: 7439-96-5 Manganese (Non-Diet)		*The group agreed to this revision by consensus.*

Comment	Response	Discussion/ Agreements
Tables A.1b (Page A-27) – Although the calculated radionuclide risk-based ALs differ for the future resident and recreational user, it is unclear from the footnotes of Table A.1.b how the exposure assumptions for the recreational user differs from that of the lifetime resident since both are described as being based on the child/adult age-adjusted lifetime scenario. Perhaps, a separate table or an expanded Table B.4 should be added to explain the exposure assumptions used in the risk calculations for the child/adult age-adjusted scenario for radionuclides since these do not currently appear in Appendix B.	For the Resident and Recreator exposure scenarios, the EPA Radionuclide PRG Calculator only allows exposure parameter entries for two life stages (i.e., child and adult), rather than the four life stage groups provided in the EPA and RAIS Chemical calculators (i.e. 0-2 years, 3-6 years, 6-16 years, 17-26 years). Accordingly, the Rad PRG Calculator does not allow entry of the "teen" exposure parameters shown in Table B.4 Therefore, the radionuclide ALs and NALs for the Recreational User and the Resident are both based on a child/adult age-adjusted lifetime scenario which assumes 26 year overall exposure duration, with 6 years as a child and 20 years as an adult. The other receptor-specific child and adult exposure parameters for the Resident and Recreator exposure scenarios (e.g., exposure frequency, exposure time, inhalation rate, ingestion rate) are used within those two life stage exposure periods in the Radionuclide PRG Calculator. The footnotes to Tables A.1b, A.3b, A.4b, and A.6b have been revised to provide a more detailed explanation of how the Radionuclide ALs and NALs for the Recreational User and Resident exposure scenarios are calculated. A revised version of Table B.5 will be provided to the RAWG.	*The group agreed that the response will address ambiguity in the RMD. Revisions to Table B5 will be provided with the complete FY 2023 RMD draft.*
Footnote from Table A.1b as an example of the revisions: For the recreational user, the radionuclide ALs were calculated using the child/adult age-adjusted ~~lifetime~~ scenario (i.e., ~~lifetime~~26 year exposure duration, with 6 years as a child and 20 years as an adult). The EPA Radiological PRG online calculator only allows exposure parameter entries for two life stages (i.e., child and adult), rather than the four life stage groups provided in the EPA and RAIS Chemical calculators. Thus, the EPA Radiological PRG calculator does not allow entry of the "teen" exposure parameters shown in Table B.4. ~~incorporates includes exposure input fields periods for child and adult time frame age groupings; therefore, the ALs for the recreational user do not use the teenager-specific exposure inputs provided in Table B.4.~~ ¶		*The group agreed to this revision by consensus.*

Comment	Response	Discussion/ Agreements
Table A.7a (Page A-84 to A-86) – Please add a footnote for the groundwater concentration to indicate that this value is the target leachate concentration and not the measured concentration in groundwater.	A new footnote has been added to the two groundwater concentration columns in Table A.7a .	*No other discussion or agreements brought forward by the group.*
Table A.7a new footnote: Groundwater concentration represents the MCLs or risk-based NALs that are used as the groundwater target concentrations in the SSL equation.		*The group agreed to this revision by consensus.*

Comment	Response	Discussion/ Agreements
Tables A.7a and A.7b (Page A-88) – The chemical-specific distribution coefficient (Kd) values provided are referenced as being from the RI/FS Report (2012) and the Risk and Performance Evaluation of C-746U Landfill document (2003). Please also include the original sources for the Kd values presented for radionuclides unless its site-specific derivation was demonstrated in these documents. It should also be noted in the footnotes whether these Kd values have been approved by the RAWG.	Although the comment mentions Table A.7a, it appears that the comment may only apply to Table A.7b. The references for the Kd values do include the derivation of the values; the references have been updated and clarified to include the original sources, as appropriate. The Paducah Groundwater Modeling Working Group will discuss whether this topic should be the subject of a white paper.	*The Sheppard and Thibault (1990) paper will be shared with the group.*
Table A.7b revised footnote:		*The group agreed to this revision by consensus.*

Radionuclide	Kd (cm³/g)	Reference	Reference Source
Americium-241	1.90E+03	DOE 2012	Sheppard and Thibault (1990)
Cesium-137+D	2.80E+02	DOE 2012	Sheppard and Thibault (1990)
Neptunium-237+D	7.00E+01	DOE 2003	Site-specific (DOE 1997 and DOE 2002)
Plutonium-238	5.50E+02	DOE 2003	Sheppard and Thibault (1990)
Plutonium-239	5.50E+02	DOE 2003	Sheppard and Thibault (1990)
Plutonium-240	5.50E+02	DOE 2003	Sheppard and Thibault (1990)
Technetium-99	2.00E-01	DOE 2003	Site-specific (DOE 1997 and DOE 2002)
Thorium-230	3.20E+03	DOE 2003	Sheppard and Thibault (1990)
Thorium-232	3.20E+03	DOE 2003	Sheppard and Thibault (1990)
Uranium-234	6.68E+01	DOE 2003	Site-specific (based on Uranium-238)
Uranium-235+D	6.68E+01	DOE 2003	Site-specific (based on Uranium-238)
Uranium-238+D	6.68E+01	DOE 2003	Site-specific (DOE 1997 and DOE 2002)

DOE 2002. *Seismic investigation Report for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky.* DOE/OR/07-2038&D1. [NEWER DOCUMENT VERSION: DOE 2004. *Seismic investigation Report for Siting of a Potential On-Site CERCLA Waste Disposal Facility at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky.* DOE/OR/07-2038&D2.]

DOE 1997. *Attachment 4, Comparison of Experimentally Derived Uranium Kds for SWMU 2 Versus Those for SWMUs 7 and 30 in Comment Response Summary for Review Comments from United States Environmental Protection Agency and Commonwealth of Kentucky Department of Environmental Protection for the February 1997 Data Summary and Interpretation Report for Interim Remedial Design at Solid Waste Management Unit 2 of Waste Area Grouping 22 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky.* DOE/OR/07-1549&D1.

Sheppard, M.I., and D.H. Thibault, 1990, "Default Soil Solid/Liquid Partition Coefficients, Kds, for Four Major Soil Types: A Compendium," Health Physics 59:471–482.

The DOE 2003 document and the D2/R2 version of the DOE 2012 document were approved by the FFA parties for those respective projects. The DOE 2012 reference will be updated to the D2/R2 (DOE 2018) version.

KYDEP Comments - Transmitted via email from Brian Begley on 1/18/202

Comment	Response	Discussion/ Agreements
General Comment 1 – a DOE has not incorporated the new screening RfC tox value for cis 1,2-DCE into its NAL calculations for the child resident. Trans 1,2-DCE is used as an analog for cis 1,2-DCE in generating the provisional screening value for cis 1,2-DCE.	The AL and NAL calculations conducted using the RAIS Chemical PRG calculator did incorporate the RfC for trans-1,2-DCE as a surrogate RfC for cis-1,2-DCE. However, the updated AL and NAL values for cis-1,2-DCE in soil, sediment, and groundwater were mistakenly omitted from the relevant RMD Appendix A tables. Tables A.1a, A.2a, A.4a, and A.5a have been revised with the correct values for cis-1,2,-DCE. Table B.6 of Appendix B has also been revised to show the RfC used for cis-1,2,-DCE in the RAIS calculator.	*No other discussion or agreements brought forward by the group.*
Table A.1a revised entry for cis-1,2-DCE as example of revisions: 156-59-2 Dichloroethylene, *cis*-1,2- mg/kg - 1.97E+03 34E+02 1.97E+03 34E+02 - 1.97E+03 35E+02 1.97E+03 35E+02 - 1.40E+04 20E+03 1.40E+04 20E+03 Table B.6a revised entry: 156-59-2 Dichloroethylene, 1,2-*cis* - - - - 2.00E-03 I 4.00E-02 PS YES		*The group agreed to this revision by consensus.*

Comment	Response	Discussion/ Agreements
General Comment 2 – It appears that the default VF value listed in Appendix B, Table B.7 (43.07) is not being used when deriving the RMD Action Level and No Action Level values. Instead, the somewhat higher RSL calculator default value is being used. Going forward, the RAWG should decide whether it wants to use the value listed in Appendix B or the RSL Calculator default value when deriving ALs and NALs for soil. The RMD value is the more conservative of the two values; however, it is uncertain how the value was derived.	The value of 43.07 mentioned in the comment is a Q/C term (i.e., dispersion factor) rather than a VF. For the reasons described below, DOE recommends updating all of the entries related to the VF and PEF parameters in the RMD to be consistent with the default values used in the RAIS/EPA calculators (both chemical and radionuclide). All of the soil/sediment ALs and NALs provided in Appendix A were calculated using the default VF and PEF parameters provided in the RAIS/EPA calculators. The correct VFs and PEFs are provided in Table B.6a, but the information in Table B.5 and Table B.7 will be revised to reflect the RAIS/EPA calculator defaults. Rationale: The available PRG/RSL calculators do not accommodate the KY-specific Q/C terms presented in Table B.7 and none of the regional Q/C values provided in the calculators (available as a pull-down menu) are similar to the KY-specific values. This prevents the calculation of KY-specific VFs using the calculators (see images of calculator entry forms on following worksheet tab). The calculators do allow the hard-entry of the KY-specific PEF value of 6.2E+08 m^3/kg. The group should discuss the use of the KY-specific PEF when the calculators won't readily allow for the calculation of the KY-specific VFs.	*KY clarified that the comment should have referred to the Q/C term not the VF.* *Origin of the 43.07 appears to be a 1996 document that was revised in 2002 (2002 supersedes the 1996 guidance). The VF and PEF values were refined in the revision. The KY values are consistent with the 1996 document but not the 2002 guidance. The default value is used in the document. The group discussed removing the 43.07 value from the table and using one of the regional default values that represents the correct soil type(s) or querying a volatile compound and compare the default input/result to a different input (TCE). This has been reviewed in prior years and was not a significant impact, although resuspension factor will have bearing on future projects. The group agreed by consensus to retain this topic for a future meeting.* *Todd (KY) shared that revision to KY risk guidance is in draft currently and recommends a PEF similar to Cleveland, OH.* *The group agreed by consensus to update information this year, as appropriate, so information can be replicated.*

Comment	Response	Discussion/ Agreements
General Comment 3 – The current Child Recreator Swimming ingestion rate used to generate ALs and NALs for the RMD is 0.096 L/hr. This value is listed in Appendix B, Table B.5. The default value as given by the RSL calculator is 0.12 L/hr. Unless there is reason to suspect that children swimming near the PGDP would behave differently than the average child (represented by the 0.12 L/hr figure) then the higher default value should be used.	As noted in footnote "y" for Table B.5, the surface water ingestion rates presented in Table B.5 are from the EPA's *Exposure Factors Handbook*, specifically the 2019 update of Chapter 3 (*Ingestion of Water and Other Select Liquids*), Table 3-7 (*Recommended Values for Water Ingestion While Swimming*). The default surface water ingestion rates provided in the EPA RSL Calculator and the RAIS Chemical PRG Calculator are from the 2011 Exposure Factors Handbook. No changes to Table B.5 are recommended.	*The group agreed by consensus that no change is needed this year and that further discussion on this topic will occur at a future meeting.*
Comment	**Response**	**Discussion/ Agreements**
Specific Comment 1 – Appendix A, Page A-39, Table A.3a: The Kentucky RAS was unable to replicate the Surface Water Swimming ALs for the Child Recreator for the following compounds: Acrylonitrile, Bromodichloromethane, Ethylbenzene, and Hexachlorobenzene.	Table A.3a was revised to incorporate the updated Adult and Teen Recreational User Surface Water Swimming ALs for these chemicals. The updated Child Recreational User Surface Water Swimming ALs for these chemicals were mistakenly omitted when Table A.3a was revised. The table has been revised to include these values.	*No other discussion or agreements brought forward by the group.*
Table A.3a updated entry for acrylonitrile as an example of revisions:		*The group agreed to this revision by consensus.*

Acrylonitrile	µg/L	4.60E+02	6.323E+04~~2.53E+05~~	4.60E+02	5.37E+04~~1.34E+04~~	4.60E+02	2.46E+04~~9.83E+04~~	4.60E+02	

Comment	Response	Discussion/ Agreements
Specific Comment 2 – Appendix A, Page A-39, Table A.3a: The Surface Water Swimming hazard value for the Adult Recreator for Acrylonitrile is 6.32 E4, not 6.33 E4. This change does not affect the AL for this compound, which is driven by its carcinogenic properties.	The value in Table A.3a has been revised as suggested.	*The group agreed to this revision by consensus.*

Risk Assessment Working Group
Meeting Summary—June 7, 2023

DOE	EPA	Kentucky	FRNP
Rich Bonczek ✓	Shanna Alexander ✓	Brian Begley ✓	Stefanie Fountain ✓
	Jonathan Dziekan ✓	Stephanie Brock	Bruce Ford ✓
ETAS	Mac McRae	Mary Evans ✓	LeAnne Garner
Martin Clauberg ✓	Ann Schnitz ✓	Nathan Garner ✓	Christine Julias
	Brett Thomas	Will Grasch ✓	Chris Saranko ✓
	Victor Weeks ✓	Brian Lainhart	Grant Walter
		Todd Mullins ✓	
		Bart Shaffer ✓	
		Chris Travis ✓	

✓ Indicates member was present. Also in attendance: Elizabeth Walton (KDEP).

Original meeting agenda items are provided followed by meeting notes; the meeting notes are provided in *italics* with action items noted in *green*.

1. Call for Issues from Risk Assessment Working Group (RAWG) Members

No items were brought forward for discussion by the group.

2. Notes from 3/1/2022 Meeting

Comments received on this meeting summary include:

- **From EPA via email 3/21/2023: Item 6, Chemical Surrogates, page 3** - The appropriate surrogate recommended by EPA's Office of Research and Development should be the PAH fluorene and not fluorine.
    - The summary will be revised per the comment.
- **From EPA via email 3/21/2023: Item 7, Emerging Contaminants, PFAS, page 3** – In the last bullet, it should be noted that I informed the group of an EPA PFAS volatility research study currently underway by EPA's Office of Research and Development. I also provided references to several other PFAS volatility publications that are currently available in the scientific literature. This section also does not fully capture the discussion on EPA's recommendation to screen PFAS data using currently published RSLs as "no action levels" in future iterations of the RMD. Currently, no PFAS information is listed in the RMD action and/or no action level tables. DOE had mentioned that the risk methodology for the RSLs may differ from that of the RMD and that this would be reviewed. I think it is important that this discussion be captured as EPA maintains its stance that an initial screening of PFAS using the RSLs (no action levels) for the six PFAS in the RSL table be captured in the RMD.
    - The summary bullet is proposed to be revised:
      PFAS volatility is a subtopic being tracked by the group. EPA relayed to the RAWG that a PFAS volatility research study currently underway by EPA's Office of Research and Development and that there are references to several other PFAS volatility publications that are currently available in the scientific literature. These references will be provided during the next meeting. EPA recommends screening PFAS data using currently published

RSLs as "no action levels" in future iterations of the RMD (currently, no PFAS information is listed in the RMD action and/or no action level tables). DOE had mentioned that the risk methodology for the RSLs may differ from that of the RMD and that this would be reviewed at a future meeting.

The group agreed by consensus to the changes; no additional comments were received from the group on the March 1, 2023 meeting summary and the summary will be finalized or inclusion in the 2024 update to the RMD.

3. FY 2023 Schedule/Work Plan

Activity	Target Finish
~~Submit Work Plan (FY2023) to RAWG~~	~~8/31/2022~~
~~Quarterly Meeting (September/FY22Q4)~~	~~9/7/2022~~
~~RAWG Concurs with FY2023 Work Plan~~	~~10/7/2022~~
~~RAWG Provide Additional Suggested Revisions/Corrections to Human Health (HH) Risk Methods Document (RMD) for FY22~~	~~10/21/2022~~
~~Quarterly Meeting (December/FY23Q1)~~	~~12/7/2022 (Moved from 12/14/2022)~~
~~Submit Draft FY2023 HH RMD Appendix A [i.e., Preliminary Remediation Goals (PRGs)] to RAWG for Review~~	~~12/8/2022~~
~~Provide Draft FY2023 HH RMD Main Text and Appendix B and D to RAWG for Review~~	~~12/20/2022~~
~~RAWG Comments Due for Draft FY2023 HH RMD Appendix A~~	~~1/20/2023~~
~~RAWG Comments Due for Draft FY2023 HH RMD Main Text and HH Appendix B and D~~	~~1/27/2023~~
~~Provide Draft FY2023 HH RMD Appendix E to RAWG for Review~~	~~2/16/2023 (Deleted)~~
~~Quarterly Meeting (March/FY23Q2)~~	~~3/1/2023~~
~~RAWG concurs with Draft FY2023 HH RMD Appendix A~~	~~3/3/2023 (was 2/17/2023)~~
~~RAWG Concurs with Draft FY2023 HH RMD Main Text and HH Appendix B and D~~	~~3/3/2023~~
~~RAWG Comments Due for Draft FY2023 HH RMD Appendix E~~	~~3/17/2023 (Deleted)~~
~~RAWG Concurs with Draft FY2023 HH RMD Appendix E~~	~~3/31/2023 (Deleted)~~
~~Provide Complete Draft FY2023 HH RMD to RAWG for Review~~	~~4/6/2023~~
~~RAWG Comments Due for Entire Revised HH RMD~~	~~5/5/2023~~
Quarterly Meeting (June/FY23Q3)	6/7/2023
Submit FY2023 HH RMD to FFA Managers (DOE/LX/07-0107&D2/R13/V1)	6/29/2023
FFA Managers Acknowledge Receipt of FY2023 HH RMD	7/28/2023
Submit Work Plan (FY2024) to RAWG	9/6/2023
Quarterly Meeting (September/FY23Q4)	9/13/2023
RAWG Concurs with FY2024 Work Plan	10/6/2023

Color code for schedule:

Due date	Quarterly meeting
Submittal date	Concurrence/acknowledgement date

The group did not have any comments on the FY 2023 schedule/work plan.

4. 2023 Risk Methods Document Updates

Comments received on the complete FY 2023 RMD from the RAWG and proposed additional clarifying edits are included in Attachment 1.

C. Saranko (Geosyntec/FRNP) gave a presentation to the group (Attachment 1) on responses to the RAWG comments on the FY 2023 RMD and calculation of dose-based PRGs that led to a clarifying discussion amongst the group members. The group did not have any comments on the responses and proposed revisions to the 2023 RMD included in Attachment 1. ***Any additional comments were requested to be provided by June 14, 2023 to support submittal dates for the document.***

5. C-400 Data

The C-400 Remedial Investigation/Feasibility Study (RI/FS) Report was submitted for FFA party review on January 5, 2023. EPA and KY have provided comments on the RI/FS Report and comment resolution discussions are planned as part of that project.

No updates or comments on this topic were provided or brought forward by the group.

6. Anthropogenic Background

The white paper was finalized and accepted by the RAWG and is planned to be included in Appendix E of this year's update to the RMD.

No updates or comments on this topic were provided or brought forward by the group.

7. Chemical Surrogates

During the March 1, 2023 meeting and in email correspondence following the meeting, fluorene was accepted by the RAWG as a surrogate for carbazole.

The next chemical surrogates list review will be as part of the FY 2023 Q4 or FY 2024 Q1 meeting.

Shanna has provided the March 8, 2023 EPA Memorandum: *STSC Peer Input and Consultation Memo - Response to Region 4 Request Regarding Suitability of Proposed Surrogates for Carbazole (ORD-053179)*; this memorandum is included as Attachment 2.

No updates or comments on this topic were provided or brought forward by the group.

8. Emerging Contaminants

- PFAS
  - PFAS is discussed as part this working group and has ties to the Groundwater Modeling Working Group (MWG) as well.
  - The Paducah Site continues to participate in the DOE HQ PFAS Working Group Meetings. Rich is a member of the DOE PFAS Coordinating Committee and plans to coordinate Paducah information and actions with Oak Ridge and Portsmouth.
    - The PFAS Coordinating Committee last met on May 17, 2023.

    - The DOE HQ PFAS Working Group last met on March 23, 2023, with the next meeting scheduled for June 1, 2023.
- The Paducah Implementation Plan was provided to DOE HQ by December 31, 2022.
    - Historical research on PFAS use at the site is due to DOE HQ in the second quarter of FY 2023. This is largely done for PGDP. DOE HQ has completed their complex-wide research.
    - The site field assessment annual survey form has been reviewed and comments were provided to DOE HQ. PFAS results as of last July will be in last year's ASER. This year's data will be in next year's ASER.
    - The publication for PFAS Updated Status Report is planned for FY 2025.
    - Bottled water has been provided on-site for many years, which satisfies the DOE requirement to provide an alternate drinking water supply if PFAS detected above regulatory limits. The potable water PFAS results were provided to EPA and KY on May 18, 2023.
    - AFFF has been addressed at PGDP. Some AFFF materials are in storage, and some have been disposed of.
    - DOE-PPPO has requested additional guidance from DOE HQ regarding disposal of PFAS-containing/contaminated wastes in Subtitle C landfills and the C-746-U Landfill.
    - Interagency partners include PNNL (TRAC) and laboratories.
    - Implementation of the Communication Plan started on May 25, 2023.
- There are multiple DOE guidance documents in development:
    - The DOE Preliminary Assessment annual update template is pending finalization.
    - The *DOE Guide for Investigating Historical and Current Uses of Per- and Polyfluoroalkyl Substances at Department of Energy Sites* (Guide for Investigating Historical and Current Uses of Per- and Polyfluoroalkyl Substances at Department of Energy Sites | Department of Energy) was released in February 2023; the Paducah Site is already beyond the performance assessment (PA) stage. The group acknowledged that action levels currently are guidance and are not regulatory requirements.
    - The draft DOE PFAS Environmental Sampling Guide is in review. This guide is expected to be final in late spring 2023.
    - The DOE disposal guidance has been internally reviewed by the DOE sites and is being finalized.
- For Paducah, the main PFAS activity for 2023 is the in-progress PFAS screening assessment project.
    - Potable water samples were collected in November 2022 (Round 1) and a second set of samples was collected in January 2023 (Round 2). Round 1 samples were collected using standard procedures and method specific sample containers (consistent with the screening assessment project QAPP). The Round 2 samples were collected based on a question on the potential for cross-contamination of samples derived from clothing or products worn by the samplers and PFAS-specific collection procedures, including special sampler

PPE, were developed, and an experienced PFAS sampler was mobilized for the sample collection; method specific sample containers were used.

- Results were provided to EPA and KY on May 18, 2023:
    - Bottled water is used for drinking water at Paducah. Available bottled water PFAS results from one vendor are nondetect. Finished water produced by the C-611 Water Treatment Plant is, however, potable water.
    - PFOS and PFOA were detected in potable water at concentrations similar to what others have detected in Ohio River water, which is the raw water used by the C-611 Water Treatment Plant, indicating the PFAS present in potable water most likely originate from the PFAS in Ohio River water.
    - All PFOS results (maximum detect of 7.53 ng/L) and eight of twelve PFOA results (maximum detect of 4.66 ng/L) are greater than the proposed MCLs for PFOS and PFOA (4 ng/L).
    - All PFOS results but no PFOA results were greater than their EPA Regional Screening Levels of 4 and 6 ng/L, respectively.
    - An investigation of sampling results from two rounds of sampling indicates that sampler-related cross-contamination (i.e., cross-contamination that could result from sampler use of PFAS-containing materials that do not contact sampled water) did not occur. This supports the conclusion of others that "generally accepted sampling procedures and common standard of care during sampling activities will avoid any contact between PFAS-containing materials and the environmental samples."

- Procedures for the sampling event have been revised for sampler precautions to address concerns raised by DOE management including potential cross-contamination from sampler personal hygiene products, clothing, PPE, etc. There has been no evidence of cross-contamination between Round 1 and Round 2 potable water results, with a roughly 50-50 split between higher concentrations per analyte and lower concentrations between the two rounds.
    - The potential for cross-contamination from the samplers themselves is thought to be minimal based on newer literature. For potable water samples, the only equipment are the sample containers, which were obtained from the lab and are specific for the analytical method.
    - To understand potential bias from the monitoring wells samples (e.g., bias related to use of existing pumps, tubing, etc.) locations upgradient or cross-gradient from the plant industrial area will be used to compare plant industrial area location results.
    - The sampling procedure revisions are complete (procedures are available at DOE PPPO Public Documents); the PFAS QAPP worksheets have been revised and will be included in the pending revision to the EMP.

        - Potable water sampling is complete. Groundwater sampling is approximately 30% complete. Other sampling is planned to be completed before September 30, 2023.
    - There is a study on PFAS in fish tissue available, including an interactive map: *(*https://www.ewg.org/interactive-maps/pfas_in_US_fish/map/*)*.
    - Interactions with FFA parties is being managed at the site level as opposed to the HQ level. The group is awaiting information from FFA Managers to understand if there will be a future PFAS project.
    - PFAS volatility:
        - PFAS volatility will be pertinent at the Paducah site and will be considered in DQOs if there is an RI-type project.
        - Jeff Ryan (EPA) presented findings on PFAS air emissions at EPA national laboratory and noted air emissions can be a significant source of PFAS.
        - EPA's Office of Research and Development paper on PFAS in air, *Predictions of PFAS Regional Scale Atmospheric Deposition and Ambient Air Exposure*, is in internal review. The paper is based on modeling the fate and transport of PFAS air emissions from the Chemours facility in North Carolina.
        - 2022. Garnett J, Halsall C. et al. Increasing Accumulation of Perfluorocarboxylate Contaminants Revealed in an Antarctic Firn Core (1958-2017). July 26, 2022. Available for download at: https://pubs.acs.org/doi/10.1021/acs.est.2c02592
        - 2022. Minnesota Pollution Control Agency. PFAS Air and Deposition Monitoring Report. Available for download at: https://www.pca.state.mn.us/sites/default/files/tdr-g1-23.pdf
        - 2010. Keiser et al. Understanding Potential Exposure Sources of Perfluorinated Carboxylic Acids in the Workplace. Ann. Occup. Hyg., Vol. 54, No. 8, pp. 915–922.

On the topic of PFAS, the group discussed:

- *Paducah has a question into DOE HQ regarding the potential for disposal of PFAS or PFAS-containing materials in a Subtitle D landfill (e.g., the U-Landfill). A formal request to DOE HQ has not been made on this topic. SRS submitted a similar formal request for disposal of solidified AFFF into an off-site, public subtitle D landfill that was denied.*
- *The group discussed the DOE PFAS website (*PFAS (Per- and Polyfluoroalkyl Substances) | Department of Energy*) and the listing of PFAS search terms included in Appendix C of the* DOE Guide for Investigating Historical and Current Uses of Per- and Polyfluoroalkyl Substances at Department of Energy Sites (Guide for Investigating Historical and Current Uses of Per- and Polyfluoroalkyl Substances at Department of Energy Sites | Department of Energy.
    - *Paducah is not pursuing a preliminary historical use assessment for PFAS as PFAS is known to have been used at the Gaseous Diffusion Plants; the current focus related to PFAS at Paducah is identification of potential source areas.*
    - *The group is not aware of any information on PFAS from Oak Ridge/K-25 and PORTS PFAS work will be performed following Paducah's.*

- *PFAS Screening Assessment Update*
  - *Preliminary results are not yet available other than for the potable water samples.*
  - *Once the PFAS Screening Assessment data are reviewed, DOE will consider potential sampling for soils or wastes.*
  - *As of the meeting, no questions have been forwarded from DOE HQ, the work force, or CAB, from release of the May 31, 2023 site communication on the potable water PFAS results.*
  - *MWs within the C-400 Complex OU have not yet been sampled for PFAS.*

- 1,4-Dioxane
  - The site responded to a DOE HQ survey on 1,4-dioxane, with responses provided by February 15, 2023.
  - 1,4-dioxane was historically used as a stabilizer in 1,1,1-trichloroethane and dichloroethane. The group plans to discuss fate & transport characteristics of 1,4-dioxane (compared to TCE) during future MWG meetings.
  - A high 1,4-dioxane result from one well at C-400 cannot be replicated or confirmed as the MW has been dry since that sampling event. The group discussed that there are two methods that could be used to analyze for 1,4-dioxane and that the SVOC method tends to bias results low and the VOC method tends to bias results high. The 1,4-dioxane results are typically isolated detections and are not indicative of a plume. The group discussed that a lesson learned from PORTS is that if there is no air stripper on a groundwater/leachate treatment system, a special vessel would be needed for treatment of 1,4-dioxane. This may be relevant to the CERCLA cell project.

No updates or comments on this topic were provided or brought forward by the group.

9. Watch Topics:

- **Derivation of Risk-based Surface Water Effluent Limits**
  As discussed during the September 7, 2022 meeting, DOE has developed DOE Order 458.1 compliant ALARA-based standards for possible C-400 effluents. The results indicate that the limiting pathway is fish consumption and that these ALARA-based values will be below current Tc-99 and uranium MCLs and result in less than a 1 mrem/year dose to a maximally exposed individual. The ALARA values are within the EPA risk range and are currently planned to be included in the C-400 project Record of Decision and should be able to be used for other projects at Paducah. DOE presented the approach to EPA and KY during the Routine Paducah Groundwater Update call on February 9, 2023.

  During the March 1, 2023 meeting, DOE shared a presentation from a prior February 2023 discussion and outlined the proposed C-400 treatment system and its likely design efficiency (99%). An efficiency of 90% was used in the evaluation and an additional column for redundancy in case of system shutdown was assumed. DOE went through the calculated concentrations, the risk scenarios evaluated, and the resultant calculated risks. DOE also compared calculated project remedial goals (PRGs) to the no action levels (NALs) in the RMD and a calculated value for fish consumption. Risk was calculated for Tc-99: 4.0E-06 for the residential drinking water scenario,

4E-06 for the recreational swimming scenario, and 2.0E-06 for the fish consumption scenario. An increased rate of fish consumption was considered (the fish consumption rate of 29 g/d was increased to 54 g/d), resulting in a calculated risk of 3.0E-06. When mixing was considered, the calculated risk drops from 3.0E-06 to 7.0E-07. Each of these calculated risks are within or below the EPA risk range. If taken to the next step, DOE will review options for inclusion in a project document. DOE noted that ALARA itself is a DOE function only.

The technical approach for risk-based surface water effluent limits has been developed; the legal approach remains in discussion between the FFA parties.

- **Status of EPA's Policy for Lead in Blood**
  - Shanna is tracking this item and will keep the team posted on any developments.
  - As part of the FY 2023 RMD update, the RAWG agreed that the no action level for lead should remain at 400 mg/kg until EPA releases additional information.
  - EPA relayed to the group during the September 7, 2022 meeting that a new EPA working group in this topic has been formed and the draft policy is in EPA internal review.

No updates or comments on this topic were provided or brought forward by the group.

10. Discussion Items for the 2024 RMD Update (September Meeting)

- The ecological volume of the RMD
- Child surface water ingestion rate (EPA email March 1, 2023):

  I looked into the child water ingestion rate while swimming issue that was discussed on the call today and found that in the November 2019 update to the RSL table, the child surface water ingestion rate was updated from 0.096 to 0.12 L/day based on the revisions made to Chapter 3 of the 2011 Exposure Factors Handbook (EFH). Therefore, it may be that the value in the RMD was obtained from the EFH prior to the update to Chapter 3 and particularly Table 3-7. See updated table and calculation below.

Update for Chapter 3 of the Exposure Factors Handbook

Chapter 3—Ingestion of Water and Other Select Liquids

Table 3-7. Recommended Values for Water Ingestion While Swimming

Age Group years	Mean mL/hour	Upper Percentile mL/hour
6 to <11	38	96
11 to <16	44	152
16 to <21	33	105
21+	28	92

Source: Dufour (2017); based on data provided to L. Phillips by A. Dufour by personal communication, 6/21/2017.

Adolescent Recreator (6-16 years) = (96 mL/hour x 5 years) + (152 mL/hour x 5 years) / 10 years = **124 mL/hour or 0.124 L/hour**

Based on this information, it seems the child surface water ingestion rate in the RMD should be equivalent to the value reflected in the RSL Calculator (i.e., 0.12 L/hour).

Although this is an insignificant change, we want to make sure that the value used in the RMD matches the value in the reference being cited.

No additional topics for the 2024 update to the RMD were provided or brought forward by the group. DOE discussed that the ecological volume of the RMD likely will need to be updated to support the Waste Disposal Alternatives project and a potential on-site waste disposal facility. A draft ecological update plan will be prepared and is planned to be discussed during the September 2023 meeting.

11. Poll RAWG Members/Open Discussion

No updates or comments were provided or brought forward by the group.

Attachment 1

RAWG Comments Discussion

Response to Risk Assessment Working Group Comments Submitted May 1-2, 2023, *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/R14/V1, 04/2023

EPA Comments – Submitted May 1 and May 2, 2023:

Two comments from EPA were received via email from Shanna Alexander. Because the two comments are related to the same issue, they are addressed in a single response below.

EPA Comment 1 (5/1/2023 email): Just circling back on a prior comment I had on the RMD regarding my inability to reproduce the calculated NALs and ALs for rads. I don't think this information was ever provided. While I greatly appreciate the write-up in the new Section B.1.3 on EPA's recommendation to migrate from the "+D" designation, I don't see any example calculations in the RMD even though the rad PRGs in App. A are said to represent both Peak Risk and Secular Equilibrium similar to EPA's rad PRG calculator. I'm still unable to reproduce these values even though I have gotten some in the same ballpark. Can someone please provide the calculation spreadsheet if the PRG calculator was not used to compute the NALs/ALs (e.g., Cs-137, U-235/238 or Np-237)? This should not impact the RMD status, but for complete transparency, I would like to be able to replicate these values and have supporting information that would allow others to do the same. I could be doing something wrong.

EPA Comment 2 (5/2/2023 email): For the upcoming June 7th RAWG meeting, EPA would like to propose a walk-through of the dose-based PRG calculations for rads in DOE's Excel spreadsheet. For example, it would be most beneficial for DOE to give a live demonstration of how the soil/sediment NALs/ALs for U-235/U-238 for the commercial worker were derived using the information in Appendix B of the FY 2023 RMD update. I have spoken to KDEP and they would appreciate a demonstration as well since Todd Mullins was also unable to replicate the dose-based PRGs. I think providing the calculation spreadsheet for at least one of the rads (particularly, U-235/U-238) could expedite our review and support validity of the calculations since an example calculation was not provided in the RMD update. Please add this topic to the agenda.

Response to EPA Comments 1 and 2: It was not clear if Comment 1 was intended to address the risk-based or dose-based screening levels for radionuclides. Based on EPA Comment 2, it appears that both comments pertain to difficulties replicating the dose-based screening levels described in Appendix B, Section B.2, and presented in Appendix A, Tables A.8 through A.11. As requested in EPA Comment 2, a presentation covering the dose-based radionuclide screening levels has been added to the agenda for the RAWG Meeting on June 7, 2023.

The description of the dose-based screening levels in Section B.2 was expanded after receipt of EPA's comments on the initial draft of FY23 RMD, Appendix B. It should be noted that despite this expanded description, there were no changes to the equations, the exposure parameters, or the DCFs used to calculate the dose-based radionuclide screening levels contained in the RMD, apart from adding Thorium-

232[1] (Th-232) to the list of radionuclides for which dose-based screening levels are presented. In fact, the dose-based radionuclide screening levels have not changed over the last several annual RMD revision cycles. Editorial revisions to the RMD as noted in this Comment Response Summary have been made for correctness and clarification

It should be noted that dose-based screening levels are included in RMD as a contractor tool in support of DOE requirements and are not intended for use under CERCLA. As such, the RMD Executive Summary contains the following statement, which is relevant to the dose-based radionuclide screening levels.

> "*This document also discusses some of the methods used to complete radiological dose assessments at PGDP. Radiological dose assessments are conducted to provide information for risk managers and are separate from the risk assessment conducted per the FFA for decision making. The methods for radiological dose assessment are presented generally, and additional discussion should be held with regulatory agencies prior to initiating any radiological dose assessment project that is part of an FFA project.*"

Section 1 of the RMD contains the following statement:

> "*Radiological dose assessments sometimes are provided to risk managers, as well, and also are discussed within these sections. The approach to radiological dose assessments discussed here is based on EPA guidance (EPA 2000a)[2] and is specific to PGDP. The radiological dose-based concentrations are based on Federal Guidance Report 13 (EPA 1999a)[3] and are not appropriate for other activities such as establishment of authorized limits. The exposure parameters used to derive the radiological dose-based concentrations presented are useful inputs when deriving authorized limits.*"

KDEP Comments – Submitted May 1, 2023:

KDEP Comment 1: DOE has not incorporated the new screening RfC tox value for cis 1,2-DCE into its NAL calculations for the child resident. Trans 1,2-DCE is used as an analog for cis 1,2-DCE in generating the provisional screening value for cis 1,2-DCE.

Response 1: This comment was previously addressed; no additional change will be made to the document. This comment was previously provided via email from B. Begley on January 18, 2023. DOE provided a response and proposed edits in an attachment to the draft agenda to the March 2023 RAWG meeting, which was transmitted via email on February 23, 2023. The edits were concurred upon by the RAWG members during the meeting and related revisions were included in the Draft 2023 Risk Methods Document (20230405 FY23 HH RMD DOE-LX-07-0107D2-R14V1 REDLINE.pdf) transmitted via email April 5, 2023. Therefore, no response is necessary.

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[1] Th-232 was added to the list of radionuclides for which risk-based ALs and NALs are developed in response to a request from EPA. Although not specifically requested, corresponding dose-based screening levels for thorium were added to the Draft FY2023 RMD to maintain consistency with respect to the list of radionuclides addressed in the RMD.

[2] EPA 2000a. *Soil Screening Guidance for Radionuclides: Technical Background Document*. EPA/540-R-00-006, Office of Radiation and Indoor Air, Office of Solid Waste and Emergency Response, Washington, DC, October.

[3] EPA 1999a. *Cancer Risk Coefficients for Environmental Exposure to Radionuclides*, Federal Guidance Report No. 13, EPA 402-R-99-001, Office of Radiation and Indoor Air, Office of Solid Waste and Emergency Response, Washington, DC, September.

KDEP Comment 2: It appears that the default VF value listed in Appendix B, Table B.7 (43.07) is not being used when deriving the RMD Action Level and No Action Level values. Instead, the somewhat higher RSL calculator default value is being used. Going forward, the RAWG should decide whether it wants to use the value listed in Appendix B or the RSL Calculator default value when deriving ALs and NALs for soil. The RMD value is the more conservative of the two values; however, it is uncertain how the value was derived.

Response 2: This comment was previously addressed; no additional change will be made to the document. See response to KDEP Comment 1.

KDEP Comment 3: The current Child Recreator Swimming ingestion rate used to generate ALs and NALs for the RMD is 0.096 L/hr. This value is listed in Appendix B, Table B.5. The default value as given by the RSL calculator is 0.12 L/hr. Unless there is reason to suspect that children swimming near the PGDP would behave differently than the average child (represented by the 0.12 L/hr figure) then the higher default value should be used.

Response 3: This comment was previously addressed; no additional change will be made to the document. See response to KDEP Comment 1.

KDEP Comment 4: Appendix A, Page A-39, Table A.3a: The Kentucky RAS was unable to replicate the Surface Water Swimming ALs for the Child Recreator for the following compounds: Acrylonitrile, Bromodichloromethane, Ethylbenzene, and Hexachlorobenzene.

Response 4: This comment was previously addressed; no additional change will be made to the document. See response to KDEP Comment 1.

KDEP Comment 5: Appendix A, Page A-39, Table A.3a: The Surface Water Swimming hazard value for the Adult Recreator for Acrylonitrile is 6.32 E4, not 6.33 E4. This change does not affect the AL for this compound, which is driven by its carcinogenic properties.

Response 5: This comment was previously addressed; no additional change will be made to the document. See response to KDEP Comment 1.

KDEP Comment 6: Appendix B, Table B.3: Note 4 beneath the table refers to risk-based screening values. Shouldn't this refer to dose-based screening values?

Response 6: Note 4 has been revised to refer to "dose-based screening values."

KDEP Comment 7: Appendix B, Section B.2.2.2, Soil/Sediment PRG Equations: There appear to be a few minor errors in this section. For instance, the dose conversion factor for inhalation should be DCFinh, not DCFing. Also, the External Dose PRG equation appears to be missing a conversion factor (1 yr/8760 hrs) in the denominator.

Response 7: The abbreviation for the inhalation dose conversion factor has been revised to "DCF_{inh}." No additional conversion factor is needed for the equation. The units for the Gamma Exposure Time Factor (T_e) were incorrectly shown as "hours/day." The units have been revised to "(hours/day)/(hours/day." Additionally, a second exposure frequency (EF_{ext}) that is specific to the external gamma equation has been added to the list of parameters. The units for this parameter are "(days/year)/(days/year)." The name and abbreviation of the EF parameter shown in the "*External Exposure to Ionizing Radiation from Soil/Sediment*" section of Table B.5 has been revised for consistency.

KDEP Comment 8: Appendix B, Section B.2.2.2, Groundwater PRG Equation: The PRG should be in units of pCi/L rather than pCi/g. Also, it appears that an hours per day ratio is missing in the denominator.

Response 8: The PRG units shown on the Groundwater Ingestion PRG Equation have been revised to "pCi/L." No hours/day conversion factor is needed. The units for the groundwater ingestion rate were incorrectly shown as "L/hour." The units have been revised to "L/day."

KDEP Comment 9: Appendix B, Section B.2.2.2, Surface Water PRG Equation: The PRG should be in units of pCi/L, not pCi/g.

Response 9: The PRG units shown on the Groundwater Ingestion PRG Equation have been revised to "pCi/L."

KDEP Comment 10: (References) Add: United States Environmental Protection Agency (USEPA). 2022 (November). Regional Screening Level (RSLs) Calculator. Available on-line at: https://semspub.epa.gov/work/HQ/199432.pdf

Response 10: The reference has been added to the list of references in Appendix B and a citation has been added to Page B-3. The EPA RSL Calculator for chemicals is not discussed or cited in the main text or other appendices so it was not added to the lists of references for other portions of the RMD.

Other Identified Clarifications to the Text:

- Remove Appendix A text referring to soil background levels as "provisional" as the soil background values were approved by EPA/KY as described in the note to Table A.12.

- There are three instances where a series of 2000 RAWG meeting minutes and notes are cited in the document. For each of these instances, the citations have been revised to include RAWG 2000a through RAWG 2000g.

- The VURAM citation has been revised to reflect the date of the latest version of the VURAM guidance in 2022.

- The EPA 2018a URL has been revised to reflect the correct URL location (https://www.epa.gov/risk/regional-human-health-risk-assessment-supplemental-guidance).

- The URL https://semspub.epa.gov/work/HQ/100001657.pdf has been added to the citation for EPA 2018b.

- A new footnote has been added in two locations Table A.3b and A.6b, which states "These receptor scenarios only consider dermal contact with surface water, not incidental surface water ingestion (see Figure B.1). Dermal absorption is not considered for radionuclides so no screening values are derived for these receptor exposure scenarios."

- References to exposure parameters in the text and table footnotes have been revised to call-out Table B.5. All references to DCFs in the text and table footnotes have been revised to call-out Table B.4.

- The 4 mrem/year dose target has been added to the TD parameter description under the Groundwater PRG Equation.

- The 4 mrem/year dose target has been added to the TD parameter description under the Surface Water PRG Equation.

- The RAIS Chemical PRG calculator only includes surface water as an exposure medium within the "Recreator" scenario/calculation module. Therefore, the Recreator calculation module is used for the calculation and the "Site Specific" mode is selected, which allows the user to enter a range of receptor-specific exposure parameter values. The footnote in Table B.5 has been revised to provide clarification.

- Occurrences of "listed in the table." within the Table B.5 notes have been revised to "listed in the table above."

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Calculation of Dose-based PRGs

Soil PRG Example Calculation for U-235 for the PGDP Commercial/Industrial Worker

PRESENTED BY
Chris Saranko, Ph.D., DABT

PRESENTED AT:
RAWG Meeting June 7, 2022

DRAFT

Introduction

- The DOE submitted via email a redline draft of the FY 2023 Risk Methods Document (RMD) to the United States Environmental Protection Agency (EPA) Region 4 and the Kentucky Department of Environmental Protection (KDEP) on April 5, 2023.

- EPA provided the following comment in an emails dated May 1 and 2, 2023:

  5/1/2023 email: Just circling back on a prior comment I had on the RMD regarding my inability to reproduce the calculated NALs and ALs for rads. I don't think this information was ever provided. While I greatly appreciate the write-up in the new Section B.1.3 on EPA's recommendation to migrate from the "+D" designation, I don't see any example calculations in the RMD even though the rad PRGs in App. A are said to represent both Peak Risk and Secular Equilibrium similar to EPA's rad PRG calculator. I'm still unable to reproduce these values even though I have gotten some in the same ballpark. Can someone please provide the calculation spreadsheet if the PRG calculator was not used to compute the NALs/ALs (e.g., Cs-137, U-235/238 or Np-237)? This should not impact the RMD status, but for complete transparency, I would like to be able to replicate these values and have supporting information that would allow others to do the same. I could be doing something wrong.

  5/2/2023 email: For the upcoming June 7th RAWG meeting, EPA would like to propose a walk-through of the dose-based PRG calculations for rads in DOE's Excel spreadsheet. For example, it would be most beneficial for DOE to give a live demonstration of how the soil/sediment NALs/ALs for U-235/U-238 for the commercial worker were derived using the information in Appendix B of the FY 2023 RMD update. I have spoken to KDEP and they would appreciate a demonstration as well since Todd Mullins was also unable to replicate the dose-based PRGs. I think providing the calculation spreadsheet for at least one of the rads (particularly, U-235/U-238) could expedite our review and support validity of the calculations since an example calculation was not provided in the RMD update. Please add this topic to the agenda.

- Based on these comment, this presentation was prepared to review the calculation methodology for the dose-based screening levels for radionuclides of potential concern at the Paducah Gas Diffusion Plant (PGDP).

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Equations and Parameters

Modified Equations/Parameters from Appendix B, Section B.2.2.2
(redline edits based on KDEP comments shown)

Soil/Sediment PRG Equations:

$$\text{Soil Ingestion } PRG_{ing}\,(pCi/g) = \frac{TD}{0.001\ g/mg \times EF \times IR_S \times DCF_{ing}}$$

$$\text{Particulate Inhalation } PRG_{inh}\,(pCi/g) = \frac{TD}{EF \times ET \times InhR \times \left(\frac{1}{PEF}\right) \times DCF_{inh} \times 1000\frac{g}{kg}}$$

$$\text{External Dose } PRG_{ext}\,(pCi/g) = \frac{TD}{EF_{ext} \times (1-S_e) \times T_e \times DCF_{ext}}$$

$$\text{Combined Pathways } PRG_{comb} = \frac{1}{(1/PRG_{ing}) + (1/PRG_{inh}) + (1/PRG_{ext})}$$

Where:

- TD = target dose (1 mrem/year, 12 mrem/year, 25 mrem/year, and 100 mrem/year)
- EF = exposure frequency (days/year)
- IR_S = soil ingestion rate (mg/day)
- DCF_{ing} = dose conversion factor—ingestion (mrem/pCi)
- ET = exposure time (hours/day)
- InhR = inhalation rate (m^3/hour)
- PEF = particulate emission factor (m^3/kg)
- DCF_{inginh} = dose conversion factor—inhalation (mrem/pCi)
- EF_{ext} = gamma exposure frequency [(days/year) / (days/year)]
- S_e = gamma shielding factor (unitless)
- T_e = gamma exposure time factor [(hours/day) / (hours/day)]
- DCF_{ext} = dose conversion factor—external gamma (mrem/year per pCi/g)

Parameters for U-235+D* for the PGDP Commercial/Industrial Worker:

Parameter	Document Location	Value	Units
TD	--	1, 12, 25, 100	mrem/year
EF	Table B.5	250	days/year
IRs	Table B.5	50	mg/day
$DCF_{ing,\ U\text{-}235+D}$	Table B.4	1.75E+04	mrem/pCi
ET	Table B.5	8	hours/day
InhR	Table B.5	2.5	m^3/hour
PEF	Table B.5	6.2E+08	m^3/kg
$DCF_{inh,\ U\text{-}235+D}$	Table B.4	3.15E-02	mrem/pCi
EF_{ext}	Table B.5	250 / 365	(days/year) / (days/year)
S_e	Table B.5	0.20	unitless
$T_{e,}$	Table B.5	8 / 24	(hours/day) / (hours/day)
$DCF_{ext,\ U\text{-}234+D}$	Table B.4	6.92E-01	mrem/yr per pCi/g

* Where applicable, +D was retained in the radionuclide names for the dose-based screening level tables because DCFs with the +D designation were used in the calculations.

DRAFT

Equations and Parameters

Modified Equations/Parameters from Appendix B, Section B.2.2.2
(RLSO edits based on KDEP comments shown)

Soil/Sediment PRG Equations:

$$\text{Soil Ingestion } PRG_{ing}\,(pCi/g) = \frac{TD}{0.001\ g/mg \times EF \times IR_S \times DCF_{ing}}$$

$$\text{Particulate Inhalation } PRG_{inh}\,(pCi/g) = \frac{TD}{EF \times ET \times InhR \times \left(\frac{1}{PEF}\right) \times DCF_{inh} \times 1000\frac{g}{kg}}$$

$$\text{External Dose } PRG_{ext}\,(pCi/g) = \frac{TD}{EF_{ext} \times (1-S_e) \times T_e \times DCF_{ext}}$$

$$\text{Combined Pathways } PRG_{comb} = \frac{1}{(1/PRG_{ing}) + (1/PRG_{inh}) + (1/PRG_{ext})}$$

Where:

- TD – target dose (1 mrem/year, 12 mrem/year, 25 mrem/year, and 100 mrem/year)
- EF = exposure frequency (days/year)
- IR_S = soil ingestion rate (mg/day)
- DCF_{ing} = dose conversion factor—ingestion (mrem/pCi)
- ET = exposure time (hours/day)
- InhR = inhalation rate (m^3/hour)
- PEF = particulate emission factor (m^3/kg)
- DCF_{inginh} = dose conversion factor—inhalation (mrem/pCi)
- EF_{ext} = gamma exposure frequency [(days/year) / (days/year)]
- S_e = gamma shielding factor (unitless)
- T_e = gamma exposure time factor [(hours/day) / (hours/day)]
- DCF_{ext} = dose conversion factor—external gamma (mrem/year per pCi/g)

Parameters for for U-235 for the PGDP Commercial/Industrial Worker:

Parameter	Document Location	Value	Units
TD	--	1, 12, 25, 100	mrem/year
EF	Table B.5	250	days/year
IRs	Table B.5	50	mg/day
$DCF_{ing,\ U\text{-}235+D}$	Table B.4	1.75E+04	mrem/pCi
ET	Table B.5	8	hours/day
InhR	Table B.5	2.5	m^3/hour
PEF	Table B.5	6.2E+08	m^3/kg
$DCF_{inh,\ U\text{-}235+D}$	Table B.4	3.15E-02	mrem/pCi
EF_{ext}	Table B.5	250 / 365	(days/year) / (days/year)
S_e	Table B.5	0.20	unitless
$T_{e,}$	Table B.5	8 / 24	(hours/day) / (hours/day)
$DCF_{ext,\ U\text{-}235+D}$	Table B.4	6.92E-01	mrem/yr per pCi/g

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Calculation Example for Uranium-235

$$\mathrm{PRG_{ing}} = \frac{\text{Target Dose}}{0.001\ \mathrm{g/mg} \times \mathrm{EF} \times \mathrm{FI} \times \mathrm{IR} \times \mathrm{DCF}}$$

$$PRG_{ing\ U-235} = \frac{1\,mrem/year}{0.001\,g/mg \times 250\ days/year \times 1 \times 50\,mg/day \times 1.75 \times 10^{-4}\ mrem/pCi} = 457\ pCi/g$$

$$\mathrm{PRG_{inh}} = \frac{\text{Target Dose}}{\mathrm{EF} \times \mathrm{ET} \times 1000\frac{\mathrm{g}}{\mathrm{kg}} \times \left(\frac{1}{\mathrm{PEF}}\right) \times \mathrm{IR} \times \mathrm{DCF}}$$

$$PRG_{inh\ U-235} = \frac{1\,mrem/year}{250\ days/year \times 8\ hours/day \times 1000\,g/kg \times \left(\frac{1}{6.2 \times 10^{8}\ m^3/kg}\right) \times 2.5\,m^3/hour \times 0.0315\,mrem/pCi} = 3940\,pCi/g$$

$$\mathrm{PRG_{ext}} = \frac{\mathrm{TD}}{\mathrm{EF_{ext}} \times (1 - \mathrm{S}_e) \times \mathrm{T}_e \times \mathrm{DCF_{ext}}}$$

$$PRG_{ext\ U-235} = \frac{1\,mrem/year}{\frac{250\ days}{365\ days} \times (1 - 0.2) \times \left(\frac{8\ hours}{24\ hours}\right) \times 0.692\,\frac{mrem/year}{pCi/g}} = 7.91\,pCi/g$$

$$\mathrm{PRG\ (pCi/g)} = \frac{1}{(1/\mathrm{PRG_{ing}}) + (1/\mathrm{PRG_{inh}}) + (1/\mathrm{PRG_{ext}})} \longrightarrow PRG_{U-235} = \frac{1}{\frac{1}{457pCi/g} + \frac{1}{3940\,pCi/g} + \frac{1}{7.91\,pCi/g}} = 7.76\,pCi/g$$

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Output from PRG Equations

Modified Equations from Section B.2.2.2

Soil/Sediment PRG Equations:

$$\text{Soil Ingestion } PRG_{ing}\,(pCi/g) = \frac{TD}{0.001\ g/mg \times EF \times IR_S \times DCF_{ing}}$$

$$\text{Particulate Inhalation } PRG_{inh}\,(pCi/g) = \frac{TD}{EF \times ET \times InhR \times \left(\frac{1}{PEF}\right) \times DCF_{inh} \times 1000\frac{g}{kg}}$$

$$\text{External Dose } PRG_{ext}\,(pCi/g) = \frac{TD}{EF_{ext} \times (1-S_e) \times T_e \times DCF_{ext}}$$

$$\text{Combined Pathways } PRG_{comb} = \frac{1}{(1/PRG_{ing}) + (1/PRG_{inh}) + (1/PRG_{ext})}$$

Adult Industrial Worker (Soil Ingestion Pathway Only)

CAS Number	Radionuclide	Units	1 mrem/year	12 mrem/year	25 mrem/year	100 mrem/year
15117-96-1	Uranium-235+D	pCi/g	4.57E+02	5.49E+03	1.14E+04	4.57E+04

+

Adult Industrial Worker (Soil Particulate Inhalation Pathway Only)

CAS Number	Radionuclide	Units	1 mrem/year	12 mrem/year	25 mrem/year	100 mrem/year
15117-96-1	Uranium-235+D	pCi/g	3.94E+03	4.72E+04	9.84E+04	3.94E+05

+

Adult Industrial Worker (Soil External Dose Pathways Only)

CAS Number	Radionuclide	Units	1 mrem/year	12 mrem/year	25 mrem/year	100 mrem/year
15117-96-1	Uranium-235+D	pCi/g	7.91E+00	9.49E+01	1.98E+02	7.91E+02

=

Adult Industrial Worker (Combined Pathways, Soil)

CAS Number	Radionuclide	Units	1 mrem/year	12 mrem/year	25 mrem/year	100 mrem/year
15117-96-1	Uranium-235+D	pCi/g	7.76E+00	9.31E+01	1.94E+02	7.76E+02

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Comparison of Results
Section B.2.2.2 Equations vs. Table A.8 values

Calculated Results from Previous Slide

Adult Industrial Worker (Combined Pathways, Soil)						
CAS Number	Radionuclide	Units	1 mrem/year	12 mrem/year	25 mrem/year	100 mrem/year
15117-96-1	Uranium-235+D	pCi/g	7.76E+00	9.31E+01	1.94E+02	7.76E+02

Table A.8. Dose-Based Soil/Sediment Screening Levels for Site-Related Radionuclides at PGDP

CAS Number	Radionuclide	Units	Industrial Worker 1 mrem/year	12 mrem/year	25 mrem/year	100 mrem/year
14596-10-2	Americium-241	pCi/g	5.29E+01	6.35E+02	1.32E+03	5.29E+03
10045-97-3	Cesium-137+D	pCi/g	1.62E+00	1.94E+01	4.05E+01	1.62E+02
13994-20-2	Neptunium-237+D	pCi/g	5.23E+00	6.28E+01	1.31E+02	5.23E+02
13981-16-3	Plutonium-238	pCi/g	7.17E+01	8.61E+02	1.79E+03	7.17E+03
15117-48-3	Plutonium-239	pCi/g	6.58E+01	7.90E+02	1.65E+03	6.58E+03
14119-33-6	Plutonium-240	pCi/g	6.59E+01	7.91E+02	1.65E+03	6.59E+03
14133-76-7	Technetium-99	pCi/g	2.00E+04	2.40E+05	5.01E+05	2.00E+06
14269-63-7	Thorium-230	pCi/g	7.76E+01	9.31E+02	1.94E+03	7.76E+03
7440-29-1	Thorium-232	pCi/g	7.14E+01	8.57E+02	1.79E+03	7.14E+03
13966-29-5	Uranium-234	pCi/g	3.84E+02	4.60E+03	9.59E+03	3.84E+04
15117-96-1	Uranium-235+D	pCi/g	7.76E+00	9.31E+01	1.94E+02	7.76E+02
7440-61-1	Uranium-238+D	pCi/g	4.10E+01	4.92E+02	1.02E+03	4.10E+03

Attachment 2

EPA Memorandum on Surrogates for Carbazole

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Center for Public Health and Environmental Assessment
Superfund Health Risk Technical Support Center (STSC)

OFFICE OF
RESEARCH AND DEVELOPMENT

March 08, 2023

MEMORANDUM

SUBJECT: STSC Peer Input and Consultation Memo - Response to Region 4 Request Regarding Suitability of Proposed Surrogates for Carbazole (ORD-053179)

FROM: Jeff Dean, PhD, EPA/ORD/CPHEA
Jay Zhao, MPH, PhD, DABT- EPA/ORD/CPHEA
ORD Superfund Technical Support Center

THRU: Avanti Shirke, EPA/ORD/CPHEA
Dahnish Shams, EPA/ORD/CPHEA
Directors, ORD Superfund Technical Support Center

TO: Shanna Alexander, EPA/Region 4

CC: Kris Thayer, EPA/ORD/CPHEA
Glenn Rice, EPA/ORD/CPHEA

Problem Statement:

U.S. EPA Region 4 office contacted the Superfund Technical Support Center (STSC) to inquire as to inquire about the suitability of proposed surrogates (Fluorene, Acenaphthene, Pyrene and Quinoline) for Carbazole (CASRN 86-74-8) (Figure 1). This memorandum serves as peer input (or peer consultation) to EPA Region 4. This memorandum contains scientific evaluation provided in response to a request for site technical support with limited scope. The evaluations herein are intended to address specific scientific questions posed to researchers and/or consultants with applicable experience. Therefore, the evaluations are written for a specific scientific audience within U.S. EPA Region 4. The peer input provided is intended to assist U.S. EPA Region 4 with relevant and innovative science to help meet site-specific environmental goals. The observations are provided in good faith, and due to the limited scope of technical support requests, include potential uncertainty. This memorandum is not to be considered the only source of information for decision making, nor should the information provided here be parsed. It would be advisable to consider this memorandum in conjunction with multiple lines of evidence including history, experience of site managers, and other pertinent information available to U.S. EPA Regional staff that retain the duties and responsibilities of all decisions and regulatory actions at the site.

Response to Region 4 Request Regarding Suitability of Proposed Surrogates

Scientists in the US EPA's Center for Public Health and Environmental Assessment (CPHEA) in Cincinnati, OH applied an expert-driven read-across approach to determine the suitability of the proposed surrogate chemicals based on three primary similarity contexts (structure, metabolism/toxicokinetics, and toxicity) as described in Wang et al. (2012), where appropriate. Structural similarity evaluations were conducted using the OECD QSAR Toolbox (http://www.oecd.org/env/ehs/risk-assessment/theoecdqsartoolbox.htm), and information on toxicokinetics (i.e., absorption, distribution, metabolism, and excretion) and toxicity was obtained by review of existing human health assessments, as well as data aggregations and predictive tools available on the U.S. EPA's CompTox Chemistry Dashboard (https://comptox.epa.gov/dashboard/). Analyses of structural, metabolic/toxicokinetic, and toxicity similarities between the target chemicals and their respective proposed surrogates follows the methodology outlined in Wang et al. (2012). This approach identifies appropriate surrogate chemicals for both oral and inhalation routes independently, where relevant data are available. Of note, CPHEA has completed an assessment of the noncancer hazard and cancer risk of total petroleum hydrocarbons (U.S. EPA, 2022a, b, c), including polycyclic aromatic hydrocarbons (PAHs). This assessment incorporated a relative potency factor (RPF) approach to address cancer risk for some PAH mixtures.

Carbazole is a polycyclic aromatic hydrocarbon (PAH) that consists of two six-member benzene rings fused on opposite sides of a five-member nitrogen containing ring as shown in Figure 1. The analogue chemicals under evaluation are also considered to be PAHs and are of a comparable size. In the context of PAH-mediated biological responses, the numbers of ring structures, their orientation, and overall size of the compound are generally considered to be associated with differing metabolism profiles and toxicities that are observed across this chemical class. As depicted in Table 1, structural similarity evaluations were performed using the OECD Toolbox to quantify the structural similarity between carbazole and each analogue chemical (OECD, 2023). As expected from a visual inspection of the chemical structures, fluorene demonstrated high structural similarity (65.8% and 79.3%) as determined by two separate methodologies (Tanimoto method and DICE method). Acenaphthene (38.2%, 55.3%), pyrene (43.1%, 60.2%), and quinoline (34.7%, 51.5%) all demonstrated greater than 50% structural similarity using the DICE methodology. So, while all the chemical structures being evaluated are PAHs with 2-4 benzene rings, fluorene is the most structurally similar analogue only differing from carbazole by the lack of a nitrogen constituent on the five-member ring.

	Target	*Analogues*			
	Carbazole	**Fluorene**	**Acenaphthene**	**Pyrene**	**Quinoline**
Structure					
CASRN	86-74-8	86-73-7	83-32-9	129-00-0	91-22-5

Figure 1. Target chemical (Carbazole) and proposed potential analogue chemicals.

Evaluation of physico-chemical property information collected from the U.S. EPA's Comptox Chemicals Dashboard provided some insight as to the structurally-relevant characteristics of the target and analogue chemicals (Table 2). Hyperlinks to the relevant data pages are located in the figure legend of Table 2. Despite all the chemicals under evaluation sharing a degree of structural similarity, several physico-chemical properties displayed a wide range of presented values. Melting points ranged from -14.9 ~ 245°C and describe the following relationship among chemicals in this request: carbazole>>pyrene>fluorene>acenaphthene>>quinoline. Reported boiling points displayed a narrower range of values (237~351°C) and different order compared to melting temperatures (pyrene>carbazole>fluorene>acenaphthene>quinoline). Vapor pressure values for the target chemical (7.50×10^{-7} mmHg) suggest that carbazole may have a low potential for inhalation exposure as a gas or vapor. Pyrene was identified as exhibiting a similar vapor pressure of 4.50×10^{-6} mmHg. Carbazole and pyrene vapor pressures were two orders of magnitude lower than the other three analogues. Fluorene (6.00×10^{-4} mmHg), acenaphthene (2.15×10^{-3} mmHg), and quinoline (6.00×10^{-2} mmHg) all demonstrate substantially higher vapor pressures, suggesting an elevated potential for inhalation exposure relative to carbazole and pyrene. Relatedly, Henry's Law constant values suggest that carbazole (1.16×10^{-7} atm-m^3/mole) and quinoline (8.66×10^{-6} atm-m^3/mole) are more likely to persist in water and may be more readily absorbed to soil or sediment compared to fluorene (9.62×10^{-5} atm-m^3/mole), pyrene (1.19×10^{-5} atm-m^3/mole), or acenaphthene (1.84×10^{-4} atm-m^3/mole). Water solubility values (expressed as mol/L) for carbazole (8.95×10^{-6}), fluorene

($1.15x10^{-5}$), acenaphthene ($4.64x10^{-5}$), and pyrene ($6.65x10^{-7}$) were comparable. The water solubility of quinoline was reported as $4.84x10^{-2}$ mol/L. All chemicals appear to be lipophilic with Log K_{ow} values >2. Pyrene (4.88) is expected to be the most lipophilic, followed by fluorene (4.18), acenapthene (3.92), carbazole (3.6). Quinoline (2.03) was the least lipophilic suggesting a reduced ability to solubilize in fat. The environmental biodegradation half-life for carbazole was predicted to be 28.9 days. Fluorene (44 days), acenaphthene (39 days), and quinoline (13.7 days, predicted) were comparable to carbazole while pyrene (237 days) is reported to be more stable in the environment.

Data describing the absorption, distribution, metabolism, and elimination (ADME) of carbazole are limited, preventing the direct comparison of ADME information across the target and analogue chemicals. Of the two studies that were identified to inform the ADME of carbazole, a 1959 study by Brown and Coller theorized that the 3- position of carbazole is the position of highest electron density and that this location is likely to be attacked by an electron deficient hydroxyl species. Johns and Wright (1961) demonstrated this in vivo by measuring radioactive counts in the urine of rats and rabbits injected with carbazole-C^{14}. This study reports that an average of 64% of the administered radioactive dose is excreted in rat urine within 3 days. The major metabolite (identified as containing the majority of radioactive counts) was identified as 3-hydroxycarbazole. The authors speculate that conjugation of such a product with either sulfuric or glucuronic acid is the most likely metabolic route of detoxification (Johns and Wright, 1961). The metabolic reactions described above for carbazole are generally accepted to be common to other PAHs of a similar size (Bhagavatula et al., 2015, Levin et al., 2015). In the absence of a more extensive characterization of the target chemical (carbazole) metabolic profile, there is insufficient information to identify relevant or preferred metabolic analogue(s) from the analogue chemical list provided in this request.

The U.S. EPA Comptox Chemicals Dashboard provides an *in silico* module for estimating human ADME parameters using *in vitro-in vivo* extrapolation (IVIVE) as described in Pearce et al. 2017. As of January 18, 2023, predictions for fluorene and acenaphthene were not available. Table 3 describes predicted estimates (assuming a 1 mg/kg/day rate of exposure) of PK half-life and steady state plasma concentrations for carbazole, pyrene, and quinoline. Hyperlinks are provided for original data pages in the figure legend beneath Table 3. Of note, the predicted PK half-life of carbazole (45.42 hours) is less than half that of pyrene (95.42 hours) and is substantially different from that of quinoline (1.364 hours). Average steady-state plasma concentration estimates for carbazole (15.48 mg/L) were predicted to be higher than those of pyrene (2.553 mg/L) and quinoline (0.2928 mg/L). While the specific relevance of these predicted values for toxicities associated with the target and analogue chemicals remains unclear, such estimations can provide insight to important toxicokinetic distinctions among these chemicals.

Following a review of existing human health assessments published for the target and analogue chemicals, the following chemical-specific narratives and Table 4 summarize each database.

Carbazole

No repeated dose systemic toxicity studies were identified for Carbazole. No RfD, RfC, or carcinogenicity assessment for carbazole is available on EPA's Integrated Risk Information System (IRIS) database (U.S. EPA, 2008). EPA's Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1997) list carbazole as a B2 carcinogen with an oral slope factor (OSF) of $2x10^{-2}$ $(mg/kg\text{-}day)^{-1}$. This OSF was derived in a Health and Environmental Effects Profile (HEEP) for carbazole (U.S. EPA, 1986) based on an increased incidence of hepatocellular carcinomas and neoplastic nodules in mice chronically exposed to carbazole through diet (Tsuda et al., 1982). The International Agency for Research on Cancer (IARC) (1983, 1999), however, considers the study by Tsuda et al. (1982) to provide "limited evidence" of carcinogenicity in animals and assigned an overall classification of Group 3, "not classifiable," for the carcinogenicity of carbazole to humans.

Fluorene

The Peiffer et al. (2016) and TRL (1989) studies cited within U.S. EPA 1990b identify the liver as a sensitive target of toxicity following subchronic oral exposure in rodents. Peiffer et al. (2016) observed statistically and biologically significant (>10%) dose-related increases in relative liver weight at ≥10 mg/kg-day in rats after 60 days of treatment. The study did not include investigation of other liver endpoints. Body weight gain was significantly reduced at the high dose of 100 mg/kg-day. The focus of this study was extensive investigation of sensitive neurobehavioral endpoints (anxiety, motor activity, or learning and memory) that showed no adverse effects on these endpoints at any dose. TRL (1989) observed statistically and biologically significant dose-related increases in absolute and relative liver weights in male and female mice at ≥250 mg/kg-day after 13 weeks of treatment. Relative liver weights were also statistically increased at the low dose of 125 mg/kg day, but the increases at this dose were small (<10%). Other changes observed at 250 and/or 500 mg/kg-day in this study included enlarged and eosinophilic centrilobular hepatocytes and pigmentation reminiscent of

hemosiderin deposition in Kupffer cells (predominantly in males); decreases in red blood cell counts, packed cell volume, and hemoglobin; increased serum total bilirubin and cholesterol and decreased BUN; hemosiderosis and hematopoietic cell proliferation in the spleen; and increased absolute and relative spleen weights. A NOAEL of 125 mg/kg-day identified in TRL (1989) was used as the POD to derive a chronic RfD in the 1990 IRIS assessment (U.S. EPA 1990b).

Acenaphthene

There was a comprehensive systemic toxicity study examining the subchronic-duration toxicity of acenaphthene in the CD-1(ICR)BR mouse (U.S. EPA, 1989b). The mice were dosed once daily by gavage with 0, 175, 350, or 700 mg/kg-day for 90 days. Absolute and relative liver weights were increased in a dose-dependent manner in both sexes in all treatment groups at study termination with the exception of absolute liver weight in low-dose males. Other statistically significant organ-weight changes included decreased absolute and relative spleen weight, decreased absolute adrenal and ovary weights in treated female mice. Minimal-to-slight centrilobular hepatocellular hypertrophy was seen in nearly all of the high-dose animals and was observed to a lesser degree in the mid- and low-dose groups. Additionally, high-dose males and mid- and high-dose females showed significant increases in cholesterol levels. The 175 mg/kg-day dose was considered a NOAEL based on increased liver weight and was used as a POD in the derivation of a chronic RfD (US EPA, 1990a).

Pyrene

Male and female CD-1 mice (20/sex/group) were gavaged with 0, 75, 125, or 250 mg/kg-day pyrene in corn oil for 13 weeks (U.S. EPA, 1989a). The toxicological parameters examined in this study included body weight changes, food consumption, mortality, clinical pathological evaluations of major organs and tissues, and hematology and serum chemistry. Treatment resulted in increases in relative and absolute liver weight, decreases in red blood cell counts and hemoglobin, and nephropathy characterized by the presence of multiple foci of renal tubular regeneration as well as reduced relative and absolute kidney weights. Based on the results of this study, the low dose (75 mg/kg/day) was considered the NOAEL and 125 mg/kg/day the LOAEL for nephropathy and decreased kidney weights. This NOAEL was used as the POD in deriving subchronic (U.S. EPA, 2007) and chronic RfDs (U.S. EPA, 1990c).

Quinoline

Several carcinogenicity studies reported consistent hepatic changes, decreased body weight, and mortality due to rupture of tumors. Hepatic changes included tumor formation. The hepatic changes (increased liver weight, fatty change, increased liver enzyme activity, oval cell infiltration, preneoplastic lesions), early mortalities, and body weight loss were considered by the various study authors to be related to the process of hepatocarcinogenesis. In addition, increase in alkaline phosphatase levels coincided with increased tumor size, and effects such as megalocytosis, endothelial dysplasia, and nodular hyperplasia appeared to be strongly correlated with increased tumor size and incidence. It is also likely that the weight changes, and possibly the histopathological changes, were at least confounded by the formation of tumors. Thus, an RfD was not derived (US EPA, 2001).

In Vivo Toxicity Summary

All four potential surrogates appear to be liver toxicants, and consistently caused liver effects such as increased liver weight and pathological changes in the liver. Regarding the target compound (carbazole), the available database contains only one carcinogenicity study (Tsuda et al., 1982) which also indicated the liver as the target tissue (increased hepatocellular carcinomas and neoplastic nodule). A full copy of this study could not be located; therefore, the details of this publication were not reviewed. Due to a lack of information regarding potential carbazole toxicity in other tissues, and all four potential surrogates demonstrating similar toxic effects in the liver, none of analogue chemicals should be preferred based on *in vivo* toxicity effects.

In Vitro Bioactivity

Given the lack of information regarding potential toxicities associated with carbazole in humans and animals, additional strategies to characterize the biomolecular response to carbazole *in vitro* were pursued. In this context, the U.S. Environmental Protection Agency's Comptox Chemicals Dashboard houses several comprehensive databases that characterize molecular and cellular-level alterations that occur in response to chemical exposure. This includes repositories of high-throughput transcriptomic (HTTr) data for interrogating chemically-induced gene expression changes as well as data from the U.S. Environmental Protection Agency's Toxicity Forecaster (ToxCast) and the federal Toxicology in the 21st Century (Tox21) programs (https://www.epa.gov/chemical-research/toxcast-owners-manual-guidance-exploring-data). Both databases serve as a means to evaluate bioactivity responses from a heterogenous *in vitro* assay platform and inform chemical-specific mode-of-action evaluations or suggest toxic effects. Such goals are outside the scope of this response. However, these data were broadly evaluated for the enrichment of high-order biological processes

that could provide contrast or comparison of the target chemical to the proposed analogues. Patterns of enrichment were evaluated without consideration for directionality or magnitude, and individual targets were considered to be enriched if they were annotated with an “active” hit call on a respective platform. The use of active hit calls to denote target or pathway level biological activity precludes discussion of individual doses or dose ranges that may promote a specific benchmark response. Likewise, quantitative estimations of relative potencies or biological thresholds across target and analogue chemicals for a given biological process remain uncertain and were not attempted.

HTTr data

Initially, HTTr data for each chemical were accessed on the U.S. Environmental Protection Agency’s Comptox Chemicals Dashboard. Methodologies underlying the analysis presented in the Dashboard can be found in Harrill et al. 2021. While no model system within this dataset was common to carbazole and all four analogue chemicals, gene expression data from the MCF7 human breast cancer cell line was identified for carbazole, fluorene, pyrene, and quinoline. HTTr data for acenaphthene was not available. Active MSigDB pathway signatures (hitcall >0.9) identified for each chemical are presented in Table 5. As depicted, carbazole was observed to significantly influence several pathways involved in estrogen signaling in addition to many pathways involved in cell cycle progression and cellular proliferation. Gene expression pathways associated with a variety of human cancers and considered relevant to human cancer initiation and progression (hypoxia, epithelial to mesenchymal transition [EMT], metastasis and telomere maintenance) were also altered after exposure to carbazole in the MCF7 model system. In the same model system, fluorene exposure elicited a more subdued gene expression response that consisted of only five discreet gene expression pathways. Functionally, minimal overlap in the signatures elicited from carbazole and fluorene was observed after six hours of exposure. 50% of gene expression signatures significantly altered after pyrene exposure were related to estrogen signaling. Cholesterol homeostasis, EMT, and RNA splicing were also enriched in response to pyrene. Estrogen signaling, cholesterol, and EMT -relevant pathways were common targets for both carbazole and pyrene. However, pyrene lacked the robust enrichment of cell cycle/proliferative pathways as well as those relevant to cancer biology observed after carbazole exposure. Lastly, quinoline was characterized as promoting significant alterations in gene expression pathways associated with estrogen signaling, homologous DNA recombination (double strand DNA damage repair), myeloma, and several prominent transcription factors (HOX and NFKB). Estrogen signaling pathway modification was common to quinoline, pyrene and carbazole. While HOXA1 target genes were the only other enriched pathway that quinoline shared with another chemical under evaluation (pyrene).

While all four chemicals display distinct patterns of gene expression pathway enrichment, quinoline and fluorene appear to be the most qualitatively unique from carbazole. Overall, carbazole elicited the most diverse gene expression response, with active hit calls being described for over twice as many pathways compared to pyrene which demonstrated the most active hit calls among potential analogues. While it is not currently possible to interpret how these differences in gene expression may contribute to toxicities that may be observed in humans, it is important to consider that such differences may be a consequence of differential metabolism of individual PAHs or the metabolic competency of the MCF7 model system. Furthermore, the gene expression response to chemical exposure should be considered temporal and dynamic, and these profiles represent a snapshot in time of that response.

ToxCast Data

To assess higher-order biological function, ToxCast concentration response data was evaluated for carbazole and the analogue chemicals. Generally, the *in vitro* assays which comprise the ToxCast/Tox21 database are endpoint specific and characterize biological activity through measuring high-level cellular responses. Similar to the high-throughput toxicogenomic responses described above, bioactivity assay responses were considered if the assay displayed an active hit call within the database. Signal directionality and dose-response data for individual assays was not considered in this evaluation, as it is currently unclear how this information would translate to human health effects or toxicities. Broadly, an active hit call should be interpreted as an indication that the chemical being tested has the ability to modify the bioactivity relating to the measured endpoint.

As described in Table 6, the target chemical carbazole was active in 41 of 671 assays performed. Super target descriptors for the active hit calls demonstrate several themes that occur across the biological space examined for carbazole. Cell cycle, cellular morphology, and nuclear receptor signaling were identified as significantly altered. Of note, several molecular targets that are associated with PAH biology (aryl hydrocarbon receptor [AhR]) and xenobiotic sensing and detoxification (pregnane x receptor, constitutive androstane receptor, and Cyp450) were among these. Bioactivity from several pathways (p53 and H2AX) involved in DNA damage sensing and repair were significantly altered and suggest that DNA damage may be occuring in response to carbazole exposure in these model systems.

Fluorene elicited a similar profile to carbazole and was active in 37 of 1001 assays examined. Cell cycle, CYP450s, and nuclear receptor activity superfamily descriptors were overrepresented among these active pathway hits. Five of seven nuclear receptor targets of fluorene were also active hit calls for carbazole, suggesting similarity among the nuclear receptor profiles responsible for driving the response to both carbazole and fluorene. CYP1A2 activity was also described as active in both chemicals in addition to CYP1A1 and 2B6 being identified for fluorene. Importantly, CYP1A2 was the only CYP evaluated for carbazole while each analogue chemical was evaluated for activity across approximately 15 CYP-directed assays in total. p53 activity was significantly altered in response to fluorene exposure, although the H2AX active hit call observed for carbazole was absent.

Pyrene exposure appeared to demonstrate the most diverse and robust overall bioactivity profile observed for chemicals within this evaluation and was active in 102 of 1076 assays performed. Cell cycle, nuclear receptor activity, CYP450 proteins (8 total), and steroid hormone signaling were all major supertarget themes identified for pyrene. However, nuclear receptor activity profiles were greatly expanded in comparison to carbazole, and this suggests that pyrene may target a substantially unique profile of nuclear receptors compared to the target chemical.

Acenaphthene was active in 29 of 927 assays, and elicited a similar profile to that of carbazole, demonstrating enrichment of cell cycle, CYP450s (5 total, including CYP1A2), and nuclear receptor activity. In comparison to pyrene, acenaphthene displayed a greatly reduced spectrum of activity against nuclear receptors and was only active in 5 assays with the nuclear receptor supertarget descriptor. 80% of the nuclear receptor targets identified for acenaphthene were shared with carbazole.

Lastly, quinoline was active in 32 of 911 assays performed, and generally represented a bioactivity profile distinct from that of all other chemicals in this evaluation. Major supertarget ontologies that were enriched after quinoline exposure centered on CYP450 activity, DNA binding transcription factors, and enzymatic (protease, phosphatase, and oxidoreductase) activity. Three specific cellular transporters (ABCB1, ABCC2, and SLCO1B1) were active as well. Of the analogue chemicals, quinoline appeared to activate the widest range (9 total) of CYP450s, including CYP1A2 that was observed to be active in response to carbazole. As observed for other PAHs described above, AhR was considered an active target. Of note, pathways involved in p53-mediated apoptosis were active in response to quinoline (p53, caspase 3, caspase 6, and FAS). This response was most similar to that of pyrene, wherein p53, phosphorylated-H2AX, and caspase 3 were active. With the exception of acenaphthene, the p53 pathway was active in response to all chemicals, however, the proapoptotic signaling observed for both pyrene and quinoline was absent from carbazole, fluorene, and acenaphthene. This suggests that the cellular responses to pyrene and quinoline may be of increased toxicity and capable of promoting apoptosis in comparison to the carbazole, fluorene, and acenaphthene.

Weight of Evidence

In total, the weight of evidence indicates that all four analogues share a degree of structural similarity (fluorene > pyrene > acenaphthene > quinoline) to the target chemical (carbazole). Fluorene was the most structurally similar analogue chemical and was 19.1% and 22.7% more similar to carbazole than the analogue with the second highest percentage similarity (pyrene). Physico-chemical properties were generally similar among the group (target and analogues). All chemicals appear to be lipophilic with log K_{OW} values >2. Carbazole and quinoline have the most similar Henry's Law Constant values which may be of relevance if there is concern regarding persistence in water or absorption into soil or sediment. Environmental biodegradation half-life values were comparable among the group, with the exception of pyrene at 237 days. Fluorene was the second highest at 44 days, and carbazole was predicted to be 28.9 days. Comparison of ADME information was precluded by a lack of information regarding the ADME properties of the target chemical, carbazole. Of the limited information available, two studies described 3-hydroxycarbazole as a major metabolite of carbazole, with 65% of the administered dose being excreted as 3-hydroxycarbazole within 3 days in rats and rabbits. ADME>IVIVE *in silico* prediction was performed, however data were not available for fluorene and acenaphthene. This approach predicted that carbazole PK half-life and steady-state plasma concentration were distinct from that of pyrene, and values for quinoline were the most divergent. While data regarding *in vivo* health effects for carbazole were limited, they describe the ability of the target chemical to promote hepatocellular carcinomas/neoplastic nodules. All analogue chemicals displayed liver-specific non-cancer effects while quinoline was also able to promote liver hyperplasia. Due to a lack of comprehensive information regarding carbazole toxicities that may occur in non-liver tissues, no preferred analogue chemical could be identified based on *in vivo* health effects.

An examination of *in vitro* bioactivity profiles accessed through the U.S. Environmental Protection Agency's Comptox Chemicals Dashboard provided a higher-order characterization of the molecular and cellular response to the chemical in this response. After the acute exposure of MCF7 cells to carbazole, pathway level gene expression changes reveal a diverse range of responses that include estrogen signaling, cell cycle/cell proliferation, and many discrete pathways that

are relevant to the biology of human cancers. None of the analogues elicited a qualitatively similar pattern of gene expression changes. However, each analogue was observed to recapitulate aspects of the overall carbazole signature. While similarity in the patterns of gene expression changes was not able to identify a clear preferred analogue, quinoline appeared to be the least similar to carbazole.

Lastly, in vitro Toxcast/Tox21 data were queried to identify high-order biological processes of the analogues and assess their similarity to those of carbazole. Several major super-target themes were identified for carbazole which were common to both fluorene and acenaphthene. The profile of pyrene was considered to be the least similar to carbazole and exhibited a greatly expanded spectrum of nuclear receptor targets as well as pro-apoptotic signaling component. Likewise, quinoline lacked many of the super-target descriptors observed in response to carbazole and instead demonstrated significant activity across a range of unique transcription factors and cellular enzymes. Fluorene and acenapthene were considered to be more similar to carbazole as they both shared several major super-targets with carbazole. Of note, the p53 pathway (considered to be a master regulator of DNA damage sensing and repair) was an active hit call in all chemical datasets except acenaphthene.

In total, data across the aforementioned similarity endpoints generally suggests that pyrene and quinoline are the least relevant analogues for carbazole. Among fluorene and acenaphthene, structural similarity scores and a slightly more qualitatively similar bioactivity profile suggest that fluorene is preferred over acenaphthene and is therefore the most suitable analogue of the potential analogues in this request, for carbazole. Additionally, the chronic RfD for fluorene ($4x10^{-2}$ mg/kg-day) is slightly more health protective than that of acenaphthene ($6x10^{-2}$ mg/kg-day). Importantly, if the subchronic duration is of concern to the end user, acenaphthene may be a more relevant analogue due to a slightly lower subchronic risk value ($2x10^{-1}$ mg/kg-day) compared to that of fluorene ($4x10^{-1}$ mg/kg-day).

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U.S. EPA. Comptox Chemicals Dashboard. Quinoline https://comptox.epa.gov/dashboard/chemical/details/DTXSID1021798 (accessed January 18, 2023).

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U.S. EPA. Provisional Peer Reviewed Toxicity Values for Total Petroleum Hydrocarbons (Aromatic High, Cancer). U.S. Environmental Protection Agency, Washington, DC, EPA/690/R-22/006F, 2022c.

Wang NC, Jay Zhao Q, Wesselkamper SC, Lambert JC, Petersen D, Hess-Wilson JK. 2012. Application of computational toxicological approaches in human health risk assessment. A tiered surrogate approach. Regul Toxicol Pharmacol. Jun;63(1):10-9.

	Table 1. Structural Similarity Scores of Carbazole to Analogue Chemicals				
	Carbazole	**Fluorene**	**Acenaphthene**	**Pyrene**	**Quinoline**
Structure					
CASRN	86-74-8	86-73-7	83-32-9	129-00-0	91-22-5
Tanimoto	100	65.8	38.2	43.1	34.7
DICE	100	79.3	55.3	60.2	51.5

Table 1. Structural similarity scores (expressed as a percentage similarity) were determined for analogue chemicals to carbazole using the OECD Toolbox (version 4.4.1). Similarity scores represent percentage similarity and are reported for the Tanimoto and DICE methodologies.

Table 2: Physicochemical Properties of Carbazole and Analogue Chemicals					
Name	**Carbazole**	**Fluorene**	**Acenaphthene**	**Pyrene**	**Quinoline**
Structure					
CASRN	86-74-8	86-73-7	83-32-9	129-00-0	91-22-5
Molecular Weight (g/mol)	167.211	166.223	154.212	202.256	129.162
Melting Point (°C)	245	115	93.9	150	-14.9
Boiling Point (°C)	351	295	279	399	237
Vapor Pressure (mmHg)	7.50×10^{-7}	6.00×10^{-4}	2.15×10^{-3}	4.50×10^{-6}	6.00×10^{-2}
Henry's Law Constant (atm-m^3/mole)	1.16×10^{-7}	9.62×10^{-5}	1.84×10^{-4}	1.19×10^{-5}	8.66×10^{-6}
Water Solubility (mol/L)	8.95×10^{-6}	1.15×10^{-5}	4.64×10^{-5}	6.65×10^{-7}	4.84×10^{-2}
Log K_{ow}	3.6	4.18	3.92	4.88	2.03
Biodeg Half Life (days)	28.9 (predicted)	44	39	237	13.7 (predicted)

Table 2. Physicochemical property information was collected from the U.S. Environmental Protection Agency's Comptox Chemicals Dashboard as of January 18, 2023. Data are presented as experimental averages unless otherwise noted.

Carbazole -https://comptox.epa.gov/dashboard/chemical/properties/DTXSID4020248
Fluorene - https://comptox.epa.gov/dashboard/chemical/properties/DTXSID8024105
Acenaphthene - https://comptox.epa.gov/dashboard/chemical/properties/DTXSID3021774
Pyrene - https://comptox.epa.gov/dashboard/chemical/properties/DTXSID3024289
Quinoline - https://comptox.epa.gov/dashboard/chemical/properties/DTXSID1021798

Table 3: ADME>IVIVE Prediction Output					
Carbazole (86-74-8)					
Label	Species	Measured	Predicted	Units	Model
Intrinsic Hepatic Clearance	Human	NA	3.362	uL/min/million hepatocytes	ADMet
Fraction Unbound in Plasma	Human	NA	0.0536		ADMet
Volume of Distribution	Human	NA	2.317	L/kg	1compartment
PK Half Life	Human	NA	45.42	hours	1compartment
Steady-State Plasma Concentration	Human	NA	15.48	mg/L	3compartmentss
Pyrene (129-00-0)					
Label	Species	Measured	Predicted	Units	Model
Intrinsic Hepatic Clearance	Human	6.18	NA	uL/min/million hepatocytes	NA
Fraction Unbound in Plasma	Human	0.02415	NA		NA
Volume of Distribution	Human	NA	8.577	L/kg	1compartment
PK Half Life	Human	NA	95.42	hours	1compartment
Steady-State Plasma Concentration	Human	NA	2.533	mg/L	3compartmentss
Quinoline (91-22-5)					
Label	Species	Measured	Predicted	Units	Model
Intrinsic Hepatic Clearance	Human	38.6	NA	uL/min/million hepatocytes	NA
Fraction Unbound in Plasma	Human	0.2036	NA		NA
Volume of Distribution	Human	NA	1.08	L/kg	1compartment
PK Half Life	Human	NA	1.364	hours	1compartment
Steady-State Plasma Concentration	Human	NA	0.2928	mg/L	3compartmentss

Table 3. ADME predictions were determined using the ADME>IVIVE prediction tool on the U.S. Environmental Protection Agency's Comptox Chemicals Dashboard. ADME predictions were not available for Fluorene and Acenaphthene as of Jan 18, 2023. Additional information regarding the methodologies employed in the generation of these predictions can be found in Pearce *et al.* 2017.

Carbazole - https://comptox.epa.gov/dashboard/chemical/adme-ivive-subtab/DTXSID4020248
Pyrene - https://comptox.epa.gov/dashboard/chemical/adme-ivive-subtab/DTXSID3024289
Quinoline - https://comptox.epa.gov/dashboard/chemical/adme-ivive-subtab/DTXSID1021798
NA = not applicable

Table 4: Health Effects of Carbazole and Analogue Chemicals					
	Carbazole	**Fluorene**	**Acenaphthene**	**Pyrene**	**Quinoline**
Structure					
CASRN	86-74-8	86-73-7	83-32-9	129-00-0	91-22-5
Database	Mouse	Mouse Subchronic	Mouse Subchronic	Mouse Subchronic	Rat
Point Of Departure (POD) for RfD	NA	Based on NOAEL of 125 mg/kg-day	Based on NOAEL of 175 mg/kg-day (chronic RfD) or BMDL of 161 mg/kg-day (subchronic RfD)	Based on NOAEL of 75 mg/kg-day	NA
Uncertainty Factor (Composite)	NA	3000	3000	3000	NA
Chronic RfD	NA	$4x10^{-2}$ (IRIS)	$6x10^{-2}$ (IRIS)	$3x10^{-2}$ (IRIS)	NA
Subchronic RfD	NA	$4x10^{-1}$ (ATSDR)	$2x10^{-1}$ (PPRTV)	$3x10^{-1}$ (PPRTV)	NA
Cancer Assessment WOE	EPA B2, IARC not classifiable	Not classifiable due to two limited oral bioassys didn't show increased tumor incidence	Inadequate information (no oral and inhalation studies)	Not classifiable (limited information on increased liver tumors in mid dose only i.p. injection)	Likely to be carcinogenic in humans (IRIS)
Liver	Hepatocellular carcinomas and neoplastic nodules in mice	Increased relative and absolute liver weight accompanied by hemosiderin in the kupffer cells of the liver	**Liver weight increase, increased liver cellular hypertrophy**	Increased relative and absolute liver weight	Increased absolute and relative liver weights, fatty change, slight-to-moderate bile duct proliferation, and slight-to-moderate oval cell infiltration. Nodular hyperplasia, a preneoplastic lesion, mortality due to rupture of tumors, hemangioendotheliomas, is uncommon in rats and mice
Kidney	NA	Increased relative and absolute kidney weight	No effect	**Nephropathy and decreased kidney weights**	NA
Spleen	NA	Increased relative and absolute spleen weight accompanied by hemosiderin in the spleen	Decreased relative and absolute spleen weight	NA	NA
Adrenal	NA	NA	Decreased adrenal weight	NA	NA
Forestomach	Tumors	NA	NA	NA	NA
CNS	NA	Hypoactivity in mice	No effect	NA	NA
Red Blood Cell	NA	**Significant decrease in RBC**	No effect	Decrease in RBC	NA
Hemoglobin	NA	**Decreased hemoglobin**	No effect	Decreased hemoglobin	NA
White Blood Cell	NA	NA	Increased eosinophils	NA	NA
Serum Bilirubin	NA	Increased	No effect	NA	NA
Cholesterol	NA	NA	Increased chlosterol	NA	NA
BUN	NA	Decreased	No effect	NA	NA
Serum Enzyme	NA	NA	NA	NA	Increased SGOT and alkaline phosphatase activities
Other Effects	NA	Hyperplasia of the pituitary gland	NA	NA	NA
DNA Damage and Genotoxicity	Negative in Ames test, short-term carcinogenecity test in rats, and cultured hepatocytes and CHO cell. Positive in chromosome aberration in mice and hamster sperm	Negative in UDS in rat hepatocytes, induced chromosomal aberrations in Chinese hamster lung cell with metabolic activation system	Negative for genotoxicity in the Salmonella typhimurium and Escherichia coli SOS chromotest gene mutation screens	In DNA damage assays in Escherichia coli and Bacillus subtilis pyrene was not mutagenic. Pyrene did not induce chromosome aberrations (as detected by micronuclei) or SCE in bone marrow of several mouse strains. Results of mammalian cell transformation assays in a variety of cell types were negative	Mitogenic and mutagenic in vitro and in vivo, a genotoxic carcinogen to the rat liver, having both tumor-initiating and tumor-promoting activity, mutagenicity requires S-9 activation indicates that it must be metabolized to its active moeity by liver enzymes

Table 4. Summary of health effects after repeated exposure to carbazole or analogues.
Bold text indicates that effects were identified as the critical effect in the dose response assessment.

Table 5. High Throughput Transcriptomic Responses to Chemical Exposure

Carbazole

		BMD
PEDERSEN_METASTASIS_BY_ERBB2_ISOFORM_1	ERBB	2.1958
STEIN_ESR1_TARGETS	Estrogen	2.9022
BOHN_PRIMARY_IMMUNODEFICIENCY_SYNDROM	B Cell	3.70549
DUTERTRE_ESTRADIOL_RESPONSE_24HR	Estrogen	5.02288
GRAHAM_CML_QUIESCENT_VS_NORMAL_QUIESCENT	Chronic Myeloid Leukemia	5.34669
DUTERTRE_ESTRADIOL_RESPONSE_6HR	Estrogen	6.99697
WHITFIELD_CELL_CYCLE_G1_S	Cell Cycle	8.54472
FISCHER_G1_S_CELL_CYCLE	Cell Cycle	10.2178
WAMUNYOKOLI_OVARIAN_CANCER_GRADES_1_2	Carcinoma	12.8789
GO_SENSORY_PERCEPTION_OF_MECHANICAL_STIMULUS	Sensory Perception	14.3617
BILD_E2F3_ONCOGENIC_SIGNATURE	E2F	18.8433
GSE13887_ACT_CD4_VS_NO_TREATED_CD4_TCELL	T Cell anti-CD3 and anti-CD28	19.0234
DORSEY_GAB2_TARGETS	GAB2	22.4306
GO_REGULATION_OF_dnA_BIOSYNTHETIC_PROCESS	DNA	22.727
GO_CELL_CYCLE_PHASE_TRANSITION	Cell Cycle	23.532
GO_REGULATION_OF_dnA_REPLICATION	DNA	25.1803
TOYOTA_TARGETS_OF_MIR34B_AND_MIR34C	MIR	25.4641
SARRIO_EPITHELIAL_MESENCHYMAL_TRANSITION	Breast Cancer	34.1727
GSE24634_TREG_VS_TCONV_POST_DAY7_IL4_CONVERSION	T Cell	34.4372
WHITFIELD_CELL_CYCLE_G2	Cell Cycle	39.612
REACTOME_CHOLESTEROL_BIOSYNTHESIS	Cholesterol	40.0709
GSE7460_CTRL_VS_TGFB_TREATED_ACT_FOXP3_HET_TCONV	Tconv Cell	40.4882
WANG_CISPLATIN_RESPONSE_AND_XPC	Anticancer Drug	40.8264
ELVIDGE_HYPOXIA	Hypoxia	42.0849
GSE10325_CD4_TCELL_VS_BCELL	B Cell vs T Cell	42.7184
VERHAAK_GLIOBLASTOMA_MESENCHYMAL	Glioblastoma	43.1737
GO_REGULATION_OF_TELOMERE_MAINTENANCE	Telomere	43.3075
ZWANG_CLASS_2_TRANSIENTLY_INDUCED_BY_EGF	EGFR	48.2127
REACTOME_METAL_ION_SLC_TRANSPORTERS	SLC	48.9928
GO_CELL_CYCLE_CHECKPOINT	Cell Cycle	49.5731
GO_CELL_SURFACE_RECEPTOR_SIGNALING_PATHWAY_INVOLVED_IN_CELL_CELL_SIGNALING	Cellular Process	52.3012

Fluorene

		BMD
GROWTH_FACTOR_PRODUCTION	VEGF	4.51427
LENAOUR_DENDRITIC_CELL_MATURATION	Dendritic Cell	15.6138
BOQUEST_STEM_CELL	Stem Cell	16.0902
GO_CELLULAR_AMINO_ACID_BIOSYNTHETIC_PROCESS	Cellular Metabolic Process	22.4084
GSE18893_TCONV_VS_TREG_2H_CULTURE	Lymphocyte vs T Cell	24.7518

Pyrene

		BMD
HALLMARK_CHOLESTEROL_HOMEOSTASIS	Cholesterol	5.41953
DUTERTRE_ESTRADIOL_RESPONSE_24HR	Estrogen	23.9317
DUTERTRE_ESTRADIOL_RESPONSE_6HR	Estrogen	30.7418
BHAT_ESR1_TARGETS_VIA_AKT1	Estrogen	35.8163
ACAWNRNSRCGG_UNKNOWN	Transcription Factor	38.6863
HALLMARK_ESTROGEN_RESPONSE_LATE	Estrogen	39.3259
HALLMARK_ESTROGEN_RESPONSE_EARLY	Estrogen	47.7347
SARRIO_EPITHELIAL_MESENCHYMAL_TRANSITION	Breast Cancer	50.703
MOHANKUMAR_HOXA1_TARGETS	HOX	50.9981
GO_REGULATION_OF_OLIGODENDROCYTE_DIFFERENTIATION	Oligodendrocyte	62.9826
BHAT_ESR1_TARGETS_NOT_VIA_AKT1	Estrogen	68.7722
GO_REGULATION_OF_RNA_SPLICING	RNA	87.2849

Quinoline

		BMD
MAGRANGEAS_MULTIPLE_MYELOMA_IGLL_VS_IGL	Myeloma	7.58354
MOHANKUMAR_HOXA1_TARGETS	HOX	12.8418
POU3F2_02	POU3F	14.3415
DUTERTRE_ESTRADIOL_RESPONSE_24HR	Estrogen	19.3444
GSE10325_LUPUS_CD4_TCELL_VS_LUPUS_BCELL	B Cell vs T Cell	22.2007
NFKB_Q6_01	NFKB	38.1392
MCLACHLAN_DENTAL_CARIES	Tooth Disorder	38.9378
KEGG_HOMOLOGOUS_RECOMBINATION	DNA	49.1871

Table 5. High-throughput transcriptomic (HTTr) data were collected from the U.S. Environmental Protection agency's Comptox Chemicals Dashboard as of January 18, 2023. The data presented represent significantly enriched MSigDB pathways identified after exposure of the MCF7 human breast cancer cell line to each chemical. Ontological superfamily descriptors for each pathway are presented to facilitate interpretation. Corresponding BMD values are also reported for each enriched pathway and represent the median pathway BMD value for individual pathways. Data were not available for Acenaphthene in MCF7 cells. See Harrill *et al.* 2021 for additional information on methodologies and experimental design.

Carbazole - https://comptox.epa.gov/dashboard/chemical/httr-summary/DTXSID4020248
Fluorene - https://comptox.epa.gov/dashboard/chemical/httr-summary/DTXSID8024105
Pyrene - https://comptox.epa.gov/dashboard/chemical/httr-summary/DTXSID3024289
Quinoline - https://comptox.epa.gov/dashboard/chemical/httr-summary/DTXSID1021798
Acenaphthene - NA

Table 6. ToxCast Bioactivity *In Vitro* Concentration-Response Assay Data

Carbazole — 41/671 Active

BSK_CASM3C_HLADR_down	cell adhesion molecules
ACEA_ER_AUC_viability	cell cycle
BSK_3C_Proliferation_down	cell cycle
TOX21_MMP_viability	cell cycle
TOX21_RT_HEK293_GLO_08hr_viability	cell cycle
TOX21_RT_HEK293_GLO_16hr_viability	cell cycle
TOX21_RT_HEK293_GLO_24hr_viability	cell cycle
TOX21_RT_HEK293_GLO_32hr_viability	cell cycle
TOX21_RT_HEK293_GLO_40hr_viability	cell cycle
TOX21_RT_HEPG2_FLO_32hr_ctrl_viability	cell cycle
TOX21_RT_HEPG2_FLO_40hr_ctrl_viability	cell cycle
TOX21_MMP_ratio_down	cell morphology
TOX21_PR_BLA_Antagonist_ch1	channel 1
TOX21_H2AX_HTRF_CHO_Agonist_ch2	channel 2
TOX21_p53_BLA_p3_ch2	channel 2
TOX21_PPARd_BLA_agonist_ch2	channel 2
TOX21_PR_BLA_Antagonist_ch2	channel 2
NVS_ADME_rCYP1A2_Activator	cyp
BSK_BE3C_IP10_down	cytokine
BSK_CASM3C_MCSF_down	cytokine
BSK_SAg_IL8_up	cytokine
ATG_Ahr_CIS_up	dna binding
TOX21_p53_BLA_p3_ratio	dna binding
BSK_3C_Thrombomodulin_down	gpcr
ATG_PXRE_CIS_up	nuclear receptor
ATG_PXR_TRANS_up	nuclear receptor
TOX21_AR_LUC_MDAKB2_Antagonist_0.5 nM_R1881	nuclear receptor
TOX21_CAR_Agonist	nuclear receptor
TOX21_ERR_Antagonist	nuclear receptor
TOX21_PR_BLA_Antagonist_ratio	nuclear receptor
TOX21_PXR_Agonist	nuclear receptor
UPITT_HCI_U2OS_AR_TIF2_Nucleoli_Anta gonist	nuclear receptor
NVS_ENZ_rMAOAC	oxidoreductase
BSK_BE3C_MMP1_down	protease
BSK_BE3C_MMP1_up	protease
NVS_TR_hNET	transporter

Fluorene — 37/1001 Active

TAMU_PeakParms_SingleDonor1434_Chronotrop y_Positive	cardiomyocyte function
ACEA_AR_antagonist_AUC_viability	cell cycle
TOX21_DT40	cell cycle
TOX21_DT40_100	cell cycle
TOX21_DT40_657	cell cycle
TOX21_RT_HEK293_FLO_24hr_viability	cell cycle
TOX21_RT_HEK293_FLO_32hr_viability	cell cycle
TOX21_RT_HEK293_FLO_40hr_viability	cell cycle
TOX21_RT_HEK293_GLO_16hr_viability	cell cycle
TOX21_RT_HEK293_GLO_32hr_viability	cell cycle
TOX21_RT_HEK293_GLO_40hr_viability	cell cycle
TOX21_RT_HEPG2_FLO_40hr_ctrl_viability	cell cycle
TOX21_p53_BLA_p5_ch2	channel 2
LTEA_HepaRG_CYP1A1_up	cyp
LTEA_HepaRG_CYP1A2_up	cyp
LTEA_HepaRG_CYP2B6_up	cyp
BSK_3C_TissueFactor_down	cytokine
TOX21_ARE_BLA_agonist_ratio	dna binding
TOX21_p53_BLA_p5_ratio	dna binding
ACEA_AR_antagonist_80hr	nuclear receptor
ACEA_ER_80hr	nuclear receptor
ATG_ERa_TRANS_up	nuclear receptor
ATG_ERE_CIS_up	nuclear receptor
ATG_PXRE_CIS_up	nuclear receptor
ATG_PXR_TRANS_up	nuclear receptor
ATG_RARb_TRANS_dn	nuclear receptor
ATG_RXRb_TRANS_up	nuclear receptor
CCTE_Deisenroth_AIME_96WELL_LUC_Inactive_	nuclear receptor
CCTE_Deisenroth_AIME_96WELL_LUC_Inactive_	nuclear receptor
TOX21_TR_LUC_GH3_Antagonist	nuclear receptor
UPITT_HCI_U2OS_AR_TIF2_Nucleoli_Antagonist	nuclear receptor
CEETOX_H295R_11DCORT_noMTC_dn	steroid hormone
CEETOX_H295R_11DCORT_noMTC_dn	steroid hormone

Pyrene — 102/1076 Active

TAMU_PeakParms_SingleDonor1434_Asystole	cardiomyocyte function
TAMU_PeakParms_SingleDonor1434_Chronotro	cardiomyocyte function
BSK_4H_VCAM1_down	cell adhesion molecules
BSK_CASM3C_HLADR_down	cell adhesion molecules
BSK_SAg_Eselectin_up	cell adhesion molecules
ACEA_AR_antagonist_AUC_viability	cell cycle
BSK_3C_Proliferation_down	cell cycle
BSK_hDFCGF_Proliferation_down	cell cycle
CCTE_Shafer_MEA_dev_AB_dn	cell cycle
CCTE_Shafer_MEA_dev_AB_dn	cell cycle
LTEA_HepaRG_CFLAR_up	cell cycle
TOX21_ERb_BLA_Agonist_viability	cell cycle
TOX21_ERb_BLA_Antagonist_viability	cell cycle
TOX21_PR_BLA_Agonist_viability	cell cycle
TOX21_RXR_BLA_Agonist_viability	cell cycle
APR_HepG2_MitoMembPot_24h_dn	cell morphology
APR_HepG2_NuclearSize_72h_dn	cell morphology
TOX21_MMP_ratio_down	cell morphology
TOX21_PR_BLA_Antagonist_ch1	channel 1
TOX21_RXR_BLA_Agonist_ch2	channel 2
LTEA_HepaRG_CYP1A1_up	cyp
LTEA_HepaRG_CYP1A2_up	cyp
LTEA_HepaRG_CYP2B6_up	cyp
LTEA_HepaRG_CYP2C19_up	cyp
LTEA_HepaRG_CYP2C8_up	cyp
LTEA_HepaRG_CYP2E1_dn	cyp
LTEA_HepaRG_CYP3A4_up	cyp
LTEA_HepaRG_CYP3A7_up	cyp
BSK_SAg_CD38_down	cytokine
BSK_SAg_CD40_down	cytokine
BSK_SAg_CD69_down	cytokine
BSK_SAg_IL8_up	cytokine
APR_HepG2_P-H2AX_72h_up	dna binding
ATG_Ahr_CIS_dn	dna binding
LTEA_HepaRG_NFE2L2_up	dna binding
LTEA_HepaRG_TP53_up	dna binding
LTEA_HepaRG_IGF1_dn	growth factor
NVS_ENZ_hSIRT1	hydrolase
LTEA_HepaRG_ADK_up	kinase
CCTE_Padilla_ZF_144hpf_TERATOSCORE_up	malformation
LTEA_HepaRG_EZR_up	membrane protein
BSK_CASM3C_LDLR_down	misc protein
ACEA_AR_antagonist_80hr	nuclear receptor
ATG_chAR_XSP2_dn	nuclear receptor
ATG_chAR_XSP2_dn	nuclear receptor
ATG_chERa_XSP2_up	nuclear receptor
ATG_DR5_CIS_up	nuclear receptor
ATG_frAR_XSP2_dn	nuclear receptor
ATG_frAR_XSP2_dn	nuclear receptor
ATG_frER1_XSP2_up	nuclear receptor
ATG_frER2_XSP2_up	nuclear receptor
ATG_hAR_XSP2_dn	nuclear receptor
ATG_hAR_XSP2_dn	nuclear receptor
ATG_hERa_XSP2_up	nuclear receptor
ATG_hERb_XSP2_up	nuclear receptor
ATG_hPPARg_XSP2_up	nuclear receptor
ATG_mPPARg_XSP2_up	nuclear receptor
ATG_mPXR_XSP2_up	nuclear receptor
ATG_PXRE_CIS_up	nuclear receptor
ATG_RXRb_TRANS_up	nuclear receptor
ATG_trAR_XSP2_dn	nuclear receptor
ATG_trAR_XSP2_dn	nuclear receptor
ATG_trERa_XSP2_up	nuclear receptor
ATG_zfAR_XSP2_dn	nuclear receptor
ATG_zfAR_XSP2_dn	nuclear receptor
ATG_zfER2a_XSP2_dn	nuclear receptor
ATG_zfER2a_XSP2_dn	nuclear receptor
ATG_zfER2b_XSP2_up	nuclear receptor
CCTE_Deisenroth_AIME_96WELL_LUC_Active_	nuclear receptor
CCTE_Deisenroth_AIME_96WELL_LUC_Active_	nuclear receptor
CCTE_Deisenroth_AIME_96WELL_LUC_Inactive	nuclear receptor
CCTE_Deisenroth_AIME_96WELL_LUC_Inactive	nuclear receptor
OT_ER_ERaERb_0480	nuclear receptor
OT_ER_ERaERb_1440	nuclear receptor
OT_ER_ERbERb_1440	nuclear receptor
TOX21_AR_LUC_MDAKB2_Antagonist_0.5nM_	nuclear receptor
TOX21_CAR_Agonist	nuclear receptor
TOX21_ERR_Antagonist	nuclear receptor
TOX21_PR_BLA_Antagonist_ratio	nuclear receptor
TOX21_PXR_Agonist	nuclear receptor
UPITT_HCI_U2OS_AR_TIF2_Nucleoli_Antagonis	nuclear receptor
LTEA_HepaRG_NQO1_up	oxidoreductase
LTEA_HepaRG_PTEN_up	phosphatase
CCTE_Deisenroth_AIME_384WELL_CTox_Activ	protease
CCTE_Deisenroth_AIME_384WELL_CTox_Inact	protease
LTEA_HepaRG_CASP3_up	protease
LTEA_HepaRG_MMP10_dn	protease
CEETOX_H295R_11DCORT_dn	steroid hormone
CEETOX_H295R_ANDR_dn	steroid hormone
CEETOX_H295R_DOC_dn	steroid hormone
CEETOX_H295R_OHPREG_dn	steroid hormone
CEETOX_H295R_OHPROG_dn	steroid hormone
CEETOX_H295R_PROG_dn	steroid hormone
CEETOX_H295R_TESTO_dn	steroid hormone
LTEA_HepaRG_UGT1A1_up	transferase
LTEA_HepaRG_ABCB11_up	transporter
LTEA_HepaRG_ABCG2_up	transporter

Acenaphthene — 29/927 Active

TAMU_PeakParms_SingleDonor1434_Chro notropy_Positive	cardiomyocyte function
CCTE_Shafer_MEA_dev_AB_dn	cell cycle
CCTE_Shafer_MEA_dev_AB_dn	cell cycle
LTEA_HepaRG_CDKN1A_dn	cell cycle
TOX21_DT40	cell cycle
TOX21_DT40_100	cell cycle
TOX21_DT40_657	cell cycle
TOX21_RT_HEK293_FLO_08hr_viability	cell cycle
TOX21_RT_HEK293_FLO_16hr_viability	cell cycle
TOX21_RT_HEK293_FLO_24hr_viability	cell cycle
TOX21_RT_HEK293_FLO_32hr_viability	cell cycle
TOX21_RT_HEK293_FLO_40hr_viability	cell cycle
TOX21_RT_HEPG2_FLO_24hr_viability	cell cycle
TOX21_RT_HEPG2_FLO_32hr_ctrl_viability	cell cycle
TOX21_RT_HEPG2_FLO_40hr_ctrl_viability	cell cycle
TOX21_VDR_BLA_Agonist_viability	cell cycle
LTEA_HepaRG_CYP1A1_up	cyp
LTEA_HepaRG_CYP1A2_up	cyp
LTEA_HepaRG_CYP2B6_up	cyp
LTEA_HepaRG_CYP2E1_dn	cyp
TOX21_Aromatase_Inhibition	cyp
NVS_LGIC_rGABAR_NonSelective	ion channel
ACEA_ER_80hr	nuclear receptor
ATG_PXRE_CIS_up	nuclear receptor
ATG_RXRb_TRANS_up	nuclear receptor
TOX21_PGC_ERR_Antagonist	nuclear receptor
TOX21_PR_BLA_Antagonist_ratio	nuclear receptor
LTEA_HepaRG_SLC22A1_dn	transporter

Quinoline — 32/911 Active

LTEA_HepaRG_CFLAR_up	cell cycle
TOX21_VDR_BLA_Agonist_viability	cell cycle
TOX21_AP1_BLA_Agonist_ch2	channel 2
LTEA_HepaRG_CYP1A1_up	cyp
LTEA_HepaRG_CYP1A2_up	cyp
LTEA_HepaRG_CYP2B6_up	cyp
LTEA_HepaRG_CYP2C19_up	cyp
LTEA_HepaRG_CYP2C8_up	cyp
LTEA_HepaRG_CYP2E1_up	cyp
LTEA_HepaRG_CYP3A4_up	cyp
LTEA_HepaRG_CYP3A5_up	cyp
LTEA_HepaRG_CYP3A7_up	cyp
LTEA_HepaRG_FAS_up	cytokine receptor
ATG_Ahr_CIS_up	dna binding
LTEA_HepaRG_FOXO1_up	dna binding
LTEA_HepaRG_HIF1A_up	dna binding
LTEA_HepaRG_NFE2L2_up	dna binding
LTEA_HepaRG_NFKB1_up	dna binding
LTEA_HepaRG_TP53_up	dna binding
TOX21_AP1_BLA_Agonist_ratio	dna binding
TOX21_HSE_BLA_agonist_ratio	dna binding
LTEA_HepaRG_IGF1_up	growth factor
LTEA_HepaRG_GCLC_up	ligase
LTEA_HepaRG_ACLY_up	lyase
LTEA_HepaRG_FMO3_up	oxidoreductase
NVS_ENZ_rabI2C	oxidoreductase
LTEA_HepaRG_PTEN_up	phosphatase
LTEA_HepaRG_CASP3_up	protease
LTEA_HepaRG_CASP8_up	protease
LTEA_HepaRG_ABCB1_up	transporter
LTEA_HepaRG_ABCC2_up	transporter
LTEA_HepaRG_SLCO1B1_up	transporter

Table 6. Data presented for each chemical represent active hit calls for assays within the ToxCast and Tox21 program databases as presented on the U.S. Environmental Protection Agency's CompTox Chemicals Dashboard as of January 18, 2023. Intended target family ontologies are listed next to each assay to facilitate data interpretation and active hit calls/total assays evaluated are reported for each chemical. Additional information and descriptions of the underlying methodologies can be found on the following chemical landing pages:

Carbazole- https://comptox.epa.gov/dashboard/chemical/invitrodb/DTXSID4020248
Fluorene- https://comptox.epa.gov/dashboard/chemical/invitrodb/DTXSID8024105
Pyrene- https://comptox.epa.gov/dashboard/chemical/invitrodb/DTXSID3024289
Acenaphthene- https://comptox.epa.gov/dashboard/chemical/invitrodb/DTXSID3021774
Quinoline- https://comptox.epa.gov/dashboard/chemical/invitrodb/DTXSID1021798

Risk Assessment Working Group
Meeting Summary—September 13, 2023

DOE	EPA	Kentucky	FRNP
Rich Bonczek ✓	Shanna Alexander	Stephanie Brock	Evan Clark ✓
	Jonathan Dziekan	Mary Evans ✓	Stefanie Fountain ✓
ETAS	Mac McRae	Nathan Garner ✓	Bruce Ford ✓
Martin Clauberg ✓	Ann Schnitz ✓	Will Grasch ✓	LeAnne Garner
	Brett Thomas	Brian Lainhart	Christine Julias
	Victor Weeks ✓	Todd Mullins ✓	Chris Saranko ✓
		Bart Shaffer ✓	Grant Walter
		Chris Travis	
		April Webb ✓	

✓ Indicates member was present. Also in attendance: Elizabeth Walton (KDEP).

Original meeting agenda items are provided followed by meeting notes; the meeting notes are provided in *italics* with action items noted in *green*.

1. Call for Issues from Risk Assessment Working Group (RAWG) Members

No items were brought forward for discussion by the group.

2. Notes from 6/7/2022 Meeting

No comments were received on the June 7, 2023 meeting summary (provided to the group on July 26, 2023). If there are no additional comments, the meeting summary will be considered final and will appear in Appendix E of the 2024 Risk Methods Document (RMD).

No comments were received from the group on the June 7, 2023 meeting summary and the summary will be finalized for inclusion in the 2024 update to the RMD.

3. FY2023 Schedule/Work Plan

Activity	Target Finish
~~Submit Work Plan (FY2023) to RAWG~~	~~8/31/2022~~
~~Quarterly Meeting (September/FY22Q4)~~	~~9/7/2022~~
~~RAWG Concurs with FY2023 Work Plan~~	~~10/7/2022~~
~~RAWG Provide Additional Suggested Revisions/Corrections to Human Health (HH) Risk Methods Document (RMD) for FY22~~	~~10/21/2022~~
~~Quarterly Meeting (December/FY23Q1)~~	~~12/7/2022 (Moved from 12/14/2022)~~
~~Submit Draft FY2023 HH RMD Appendix A [i.e., Preliminary Remediation Goals (PRGs)] to RAWG for Review~~	~~12/8/2022~~
~~Provide Draft FY2023 HH RMD Main Text and Appendix B and D to RAWG for Review~~	~~12/20/2022~~
~~RAWG Comments Due for Draft FY2023 HH RMD Appendix A~~	~~1/20/2023~~

Activity	Target Finish
~~RAWG Comments Due for Draft FY2023 HH RMD Main Text and HH Appendix B and D~~	~~1/27/2023~~
~~Provide Draft FY2023 HH RMD Appendix E to RAWG for Review~~	~~2/16/2023 (Deleted)~~
~~Quarterly Meeting (March/FY23Q2)~~	~~3/1/2023~~
~~RAWG concurs with Draft FY2023 HH RMD Appendix A~~	~~3/3/2023 (was 2/17/2023)~~
~~RAWG Concurs with Draft FY2023 HH RMD Main Text and HH Appendix B and D~~	~~3/3/2023~~
~~RAWG Comments Due for Draft FY2023 HH RMD Appendix E~~	~~3/17/2023 (Deleted)~~
~~RAWG Concurs with Draft FY2023 HH RMD Appendix E~~	~~3/31/2023 (Deleted)~~
~~Provide Complete Draft FY2023 HH RMD to RAWG for Review~~	~~4/6/2023~~
~~RAWG Comments Due for Entire Revised HH RMD~~	~~5/5/2023~~
~~Quarterly Meeting (June/FY23Q3)~~	~~6/7/2023~~
~~Submit FY2023 HH RMD to FFA Managers (DOE/LX/07-0107&D2/R13/V1)~~	~~6/29/2023~~
~~FFA Managers Acknowledge Receipt of FY2023 HH RMD~~	~~7/28/2023~~
Submit Work Plan (FY2024) to RAWG (see Agenda Item 4)	9/5/2023 (was 9/6/2023)
Quarterly Meeting (September/FY23Q4)	9/13/2023
RAWG Concurs with FY2024 Work Plan	TBD (was 10/6/2023)

Color code for schedule:

Due date	Quarterly meeting
Submittal date	Concurrence/acknowledgement date

4. FY2024 DRAFT Schedule/Work Plan

Activity	Target Finish
Submit Work Plan (FY2024) to RAWG	9/6/2023
Quarterly Meeting (September/FY2023Q4)	9/13/2023
RAWG Concurs with FY2024 Work Plan	TBD (was 10/6/2023)
RAWG Provide Additional Suggested Revisions/Corrections to Human Health (HH) Risk Methods Document (RMD) for FY2024	10/27/2023
Submit Draft FY2024 HH RMD Appendix A [i.e., Preliminary Remediation Goals (PRGs)] to RAWG for Review	12/7/2023
Quarterly Meeting (December/FY2024Q1)	12/13/2023
Provide Draft FY2024 HH RMD Main Text and Appendix B and D to RAWG for Review	1/11/2024
RAWG Comments Due for Draft FY2024 HH RMD Appendix A	1/19/2024
RAWG Comments Due for Draft FY2024 HH RMD Main Text and HH Appendix B and D	2/9/2024
RAWG concurs with Draft FY2024 HH RMD Appendix A	2/16/2024
Quarterly Meeting (March/FY2024Q2)	3/6/2024
Provide Draft FY2024 HH RMD Appendix E to RAWG for Review	3/7/2024
RAWG Concurs with Draft FY2024 HH RMD Main Text and HH Appendix B and D	3/8/2024
RAWG Comments Due for Draft FY2024 HH RMD Appendix E	4/5/2024
Provide Complete Draft FY2024 HH RMD to RAWG for Review	4/18/2024

Activity	Target Finish
RAWG Concurs with Draft FY2024 HH RMD Appendix E	5/3/2024
RAWG Comments Due for Entire Revised HH RMD	5/31/2024
Quarterly Meeting (June/FY2024Q3)	6/5/2024
Submit FY2024 HH RMD to FFA Managers (DOE/LX/07-0107&D2/R13/V1)	7/18/2024
FFA Managers Acknowledge Receipt of FY2024 HH RMD	8/15/2024
Submit Work Plan (FY2025) to RAWG	9/4/2024
Quarterly Meeting (September/FY2024Q4)	9/11/2024
RAWG Concurs with FY 2025 Work Plan	10/11/2024

Color code for schedule:

Due date	Quarterly meeting
Submittal date	Concurrence/acknowledgement date

The dates for the ecological volume of the RMD will be added to the work plan and will be emailed to the group by September 26, 2023.

5. FY2023 Risk Methods Document Updates

The FY2023 RMD was provided to the RAWG on July 11, 2023 and acknowledged and accepted by EPA on July 17, 2023 and by KY on July 26, 2023. The document can be accessed at: https://pubdocs.pad.pppo.gov/?dir=Risk%20Methods%20Document/RMD%202023

No updates or comments on this topic were provided or brought forward by the group.

6. Discussion Items for the FY2024 RMD Update

- The ecological volume of the RMD (not currently in FY2024 work plan)

  The group agreed by consensus to update the ecological volume to obtain current toxicity reference values and benchmarks and be prepared for an ecological risk assessment for a possible Paducah on-site waste disposal facility. A revised FY2024 work plan will be provided to the group. A list of proposed changes will be provided to the group to understand if a scoping meeting is needed. The group agreed by consensus to review the C-400 ecological risk information and incorporate into this document as appropriate.

- Updates to RAIS, including RSL updates (annual review)
  - Changes that affect RMD chemicals [e.g., vinyl chloride change in inhalation RfC from 0.08 mg/m3 (ATSDR subchronic) to 0.01 mg/m3 (IRIS chronic)]

  No updates or comments on this topic were provided or brought forward by the group.

- Changes to recreational user surface water ingestion rates (EPA email March 1, 2023): Revise Teen Recreational User incidental surface water ingestion rate from 0.150 L/hour to 0.124 L/hour in Table B-5. Note - Will result in changes to surface water AL/NAL values for this receptor in Appendix A.

The group discussed that this change is based on a weighted average approach for different age cohorts and represents a 10% change in the value. DOE requested that KY review and provide feedback or agreement with the change

- Consideration of newer references for livestock production and dairy to be provided by EPA or KY. The current references are old but are more relevant to "subsistence farming" than modern agricultural methods.

  DOE discussed that the values in the current RMD are protective and requested that additional information on references, reference values, and impacts be provided. Changes to these values, if agreed upon by the group, would be documented in Appendix D and would not impact Action Levels (ALs) or No Action Levels (NALs). This item will be forwarded to Shanna and Todd for input.

- Comparison of current RMD, EPA's Radionuclide PRG Calculator User's Guide, and Exposure Factors Handbook
  - Fish ingestion rates
  - References for raising laying hens under the farming scenario
  - Information in Sections E.2.2 (Summary of Agricultural Practices in Ballard County), E.2.3 (Summary of Agricultural Practices in McCracken County), E.2.4 (Area of Crop Land in Ballard and McCracken County, Kentucky), and E.2.6 (Annual Harvests of Turkeys and Deer in McCracken and Ballard Counties, Kentucky, and Waterfowl in Ballard County, Kentucky)
  - Foraging intake rates, livestock consumption rates, and transfer factors for local range animals

  See above item. This item will be forwarded to Shanna and Todd for input.

- Consideration of changes in DOE-STD-1196-2021

  If incorporated, changes related to DOE-STD-1196-2021 would result in changes to the ALs/NALs. DOE discussed that the changes reflect a more sophisticated dose evaluation with different age cohorts and that these changes would be difficult to discuss/explain in the document. DOE proposed adding a footnote to the relevant dose-based tables explaining there is a difference between the RMD value and this DOE standard document. The proposed footnote and list of tables the footnote will be applied to will be sent to the group.

- Inclusion of PFAS information/items including calculation of No Action and Action Levels and information on PFAS volatility

  Shanna relayed via email on September 12, 2023, that two new PFAS toxicity values will be added to the RSL table soon and that these include IRIS updates to the oral reference doses for PFHxS and PFDA, bringing the PFAS count up to 10 in the RSL table.

  The group agreed by consensus to calculate site-specific ALs/NALs for PFAS compounds with toxicity information and to include a footnote that RSLs have been published by EPA.

- Confirm chemical surrogates (annual review)

  An email will be sent to the group requesting surrogate review and input. Changes are needed prior to October 31, 2023.

- Anthropogenic background (annual review)

  The group discussed adding a white paper on PFAS background to the FY 2024 work plan/schedule. DOE discussed that use of Ohio River water at the site and that published PFAS results (performed by others) are above the draft/proposed EPA MCLs. EPA agreed that it is necessary to establish site background levels. This potential white paper will be discussed by the RAWG in more detail following review of data from the Sitewide PFAS Screening Assessment project. This topic will be added to the next meeting agenda.

- Consideration of groundwater and soil parameters from the C-400 RI/FS as they relate to the probabilistic modeling discussion in Appendix E

  The RMD currently has a discussion of probabilistic modeling in Appendix E. DOE asked the group if the Appendix E information should be updated or if alternate values from C-400 should be added to the document. This topic will be forwarded to the next Groundwater Modeling Working Group meeting.

- Provisional Peer-Reviewed Toxicity Values (PPRTVs) for certain chemicals (e.g., cis- and trans-dichloroethene)

  The current hierarchy of value selection will be reviewed and a proposal will be emailed to the group.

- The preferred toxicity value hierarchy included in the RMD

  The current hierarchy of value selection will be reviewed and a proposal will be emailed to the group.

- Review soil intrusion exposure scenarios in the context of potential remedial activities

  In addition to the proposed trench model for vapor intrusion in the forward risk calculations, the current soil intrusion exposure scenarios and models included in the document will be reviewed and a proposal will be emailed to the group.

7. C-400 Data

The C-400 Remedial Investigation/Feasibility Study (RI/FS) Report was submitted for FFA party review on January 5, 2023. EPA and KY have provided comments on the RI/FS Report and comment resolution discussions are in progress as part of that project.

No updates or comments on this topic were provided or brought forward by the group.

8. Anthropogenic Background

The white paper was finalized and accepted by the RAWG and was included in Appendix E of this year's update to the RMD.

See anthropogenic PFAS background discussion under Item 6.

9. Chemical Surrogates

The next chemical surrogates list review will be as part of the FY 2024 Q1 meeting.

No updates or comments on this topic were provided or brought forward by the group. DOE requested the RAWG review the list currently in the RMD prior to the next meeting.

10. Emerging Contaminants

- PFAS
  - PFAS is discussed as part this working group and has ties to the Groundwater Modeling Working Group (MWG) as well.
  - An update to Paducah and PORTS PFAS information in the DOE-wide PFAS Assessment is expected in fall 2024. Paducah was involved in development and review of the related survey in summer 2023.
  - The Paducah Site continues to participate in the DOE HQ PFAS Working Group Meetings. Rich is a member of the DOE PFAS Coordinating Committee and plans to coordinate Paducah information and actions with Oak Ridge and Portsmouth.
    - The PFAS Coordinating Committee last met on July 13, 2023.
    - The DOE HQ PFAS Working Group last met on August 3, 2023.
    - The preliminary assessment (PA) guidance (Guide for Investigating Historical and Current Uses of Per-and Polyfluoroalkyl Substances at Department of Energy Sites) is final and available at: https://www.energy.gov/sites/default/files/2023-02/Final%20PFAS%20Investigation%20Guide%20Final%20%28002%29_0.pdf
    - PFAS Coordinating Committee put *PFAS Storage and Disposal Guidance for DOE* on-hold pending release of EPA's updated *Interim Guidance on Destroying and Disposing of Certain PFAS and PFAS-Containing Materials*.
    - The DOE Environmental Sampling Guidance is final and available at: PFAS Environmental Sample Guidance 2023 (energy.gov)
    - The DOE LFRG memo on disposal of PFAS is awaiting signature at DOE HQ. This memo gives LFRG approval for disposal of PFAS-containing waste into facilities with Operating Disposal Authorization Statements like the PORTS OSWDF.
    - Paducah has a question into DOE HQ regarding the potential for disposal of PFAS or PFAS-containing materials in a Subtitle D landfill (e.g., the U-Landfill). A formal request to DOE HQ has not been made on this topic.

- For Paducah, the main PFAS activity for 2023 is the in-progress PFAS screening assessment project.
  - Potable water samples were collected in November 2022 and January 2023. These results were shared with the EPA/KY, and DOE-HQ on May 18, 2023, and with the Paducah workforce and CAB on May 25, 2023.
  - Sampling is planned to be completed this fiscal year with a technical report available to the MWG in the second quarter of FY2024.
  - Environmental sampling status as of 8/27/2023:

Sample Type and Planned Month	Planned	Sampled	% Complete
MWs (September)	191	133	70%
Potable Water (Complete)	5	5	100%
Surface Water (Complete)	16	116	100%
Treated Wastewater (September)	1	0	0%
Leachate (Complete)	3	3	100%
GW and Treated GW (Complete)	6	6	100%
Total	**222**	**163**	**73%**

- Interactions with FFA parties is being managed at the site level as opposed to the HQ level. The group is awaiting information from FFA Managers to understand if there will be a future PFAS project.
- PFAS volatility: PFAS volatility will be pertinent at the Paducah site and will be considered in DQOs if there is an RI-type project. Several references on this topic were provided during the June meeting.

DOE related that the DOE Coordinating Committee guidance documents are complete, but are being held for distribution until EPA completes their guidance. The next Coordinating Committee meeting is September 13, 2023.

Paducah is participating in the beta test of the Annual Site PFAS Status Update survey platform. Site data is to be submitted through this platform by January.

The group discussed potential for the SWMU Assessment Report (SAR) or a Preliminary Assessment (PA)/Site Investigation (SI) to document sampling at the Fire Training Area (FTA). EPA requested that any sampling and reporting be scoped with the FFA parties. DOE discussed that the LFRG memorandum on PFAS-containing waste would need to be considered prior to disposal of any PFAS-containing waste. FRNP confirmed during the call that the FTA is still in use, but that PFAS foams are not being used for training. Language regarding use of this area in the SWMU Assessment Report and CERCLA Five Year Review (in progress) will be reviewed.

The group discussed reporting for the Sitewide PFAS Screening Assessment and that it may be possible to discuss the results of the project late-November. The scope of the technical report is expected to include: context, sampling performed, data quality objectives, and results. EPA requested scoping of the reporting and a meeting including EPA HQ representatives. DOE requested a list of potential dates and times be provided to aid in scheduling this meeting.

An updated summary of the sampling status table was provided to the group following the meeting:

Sample Type and Planned Month	Planned	Sampled	% Complete
MWs (Complete)	191	191*	100%
Potable Water (Complete)	5	5	100%
Surface Water (Complete)	16	16	100%
Treated Wastewater (Complete)	1	1	100%
Leachate (Complete)	3	3	100%
GW and Treated GW (Complete)	6	6	100%
Total	**222**	**222**	**100%**

* MW376, MW377, and MW389 were not able to be sampled due to insufficient water.

- 1,4-Dioxane
  - 1,4-dioxane was historically used as a stabilizer in 1,1,1-trichloroethane and dichloroethane. The group plans to discuss fate & transport characteristics of 1,4-dioxane (compared to TCE) during future MWG meetings.
  - A high 1,4-dioxane result from one well at C-400 cannot be replicated or confirmed as the MW has been dry since that sampling event. The group discussed that there are two methods that could be used to analyze for 1,4-dioxane and that the SVOC method tends to bias results low and the VOC method tends to bias results high. The 1,4-dioxane results are typically isolated detections and are not indicative of a plume.

DOE discussed that 1,4-dioxane requires different treatment technology from what is currently part of the two site groundwater treatment systems, that there is no defined source area for 1,4-dioxane, and that 1,4-dioxane is coincident with TCE.

11. Watch Topics:

- **Derivation of Risk-based Surface Water Effluent Limits**
  The technical approach for risk-based surface water effluent limits has been developed and has been discussed at multiple prior working group meetings; the legal approach remains in discussion between the FFA parties.

  EPA requested information on how this topic is addressed for the DOE Portsmouth Site (PORTS) on-site waste disposal facility (OSWDF). DOE discussed that PORTS is in Ohio, which is an NRC Agreement State and the ARARs for the project are the NRC regulations. The PORTS OSWDF leachate treatment system has an off-the-shelf ion exchange component that is designed to achieve ALARA Tc-99 discharge concentrations below 100 pCi/L. DOE asked that EPA send an email request for additional information.

- **Status of EPA's Policy for Lead in Blood**
  - Shanna is tracking this item and will keep the team posted on any developments.
  - As part of the FY 2023 RMD update, the RAWG agreed that the no action level for lead should remain at 400 mg/kg until EPA releases additional information.
  - EPA relayed to the group during the September 7, 2022 meeting that a new EPA working group in this topic has been formed and the draft policy is in EPA internal review.

Shanna relayed via email on September 12, 2023, that EPA's lead policy is anticipated to be finalized this calendar year

12. Poll RAWG Members/Open Discussion

Items discussed during this portion of the meeting are integrated into their appropriate topics above.

E.12. ANTHROPOGENIC BACKGROUND AT PGDP

The anthropogenic background white paper is presented herein.

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FRNP-RPT-0286

Anthropogenic Background at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

FOUR RIVERS NUCLEAR PARTNERSHIP, LLC

This document is approved for public release per review by:

JOHN EVANS (Affiliate) Digitally signed by JOHN EVANS (Affiliate) Date: 2023.04.27 09:54:29 -05'00'

FRNP Classification Support Date

FRNP-RPT-0286

Anthropogenic Background at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky

Date Issued—April 2023

U.S. DEPARTMENT OF ENERGY
Office of Environmental Management

Prepared by
FOUR RIVERS NUCLEAR PARTNERSHIP, LLC,
managing the
Deactivation and Remediation Project at the
Paducah Gaseous Diffusion Plant
under Contract DE-EM0004895

CONTENTS

ACRONYMS iii

1. IDENTIFICATION OF THE PROBLEM 1

2. DISCUSSION 1
   2.1. PLANT INDUSTRIAL VAPOR INTRUSION PROJECT BACKGROUND 1
   2.2. SUMMARY OF PLANT INDUSTRIAL VAPOR INTRUSION PROJECT RESULTS 2
   2.3. CHLOROFORM PROPERTIES AND USE 3
   2.4. ANTHROPOGENIC CHLOROFORM SOURCES AT THE PADUCAH GASEOUS DIFFUSION PLANT 4

3. SUMMARY 7

4. REFERENCES 8

ACRONYMS

BHHRA	baseline human health risk assessment
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CSM	conceptual site model
EPA	U.S. Environmental Protection Agency
HPFW	high-pressure fire water
PAH	polycyclic aromatic hydrocarbon
PGDP	Paducah Gaseous Diffusion Plant
PI	preliminary investigation
RCW	recirculating cooling water
UCRS	Upper Continental Recharge System
VI	vapor intrusion
VISL	vapor intrusion screening level

1. IDENTIFICATION OF THE PROBLEM

The U.S. Environmental Protection Agency (EPA) defines anthropogenic background as "natural and human-made substances present in the environment as a result of human activities (not specifically related to the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) site in question)" (EPA 2002).

Some of these substances are contaminants, such as polycyclic aromatic hydrocarbons (PAHs), which are a group of related chemicals that are most often associated with anthropogenic background conditions in soil due to their widespread presence and how they form as a result of incomplete combustion of organic materials from vehicular exhaust and from the wearing of tire emissions (ITRC 2021). A primary source of PAHs at the Paducah Gaseous Diffusion Plant (PGDP) is the historical use of coal at the C-600 Steam Plant and the transport and storage of coal at PGDP. As such, *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/R13/V1 (Risk Methods Document), Section E.7, "PAH Contamination and Establishment of Remedial Goals," discusses PAHs as anthropogenic background contaminants at PGDP (DOE 2022a). Section E.7 of the Risk Methods Document also establishes the concept of evaluating PAHs associated with anthropogenic sources on a project-specific basis to ensure that potential exposures to residual PAHs in environmental media are addressed appropriately. Consistent with the evaluation of PAHs in the Risk Methods Document, this white paper provides a discussion of the sources of anthropogenic chloroform at PGDP.

Environmental investigation activities conducted during the plant industrial vapor intrusion (VI) project resulted in the identification of chloroform as a contaminant that was widely detected in subslab vapor, crawlspace air, indoor air, and outdoor air in the industrial area of PGDP (DOE 2022b). The project concluded that, because there were no known environmental sources of chloroform present near the sampling locations, the source of chloroform in the air samples was likely from an anthropogenic background source (i.e., the interaction of chlorine in leaking potable water containing chlorine and organic matter resulted in the production and off-gassing of chloroform).

In evaluating risk and/or hazard at PGDP, the need to sample for chloroform and to evaluate the results of those samples will be determined on a project-by-project basis and will incorporate uncertainties concerning the presence of chloroform into the risk management process. This evaluation process will include the quantitative evaluation of the risk and/or hazard presented by chloroform in the baseline human health risk assessment (BHHRA) in chloroform samples, which is consistent with the Risk Methods Document. Subsequently, the BHHRA will discuss the uncertainties associated with the presence of chloroform, and these uncertainties will be combined with risk characterization in the Observations section of the BHHRA. The project documents will address these uncertainties and will incorporate regulatory requirements to ensure that potential exposure to residual chloroform in environmental media is addressed appropriately.

2. DISCUSSION

2.1. PLANT INDUSTRIAL VAPOR INTRUSION PROJECT BACKGROUND

The plant industrial VI project was undertaken pursuant to the March 2019 *Memorandum of Agreement for Resolution of Formal Dispute Concerning Kentucky Department for Environmental Protection Nonconcurrence and U.S. Environmental Protection Agency Conditions Submitted on the Site Management Plan, Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Annual Revision—Fiscal Year 2018*,

DOE/LX/07-2418&D2 (DOE 2019). The VI investigation activities were performed in accordance with the *Paducah Gaseous Diffusion Plant Industrial Area Vapor Intrusion Preliminary Investigation Work Plan for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (VI Work Plan) (DOE 2020) and were reported in the *Plant Industrial Area Vapor Intrusion Preliminary Risk Assessment Report, Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-2471&D2 (DOE 2022b).

The objectives of the plant industrial VI project were to evaluate whether the subsurface-to-indoor air VI pathways were complete and if they presented an unacceptable risk to workers in the buildings within the PGDP industrial area under current conditions. The VI Work Plan was developed to (1) document the preliminary VI conceptual site model (CSM) for facilities within the PGDP industrial area; (2) document the CSM-based selection process for facilities to be included in the preliminary investigation (PI); and (3) provide assessment methods to guide the collection of vapor samples during the PI to evaluate if VI pathways present an unacceptable risk to human health under current conditions.

In the VI Work Plan, preliminary CSMs were developed using existing information and data for PGDP facilities, ranging from the VI pathway being incomplete (i.e., the facility does not meet the definition of a building, there is no known source near the facility) to the VI pathway needing further evaluation to determine completeness. Based on the preliminary CSMs, 23 buildings with the highest likelihood of a complete VI pathway were selected for inclusion in the PI. Some of the PI buildings were selected to represent groups of buildings with similar CSMs. In those cases, the results from 23 PI buildings served as proxy results for the 38 buildings represented by proxy. Seven chemicals were chosen for evaluation in the PI based on (1) their presence in groundwater above their respective target concentrations or vapor intrusion screening levels (VISLs); and/or (2) their use in operations or processes at PGDP, and/or (3) their association with the degradation of other PI chemicals.

A combination of indoor air samples (coupled with outdoor air samples for background comparison), subslab vapor samples, and/or crawlspace air samples were collected from 23 PI buildings, which represented the 38 by-proxy buildings. The samples were analyzed for the PI analytes chloroform, *cis*-1,2-dichloroethene, *trans*-1,2-dichloroethene, 1,1,1-trichloroethane, trichloroethene, and vinyl chloride using EPA Method TO-15. Screening-level mercury concentrations were collected from indoor air sampling locations using a Jerome® field meter. Additionally, weather data were collected during sampling, and cross-slab differential pressure was recorded at one subslab location per building where paired indoor air samples were collected and subslab sample ports were installed.

2.2. SUMMARY OF PLANT INDUSTRIAL VAPOR INTRUSION PROJECT RESULTS

As reported in the *Plant Industrial Area Vapor Intrusion Preliminary Risk Assessment Report, Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-2471&D2, results from the VI investigation indicated that chloroform was the most detected compound, with 61 out of 113 samples in 19 out of 23 PI buildings (DOE 2022b). Chloroform was also detected in all four media (i.e., subslab vapor, indoor air, crawlspace air, outdoor air). Results for samples from subslab vapor, indoor air, crawlspace air, and outdoor air are listed by media type.

- Indoor air samples
  - Chloroform was detected in 38 indoor air samples from 12 PI buildings: C-100, C-103, C-200, C-304, C-310, C-337, C-409, C-615, C-720-G, C-720, C-724-A, C-724-B, and C-746-U1.
  - Detected concentrations of chloroform in indoor air ranged from 0.19 micrograms per cubic meter ($\mu g/m^3$) in C-720 to 25 $\mu g/m^3$ in C-200.

- Crawlspace air samples
  - Chloroform was detected in 8 crawlspace air samples from 7 PI buildings: C-103, C-412-T11A, C-752-A-T10, C-752-B-T01, C-755-T16, C-755-T27, and C-764-T03.
  - Detected concentrations of chloroform in crawlspace air ranged from 1.3 µg/m^3 in C-412-T11A to 3 µg/m^3 in C-764-T03.
- Subslab vapor samples
  - Chloroform was detected in 11 subslab vapor samples from 7 PI buildings: C-200, C-310, C-337, C-409, C-720, C-724-A, C-724-B, and C-725.
  - Detected concentrations of chloroform in subslab vapor ranged from 1.9 µg/m^3 in C-720 to 850 µg/m^3 in C-337.
- Outdoor air samples
  - Chloroform was detected at concentrations of 0.2 µg/m^3, 0.8 µg/m^3, and 0.63 µg/m^3 outside of C-200, C-615, and C-724-A and C-724-B, respectively.

Chloroform was the only PI analyte with exceedances of EPA's default commercial VISL in indoor air. Of the 61 detections described in the preceding bullets, 43 samples exceeded the VISL (Table 1).

Table 1. Chloroform Exceedances by Media

	Subslab Vapor[a]	Indoor Air[b]	Crawlspace Air[b]	Outdoor Air[b]
VISL Exceedances	6	26[c]	8	3[d]

[a] Subslab vapor sample results were compared to the EPA default soil gas VISL of 17.8 µg/m^3 for commercial receptors based on a target cancer risk of 1E-6.
[b] Indoor air, crawlspace air, and outdoor air sample results were compared to the EPA default indoor air VISL of 0.533 µg/m^3 for commercial receptors based on a target cancer risk of 1E-6.
[c] 11/26 sample results were "J" qualified.
[d] Includes a duplicate sample; all 3 sample results were "J" qualified.

2.3. CHLOROFORM PROPERTIES AND USE

Chloroform belongs to the family of polyhalogenated compounds, which are organic compounds that have two or more halogen atoms. Each molecule of chloroform consists of three chlorine atoms attached to one carbon atom. Chloroform is a colorless, volatile, liquid derivative of trichloromethane with an ether-like odor.

Common industrial and institutional uses of chloroform in the United States have included its use as an extraction solvent for oils, greases, waxes, lacquers, floor polishes, resins, rubber, gums, and adhesives (ATSDR 1997). Chloroform is also used in the production of materials that may have been acquired for use at PGDP such as refrigerants (e.g., chlorofluorocarbon-22, fluorocarbon-22), fumigants, plastics (including polyvinyl chloride), and in fire extinguishers to help lower the freezing temperature of carbon tetrachloride (Holbrook 2018, NCBI 2018). No information related to the historical use of chloroform as a widely-used solvent at PGDP has been identified, and there were no known environmental sources of chloroform present near the VI sampling locations. This suggests that the source of chloroform in the air samples was from another widely distributed source, which was likely from an anthropogenic background source.

2.4. ANTHROPOGENIC CHLOROFORM SOURCES AT THE PADUCAH GASEOUS DIFFUSION PLANT

Chloroform is commonly detected in association with chlorinated water supplies. According to the EPA, "Chloroform may be released to the air as a result of its formation in the chlorination of drinking water, wastewater and swimming pools" (EPA 2000). Chloroform has been detected at low concentrations in groundwater across a wide portion of the Paducah Site, which is consistent with widespread potable water leaks (Figure 1). As documented in the sitewide groundwater flow model, various sources of anthropogenic recharge (i.e., recharge that is caused or produced by human activity) are present in the plant industrial area. Sources include leakage from the underground water supply lines, fire protection lines, and cooling towers (DOE 2022c). For PGDP, more than 142 miles of piping exists within the footprint of the plant industrial area from the time when the plant was operational (Figure 2). Table 2 provides information on the total lengths and pressures of various water and sewer lines present at PGDP, as well as any additives used within them. Figure 2 delineates water and sewer lines located within the plant industrial area and includes facilities noted to have chloroform detections.

Prior to 2014, the HPFW system and the cooling towers were chlorinated using chlorine gas. After 2014, the HPFW system and the cooling towers were chlorinated using sodium hypochlorite tablets. The HPFW system was taken offline in November 2021. Based on the typical range of chloroform levels [2 to 44 micrograms per liter (μg/L)] reported in treated drinking water systems (ATSDR 1997), both water systems at PGDP are expected to leak water containing chloroform at concentrations greater than the default groundwater VISL for commercial receptors of 3.55 μg/L. This indicates that the water supply and wastewater piping leaks may be important widespread sources of chloroform to soil gas and indoor air at PGDP.

Although there were variability and uncertainty in recharge rates across the site, anthropogenic recharge rates tended to be higher in 2014 than in 1995, which is consistent with the notion that more leaks would occur as the infrastructure ages. Quantifying historical leakage rates is imprecise; however, in 2016, leakage from the HPFW system was estimated to be 40 gallons per minute (gpm) based on the refill rate required to maintain a constant water level in the HPFW supply tower. Moreover, the locations of historical leaks are not well characterized, but it is likely that leaks in the piping system spread horizontally within the piping subbase gravel before migrating vertically to groundwater in the Upper Continental Recharge System (UCRS).

The quantification of historical leakage rates over the years has been imprecise. Even though maintenance records are available, to some extent, from the transfer of operational responsibilities between United States Enrichment Corporation and U.S. Department of Energy, the records cannot be considered complete. The locations of historical leaks and the associated volumes are not well characterized; however, personal interviews with maintenance operators have indicated that historical leaks ranged from minimal to quite extensive based on the method of discovery (e.g., noticeable soft soil surface area to pressure reading/level drops) and which system's integrity failed. For instance, one particular level drop was noticed in 2016 in the HPFW supply tower as the tower was unable to maintain the required constant water level. The associated investigation led to the discovery of an estimated 40 gpm leak from the HPFW piping. As with any leak of liquids into the soil, the first indication is to follow the path of least resistance, which in this case indicated that leaks in the piping system spread horizontally within the piping subbase gravel before migrating vertically to recharge the UCRS.

Figure 1. Subsurface Chloroform Results in Relation to Vapor Intrusion Study Facilities (DOE 2022b)

Figure 2. PGDP Water Lines

Table 2. Length of Water and Sewer Lines Present at PGDP[a]

Water Lines	Length (ft)	Pressure (psig)
Raw water lines	20,758	< 70
High-pressure fire water (HPFW) lines	57,028	125
Recirculating cooling water (RCW) water lines	114,196	80
RCW waste heat lines	11,307	< 60
Plant water lines	35,313	35
Sanitary water lines	213,195	~ 75
Total Length	**451,797**	
Sewer Line	**Length (ft)**	
Sanitary sewer lines	57,800	~ 20[b]
Storm drain system	238,080	N/A
Total Length	**295,880**	

Notes:
psig = pounds per square inch gauge
N/A = Not Applicable
[a] Lengths obtained from utility maps available as part of the 2016 sitewide groundwater model update (DOE 2022c).
[b] Forced main lines on the plant site include the C-615-H1 lift station to 14th Street, as well as the line from DUF_6 to C-104 to the C-615-H10 lift station. There is not pressure indication for the lines, but based on the lift pump pressures at other locations, the pressure is estimated as 20 psig or below.

A subset of monitoring wells in the PGDP industrial area is sampled periodically and analyzed for chloroform, as detailed in each fiscal year Environmental Monitoring Plan. Of the 1,990 chloroform results in groundwater samples included in Appendix B of the VI Work Plan, 1,940 (or 97%) have reporting limits or detected concentrations less than 80 µg/L (the maximum contaminant level for total trihalomethanes[1] in drinking water). Of the 50 samples with detections or reporting limits above 80 µg/L, only 30 (or 1.5%) of the samples had chloroform detections between 80 and 1,200 µg/L, all of which were located near C-747 and C-748-B. These two buildings and the adjacent facilities include inactive burial areas (C-747), inactive uranium scrap burial yards (C-748-B and C-749), and the uranium hexafluoride cylinder storage yards (C-745-A, C-745-B, and C-745-C). Of the 20 non-detect samples with reporting limits greater than 80 µg/L, a majority of the samples were taken from locations near C-400, C-747, and C-748-B buildings as noted above. While some higher reporting limits from laboratory-diluted aqueous samples do not preclude the presence of chloroform at higher concentrations, the range of observed chloroform detections is more consistent with potable water leaks than with environmental releases of chloroform-containing contaminants.

3. SUMMARY

In an EPA study titled *Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences (1990–2005)*, chloroform was detected in 69% of the collected indoor air samples across 15 case studies (EPA 2011). The use of chlorinated water in a building can certainly result in the release of chloroform to indoor air directly (e.g., showering, laundry). Continuing and episodic releases of chlorinated water to the subsurface near buildings is another highly plausible mechanism to deliver a low concentration supply of chloroform to soil gas, subslab soil gas, and indoor air via the VI pathway.

No information that relates to the historical use of chloroform as a solvent at PGDP has been identified; however, the chlorination of drinking water and water used for industrial purposes did occur throughout the production period and, to some degree, will continue until the systems are no longer needed or are turned

[1] Total trihalomethanes include chloroform and other chemical compounds in which three of the four hydrogen atoms of methane are replaced by halogen atoms.

over to a municipality. Based on the multiple lines of evidence described in the *Plant Industrial Area Vapor Intrusion Preliminary Risk Assessment Report, Paducah Gaseous Diffusion Plant, Paducah, Kentucky,* DOE/LX/07-2471&D2, and summarized herein, the source of chloroform in the subslab vapor, crawlspace air, and indoor air samples was most likely associated with an anthropogenic background source (i.e., the interaction of chlorine in leaking potable water containing organic matter resulted in the production and off-gassing of chloroform) (DOE 2022b).

Although chloroform is a common background contaminant and multiple sources of anthropogenic chloroform exist across PGDP, chloroform's likely presence in environmental media across the Paducah Site indicates that chloroform should be considered when selecting analytes during project scoping for future investigations unless information exists to support its exclusion from the analyte list.

4. REFERENCES

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E.13. PFAS ANTHROPOGENIC BACKGROUND AT PGDP

This white paper is planned to be developed in FY 2024 and included in the FY 2025 update to this document.

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ATTACHMENT E1

1995 QUESTIONNAIRE AND RESPONSES REGARDING RECREATIONAL USAGE OF BAYOU AND LITTLE BAYOU CREEKS

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409
North Forbes Road
Lexington, Kentucky
40511-2050

606-233-0574
606-254-4800 FAX

Fuller Mossbarger Scott & May
FMSM
ENGINEERS

October 26, 1995 O.1.1.94355L05

Mr. Charles Logsdon
Kentucky Department of Fish and Wildlife Resources
10535 Ogden Landing Road
Kevil, Kentucky 42053

Re: PCB Risk Calculations
Paducah Gaseous Diffusion Plant

Dear Mr. Logsdon:

FMSM is conducting a preliminary risk calculation for the Little Bayou and Big Bayou areas around the Paducah Gaseous Diffusion Plant. This subject was discussed at a meeting in which you attended on September 7, 1995. During that meeting you indicated that your office could provide information on the recreational use of these areas. In response to your suggestion, we have developed the following list of questions. Please try to research your site use data and answer as many of these questions as possible. If data is not directly available to answer these questions we would appreciate an estimate based on your best professional judgment.

Big Bayou

1. What is the average number of visitors per year to Big Bayou?

2. Of this number, how many are adults and how many are children?

3. Are most of your visitors repeat or one-time visitors on a yearly basis?

4. What is the average time (hours) spent in Big Bayou? Is there a difference in average time spent between adult and child usage?

5. What are the common recreational usages in the area? What is the percentage breakdown of usages by the visitors (i.e. what percentage of visitors fish, hunt, hike, swim, etc.)?

6. What is the number of repeat visits per year by any one individual or group of individuals? What is the average time spent (hours) in the area by the higher frequency visitors?

7. For individuals who are fishing in the area, are they mostly bank fishing or wade fishing? Can you estimate the percentage breakdown between the two? What is the average time spent in the area by a fisherman?

8. Is there a harvestable fish population in Big Bayou? If there is, is there enough to support subsistence fishing (i.e., 0.284 kilograms of meat flesh/meal) for one person to eat 128 meals a year? If not, how much fish, and how often could a person best expect to harvest a meal for consumption?

Little Bayou

I realize that during the September 7th meeting, you stated there is little to no recreational use of the Little Bayou areas. However, it would be helpful if you could answer the same questions about Little Bayou, as asked of Little Bayou. Therefore, we are repeating the following questions.

1. What is the average number of visitors per year to Little Bayou?

2. Of this number, how many are adults and how many are children?

3. Are most of your visitors repeat or one-time visitors on a yearly basis?

4. What is the average time (hours) spent in Little Bayou? Is there a difference in average time spent between adult and child usage?

5. What are the common recreational usages in the area? What is the percentage breakdown of usages by the visitors (i.e. what percentage of visitors fish, hunt, hike, swim, etc.)?

6. What is the number of repeat visits per year by any one individual or group of individuals? What is the average time spent (hours) in the area by the higher frequency visitors?

7. For individuals who are fishing in the area, are they mostly bank fishing or wade fishing? Can you estimate the percentage breakdown between the two? What is the average time spent in the area by a fisherman?

8. Is there a harvestable fish population in Little Bayou? If there is, is there enough to support subsistence fishing (i.e., 0.284 kilograms of meat flesh/meal) for one person to eat 128 meals a year? If not, how much fish, and how often could a person best expect to harvest a meal for consumption?

We appreciate your help in answering these questions. After you have reviewed these, if you have any questions, or if the questions need clarification, please call.

Sincerely,

FULLER, MOSSBARGER, SCOTT AND MAY
ENGINEERS, INC.

Stephen L. Scott, P.E.
Project Manager

/esh

c: David Asburn
Tom McGee
Bob Sneed
David Brancato

94355L05.doc

facsimile
TRANSMITTAL

to: Stephen Scott, P.E.
fax #: 606-254-4800
re: Big Bayou & Little Bayou
date: November 8, 1995
pages: 4, including this cover sheet.

From the desk of...

Charlie Logsdon
WMA Supervisor
Ky. Dept. Of Fish & Wildlife Resources
10535 Ogden Landing Rd.
Kevil, KY. 42053

(502)488-3233
Fax:

Stephen Scott, P.E.
Fuller, Mossbarger, Scott and May
Engineers, Inc.
1409 North Forbes Road
Lexington, Ky. 40511-2050

Dear Mr. Scott:

I have answered these question as accurately as possible. If you have any other questions, or questions about my answers feel free to contact me. Sorry about the delay, but you're letter came during some of our deer hunting seasons.

Sincerely,

Charlie Logsdon

Charlie Logsdon

cc: Wayne Davis
Don Walker

Little Bayou

1. The number of people visiting Little Bayou is essentially zero, with the exception of PGDP personnel and a few fishermen(maybe, 20 visits annually) that fish a large beaver pond above the outfalls of the plant. A few people (bowhunters and dog trainers) may cross the creek occasionally, but these visits would be brief(the majority would be measured in seconds or minutes). Field trial galleries do cross the creek(over a large dirt-covered culvert) north of McCaw Road, however, they do not enter the creek and the whole process takes seconds.

2. The visitors would be adults.

3. Refer to Big Bayou question 3. Visitors to Little Bayou would be repeat users, probably less than 10 visits per year and most of them in the brief encounter scenario described in question 1.

4. Most encounters with Little Bayou would be measured in seconds. Fishermen that use the beaver pond above the outfalls, may fish on average 2 hours.

5. See Big Bayou question 5.

6. Field trials that cross the creek may occur 12-15 weekends of the year. Most of the participants would be repeat users. The sum of all the encounters with Little Bayou would be measured in minutes for the most frequent user and most would only cross the creek on the culvert and dirt crossings.

7. All fishermen in the beaver pond would be bank fishermen as the pond is too deep to wade.

8. Other than the beaver pond above the outfalls, it would be nearly impossible to catch 0.284 kgs of fish from Little Bayou. There is a fish population, but most would fall in the minnow category and are not desirable by fishermen. In the beaver pond, it would be possible to catch this amount, but it would not support subsistence fishing(128 meals/year).

Big Bayou

Question 1: The number of visits by people using Big Bayou specifically, is estimated to be 150 visits. This is for a specific activity involving Big Bayou, such as fishing. More people may be in the vicinity while using the WKWMA, but their use of Big Bayou maybe for only an instant(i.e., using a log to cross Big Bayou to hunt on the other side of the creek).

Question 2: Of the 150 visits of people using Big Bayou, 100 are adults and 50 are children. This is an estimate based on our observations of people using the area.

Question 3: Most of these people would be one time users. However, 10% of the total number of users could be classified as repeat users. The highest number of visits by one person specifically using Big Bayou, would probably be <10.

Question 4: The average time spent in Big Bayou by users is unknown. However, I feel the amount of time spent/trip would be similar to other activities. During 1994, the average number of hours spent/trip for the following activities were: Quail hunting - 3.49 hrs/trip(n= 158), rabbit hunting - 3.25(n=168), bowhunting for deer - 3.48(n=1115), duck hunting - 2.4(n=69), and raccoon hunting - 2.63(n=20). Raccoon hunting and duck hunting would be the activities most likely associated with Big Bayou. There would be little, if any, difference between adult and child usage of the area.

Question 5: This question is difficult to answer. Do you mean for WKWMA or Big Bayou? WKWMA is heavily used by a wide variety of users. Annually, the estimated number of visits for the following activities are: fishing - 5000 visits/year, hunting and dog training 4-6000, field trials - 1500, hiking - 100, berry & nut picking - 200, driving through for a variety of reasons - 50,000.
For activities involving Big Bayou alone: fishing - 150, hunting - ?(explained in question 1).

Question 6: Refer to questions 3 and 4.

Question 7. Most, if not all would be bank fishermen. Most of the fishing would occur at 3 points: 1) where the iron bridge in tract 4 crosses Big Bayou, 2) where the collapsed bridge in tract 4 crosses Big Bayou(by weir constructed by PGDP), and 3) where the concrete crossing bridges Big Bayou in tract 6. While it may occur, no wade fishing has been observed. No actual data is available, but should be similar to the length of visits noted in question 4.

Question 8: There is a harvestable fish population in Big Bayou. A person could potentially expect to catch 0.284 kgs of fish on a regular basis(depending on the skill of the fisherman), however, this is assuming that the person is not culling(throwing back extremely small fish). The frequency of being able to catch 0.248 kgs of fish would increase as one approaches the mouth of Big Bayou. Also, the only way the creek could support 128 meals a year is if there was major influx of fish from the Ohio River. This does occur when there is a backwater. During the backwater periods catches of 50 to several hundred pounds of catfish can be taken(this has been observed) on trotlines. This would not be indicative of risks associated with the plant.

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ATTACHMENT E2

2014 E-MAIL UPDATE REGARDING RECREATIONAL USAGE OF BAYOU AND LITTLE BAYOU CREEKS

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Used with permission for inclusion in *Methods for Conducting Risk Assessment and Risk Evaluation at the Paducah Gaseous Diffusion Plant Paducah, Kentucky, Volume 1. Human Health.*

Garner, Leanne K (YLN)

From: Kreher, Timothy (FW) <Timothy.Kreher@ky.gov>
Sent: Tuesday, January 21, 2014 11:41 AM
To: Garner, Leanne K (YLN)
Subject: RE: Update of Recreational Use of Bayou and Little Bayou Creeks near PGDP

LeAnne,

I would concur with the numbers and estimates originally provided by Charlie Logsdon for the most part. I would suggest that there are brief exposures to both Little Bayou and Bayou Creeks by dog trainers riding horses where they cross the creek via the method of the horse and dog wading through the creek while the rider is mounted (i.e., the riders does not have contact with the water for the most part). Such crossings are brief, less than 10 seconds at a time. I would also suggest that there may be cases where hunters cross one or both creeks by wading through shallow spots, but in most cases these people are wearing rubber boots or waders, and I would not consider this a major source of exposure (?). When hunters do wade through the creeks, it is again a brief exposure of less than 30 seconds each time.

I would suggest increasing the **frequency** of visits / exposures by a factor of 1.5 for all of Charlie's answers to factor in increased use of the WMA.

I almost never see fishing activity in the creeks outside of the portion that crosses through TVA-owned property near where the creeks join and meet the Ohio River (what we refer to as Tract 6 of the WKWMA). As Charlie mentioned, the great majority of this fishing activity occurs when the Ohio River levels are elevated and have the creeks "backed up" with water from the river. I assume this also decreases the effects of any particular exposure during these instances.

Tim Kreher
Wildlife Biologist, Kentucky Department of Fish and Wildlife Resources
Doug Travis, Obion Creek, and West Kentucky Wildlife Management Areas
10535 Ogden Landing Road, Kevil, KY 42053
office 270-488-3233; cell 270-292-9010; fax 270-488-2589
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From: Garner, Leanne K (YLN) [mailto:Leanne.Garner@lataky.com]
Sent: Tuesday, January 21, 2014 8:52 AM
To: Kreher, Timothy (FW)
Subject: RE: Update of Recreational Use of Bayou and Little Bayou Creeks near PGDP

Any thoughts on this, Tim?
If there are no updates, I can just use to older information.

Thanks.

LeAnne

From: Garner, Leanne K (YLN)
Sent: Tuesday, January 07, 2014 8:56 AM
To: 'Timothy.Kreher@ky.gov'
Subject: RE: Update of Recreational Use of Bayou and Little Bayou Creeks near PGDP

Good morning, Tim!
I hope you had a good holiday!

We are updating the Risk Methods Document (the *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant Paducah, Kentucky Volume 1. Human Health*) with more current information.

Some of the information we are updating is "Recreational Use of Bayou and Little Bayou Creeks near PGDP." I have attached that information.
The entire document can be found here:
http://www.paducaheic.com/media/112385/ENV1.A-00440-ARI41.pdf

If you could, please look at the attached and let me know if you think any of the information needs updating.
If so, do you have that information?

I would appreciate any help you could give.

Thank you.

LeAnne Garner
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