US Department of Energy
Paducah Gaseous
Diffusion Plant

2022

Paducah Site
Annual Site Environmental Report

FRNP-RPT-0287

Paducah Site

Annual Site Environmental Report 2022

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Paducah Site
Annual Site Environmental Report 2022

September 2023

Prepared for the
US 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

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Acronyms and Abbreviations

A	ALARA	as low as reasonably achievable
	ANSI	American National Standards Institute
	ASER	Annual Site Environmental Report
	ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
B	BCG	biota concentration guide
C	CAP-88 PC	Clean Air Act Assessment Package-1988 Personal Computer
	CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
	CFR	*Code of Federal Regulations*
D	DOE	US Department of Energy
	DOECAP	DOE Consolidated Audit Program
	DUF_6	depleted uranium hexafluoride
E	EISA	Energy Independence and Security Act
	EMS	Environmental Management System
	EPCRA	Emergency Planning and Community Right-to-Know Act
F	FFA	Federal Facility Agreement
	FRNP	Four Rivers Nuclear Partnership, LLC
	FY	fiscal year
G	GSA	General Services Administration
I	ILA	industrial, landscaping, and agriculture

K	*KAR*	*Kentucky Administrative Regulations*
	KDEP	Kentucky Department for Environmental Protection
	KDOW	Kentucky Division of Water
	KDWM	Kentucky Department of Waste Management
	KPDES	Kentucky Pollutant Discharge Elimination System
M	MCS	Mid-America Conversion Services, LLC
	MEI	maximally exposed individual
N	NEPA	National Environmental Policy Act
	NESHAP	National Emission Standards for Hazardous Air Pollutants
O	OREIS	Oak Ridge Environmental Information System
P	PEGASIS	PPPO Environmental Geographic Analytical Spatial Information System
	PEMS	Project Environmental Measurements System
	PFAS	per- and polyfluoroalkyl substances
	PGDP	Paducah Gaseous Diffusion Plant
	PPPO	Portsmouth/Paducah Project Office
Q	QA	quality assurance
	QC	quality control
R	RCRA	Resource Conservation and Recovery Act
S	SST	Swift & Staley, Inc.
T	TSDF	treatment, storage, and disposal facility
U	US EPA	US Environmental Protection Agency
W	WKWMA	West Kentucky Wildlife Management Area

Request for Comments

The US Department of Energy requires an annual site environmental report from each of its sites. This *Paducah Site Annual Site Environmental Report 2022* presents the results from the various environmental monitoring programs and activities carried out during the year. This report is a public document that is distributed to government regulators, businesses, special interest groups, and members of the public. Please note that hyperlinks appear throughout this report to take the reader directly to the website or other locations where data, tables, or supporting documents can be found. These links were active at the time of publication, but may become inactive if items have moved or a website has been renamed.

This report is based on many environmental samples collected at or near the Paducah Site. Significant efforts were made to provide the data collected and details of the Paducah Site environmental management programs in a clear and concise manner. The editors of this report encourage comments in order to better address the needs of our readers in future Paducah Site environmental reports. You can complete a comment form online here.

If you prefer, written comments may be sent to the following address:

US Department of Energy
Portsmouth/Paducah Project Office
1017 Majestic Drive, Suite 200
Lexington, Kentucky 40513

Executive Summary

The US Department of Energy's (DOE's) Paducah Site is in a rural area of McCracken County, Kentucky, 10 miles west of Paducah and 3.5 miles south of the Ohio River. Constructed on a portion of a World War II-era munitions plant, the Paducah Site became one of three uranium enrichment plants serving both national security and the commercial sector.

Figure ES.1. Flock of ducks preparing to enter a pond

Since 1988, DOE's Office of Environmental Management has been conducting cleanup operations at Paducah even as the Site supported the commercial nuclear sector. DOE's activities at the Paducah Site include restoring impacts from past operations to protect human health and the environment; stabilizing infrastructure; removing radioactive and hazardous wastes from facilities; characterizing and disposing of waste stored or generated on site; and decontaminating and demolishing the gaseous diffusion plant and its support facilities (Figure ES-1).

Each year, the Paducah Site prepares the Annual Site Environmental Report (ASER) according to the requirements of DOE Order 231.1B, *Environment, Safety, and Health Reporting*. The ASER is a key component of DOE's effort to keep the public informed about environmental conditions at the Paducah Site. This report and previous ASERs can be found here.

The ASER offers a detailed overview of environmental activities at Paducah, which are organized as follows:

DOE conducts environmental monitoring to assess the potential impact of Paducah Site activities on public health and the environment. In 2022, measurements for direct radiation were taken on and around the Paducah Site; more than 1,600 samples of air, sediment, and water were collected and analyzed for radioactive and nonradioactive contaminants.

Chapter 1: Introduction to the Paducah Site's history and mission

Chapter 2: Summary of compliance with laws and regulations

Chapter 3: Details of Paducah Site environmental management programs

Chapter 4: Types of radiological environmental monitoring conducted at the Paducah Site and the calculated impacts

Chapter 5: Nonradiological monitoring of air, surface water, and sediment

Chapter 6: Groundwater protection

Chapter 7: Actions to ensure the quality of information from field sampling to analytical laboratory to data management

DOE conducts environmental monitoring to evaluate and assess any unplanned releases. Major sampling efforts of environmental monitoring for 2022 are summarized below.

- DOE monitored for radionuclides, trichloroethene, metals, and other water quality parameters under the Kentucky Pollutant Discharge Elimination System (KPDES) Permit and the Environmental Radiation Protection Program at 15 locations where surface water flows into Bayou Creek and Little Bayou Creek.
- External radiation was measured continuously at 64 locations. The measurements were reported quarterly.[1]
- Ambient air was sampled at nine locations, on site and off site, and was analyzed for radionuclides.
- Surface water samples were collected quarterly from seven locations and annually from two locations, both on site and off site, and analyzed for radionuclides.
- Surface water samples were collected quarterly from two on-site landfill locations and analyzed for metals and volatiles; and one off-site location and analyzed for trichloroethene.
- Sediment was sampled at 6 locations and analyzed for radionuclides and at 14 locations for polychlorinated biphenyls.
- Surface water sampling included testing fathead minnows and water fleas for chronic toxicity at three locations and acute toxicity at one location.
- More than 200 wells were sampled at varying frequencies to monitor corrective actions, movement of groundwater contaminants, and groundwater quality.
- Potable water was sampled at five locations for per- and polyfluoroalkyl substances (PFAS) compounds.

2022 Environmental Performance Summary

DOE's monitoring performance at Paducah for 2022 is summarized below.

- Environmental monitoring data collected in 2022 are similar to data collected in previous years and indicate that radionuclides, metals, and other chemicals released by Paducah would only minimally affect human health and the environment.
- The calculated radiation dose that could be received by a member of the public from DOE activities at the Paducah Site (see Figure ES.2) was 4.3 millirem (mrem), compared to the DOE annual dose limit of 100 mrem.
- Concentrations of most contaminants detected in the groundwater plumes at Paducah were stable or decreasing in 2022. A groundwater strategy initiative that collects information on sources and levels of contamination in groundwater was continued from previous years. This information will lead to a better understanding of the extent of groundwater contamination and how this contamination migrates.

[1] The terms external radiation and direct radiation are used synonymously in this document.

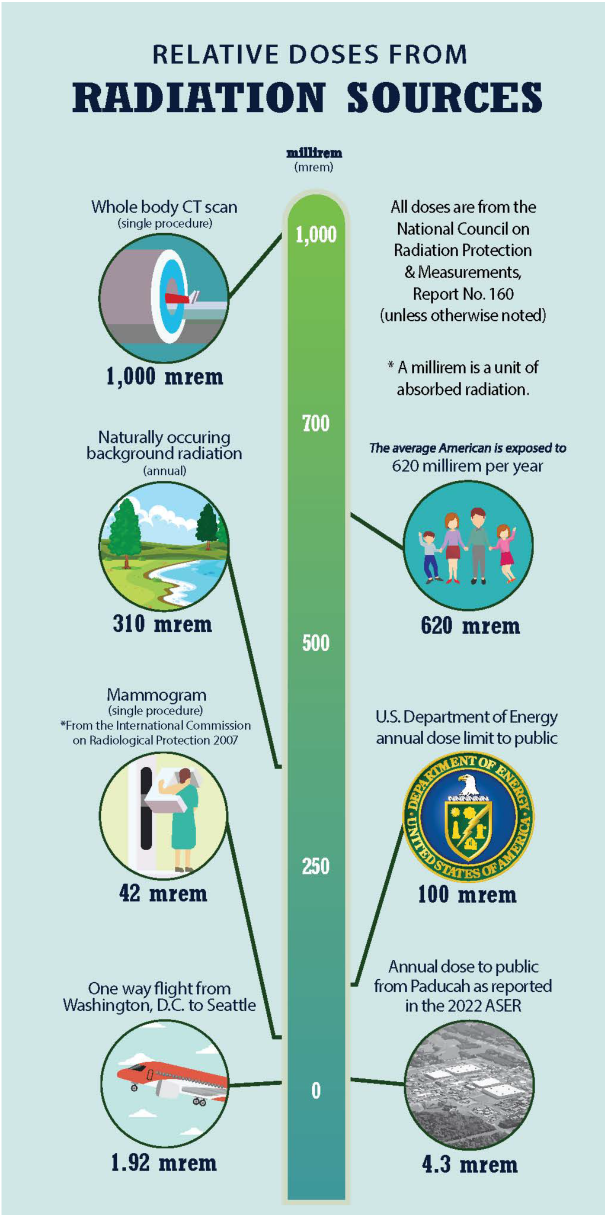

Figure ES.2. Relative doses from radiation sources

- In 2017, the Paducah Site began investigating the history of on-site use of PFAS compounds. Based on the most likely known potential source of PFAS contaminants (fire suppression chemicals), samples were collected in 2019 from 2 groundwater monitoring wells in the Fire Training Area and analyzed for 18 PFAS compounds. Analytical results indicate detectable levels of PFAS contamination in groundwater in the vicinity of the Fire Training Area.
- In 2022 and early 2023, the Paducah Site evaluated the presence of PFAS in potable water. Multiple PFAS were detected in Paducah Site potable water. The Paducah Site supplies its facilities with on-site potable water from the Ohio River. Potable water is used mostly for showering, cleaning, etc., and can also be consumed by employees. The Paducah Site also provides employees with commercially-supplied bottled water for drinking. All results for perfluorooctanoic acid and perfluorooctanesulfonate exceed the U.S. Environmental Protection Agency (US EPA) provisional health advisory levels and maximum contaminant level goals. Some results for perfluorooctanoic acid and perfluorooctanesulfonate exceed the draft maximum contaminant levels. The results are similar to those found in the Ohio River, which is the raw water supply for the Paducah Site. PFAS found in the potable water most likely originate from the Ohio River and are unrelated to the Paducah Site water treatment process and/or distribution system.
- DOE paid water bills for municipal water hookups for affected residences and businesses in areas where the groundwater either is known to be contaminated or has the potential to become contaminated with trichloroethene and technetium-99.
- Ambient air monitoring indicates that, as in past years, contaminant levels for radionuclides in air are not detected; are below DOE standards; or are within background levels.
- The 2022 radiological results for sediment are similar in magnitude to those measured during previous years.
- Polychlorinated biphenyls were detected in sediment samples and are being addressed as part of the ongoing Paducah Site cleanup mission. Total polychlorinated biphenyls detected in sediment in 2022 ranged from 2.28 µg/kg to 388 µg/kg. The potential risks and hazards from exposure to polychlorinated biphenyls at these concentrations are within Comprehensive Environmental

Response, Compensation, and Liability Act's (CERCLA's) acceptable risk range. The US EPA's generally acceptable risk range is 10^{-4} to 10^{-6} for carcinogenic risk and below the hazard index of 1 for noncarcinogens (US EPA 1999).

- The Paducah Site received no notices of violation during 2022. A toxicity exceedance for KPDES Outfall 010 in September 2022 resulted in a Notice of Violation that was received in May 2023.

DOE and its contractors at Paducah are committed to enhancing environmental stewardship and reducing any impacts that Paducah Site cleanup operations may have on the environment. The Paducah Site implements sound stewardship practices in protecting land, air, water, and other natural or cultural resources potentially affected by its operations. A report of progress in achieving specified Environmental Management System (EMS) goals is submitted annually to DOE Headquarters. The environmental stewardship scorecard for Paducah was green for fiscal year (FY) 2022, indicating that the Paducah Site met standards for implementing the EMS.

The chapters that follow this Executive Summary offer a more complete description of the environmental program at the Paducah Site.

1. Introduction

The Paducah Gaseous Diffusion Plant (PGDP) was constructed in the early 1950s and began enriching uranium in 1952. In fact, the Paducah Site was an active uranium enrichment facility until 2013. The Energy Policy Act of 1992 provided for the lease of the enrichment facilities to a commercial entity that operated the enrichment facilities from 1998 to 2013. In 2014, the leased facilities were returned to DOE control, and then a DOE contractor began managing the uranium enrichment facilities for DOE. These facilities are now undergoing deactivation in preparation for decommissioning.

DOE requires that environmental monitoring be conducted and documented for its facilities under DOE Order 231.1B, *Environment, Safety, and Health Reporting*. Several other laws, regulations, and DOE directives require compliance with environmental standards. The purpose of this Annual Site Environmental Report is to summarize 2022 environmental management activities, including effluent monitoring and environmental surveillance, at the Paducah Site; report on environmental compliance status; and highlight significant Paducah Site program efforts. References in this report to the Paducah Site generally mean the property, programs, and facilities at or near PGDP for which DOE has ultimate responsibility.

Environmental monitoring includes two major activities: effluent monitoring and environmental surveillance. Effluent monitoring is the direct measurement or the collection and analysis of samples of liquid and gaseous discharges to the environment. At the Paducah Site, environmental surveillance includes the direct measurement or the collection and analysis of samples of ambient air, surface water, groundwater, and sediment. Effluent monitoring and environmental surveillance are performed to characterize and quantify contaminants; assess radiation exposure; demonstrate compliance with applicable standards and permit requirements; and detect and assess the effects, if any, on the local population and environment. Samples are collected throughout the year and are analyzed for radioactivity, chemical constituents, and various physical properties.

DOE's overall goals for environmental management are to protect Paducah Site personnel, the environment, and the community and to maintain full compliance with all current applicable environmental regulations. DOE operates the Paducah Site in a manner that controls and reduces exposures of the public, workers, and the environment to harmful chemicals and radiation.

This report fulfills the requirements of DOE Order 231.1B and DOE Order 458.1. Data and information contained in this report were collected in accordance with the Paducah Site Environmental Monitoring Plan approved by DOE (FRNP 2022a). This report is not intended to provide the results of all sampling conducted at the Paducah Site. Additional data collected for other Paducah Site purposes, such as environmental restoration, remedial investigation reports, and waste management characterization sampling, are presented in other documents that have been prepared in accordance with applicable DOE guidance and federal or state laws. DOE intends the annual site environmental report to cover activities for each calendar year; however, some monitoring and reporting is by fiscal year (October 1–September 30). Unless noted otherwise, readers can assume that, when 2022 is mentioned, the reference is for the calendar year.

In 1994, the President of the United States issued Executive Order 12898, "Federal Actions to Address Environmental Justice in Minority and Low-Income Populations." The purpose of the Executive Order is to focus the attention of federal agencies on human health and environmental conditions in minority and low-income communities. Environmental justice analyses identify disproportionate placement of high and adverse environmental or health impacts from proposed federal actions on minority or low-income populations and identify alternatives that could mitigate such impacts. DOE analyzes environmental justice concerns in accordance with Executive Order 12898. For the Paducah Site, the results of this analysis determined that the minority population and the low income population for the affected environment are lower than the state average. Details of this analysis can be found in the Community Relations Plan (DOE 2022a).

Other documents are referenced in this report; where available, electronic hyperlinks to the documents are provided.

1.1 Site Location and History

The Paducah Site is in a rural area of McCracken County, Kentucky, 10 miles west of Paducah and 3.5 miles south of the Ohio River, as shown in Figure 1.1. The population of McCracken County is approximately 67,000. The major city in McCracken County (Paducah) has a population of approximately 27,000. Three small communities are located within 3 miles of the DOE property boundary at the Paducah Site: Heath and Grahamville to the east and Kevil to the southwest. The closest commercial airport is Barkley Regional Airport, which is approximately 5 miles to the southeast of the DOE property boundary at the Paducah Site.

The plant occupies a 3,556-acre DOE-owned Site, approximately 1,973 acres of which are licensed to the Commonwealth of Kentucky as part of the West Kentucky Wildlife Management Area (WKWMA). During World War II, Kentucky Ordnance Works operated its main process and some storage in an area southwest and west of the plant on what is now the WKWMA. WKWMA now consists of woodlands, meadows, and cultivated fields. Hunters and trappers of wildlife, such as rabbit, deer, quail, raccoon, squirrel, dove, turkey, waterfowl, and beaver, use the area, where fishing is also popular. The Kentucky Department of Fish and Wildlife Resources also sponsors field hunting trials for dogs in the WKWMA.

1.2 Environmental Setting

The Paducah Site is in the humid continental zone, where summers are warm (July averages 79°F) and winters are moderately cold (January averages 35°F). Yearly precipitation averages about 49 inches. The prevailing wind is from the south-southwest at approximately 10 miles per hour.

The Paducah Site is in the western part of the Ohio River basin. The confluence of the Ohio River with the Tennessee River is about 15 miles upstream of the Site, and the Ohio River joins the Mississippi River about 35 miles downstream. The Paducah Site is on a local drainage divide: surface water from the east side of the plant flows east-northeast toward Little Bayou Creek, and surface water from the west side of the plant flows west-northwest toward Bayou Creek. Bayou Creek is a perennial stream that flows toward the Ohio River along a 9-mile course. Little Bayou Creek, an intermittent stream, flows north toward the Ohio River along a 7-mile course. The two creeks converge 3 miles north of the plant before emptying into the Ohio River.

Flooding in the area is associated with Bayou Creek, Little Bayou Creek, and the Ohio River. Maps developed in support of the National Flood Insurance Program show a flood hazard within the DOE boundary at the Paducah Site but only slightly within the industrialized area (FEMA 2018). This flood hazard defines the 100-year flood line.

Several environmental studies were conducted in the area of the Paducah Site in the 1990s (CH2M HILL 1991, CH2M HILL 1992, COE 1994). These studies have been re-evaluated by recent projects and were determined to be consistent with current conditions. A study of about 12,000 acres in and around the Paducah Site found approximately 1,100 separate wetlands, totaling over 1,500 acres (COE 1994). More than 60 percent of the total wetland area is forested. Area soils are predominantly silty

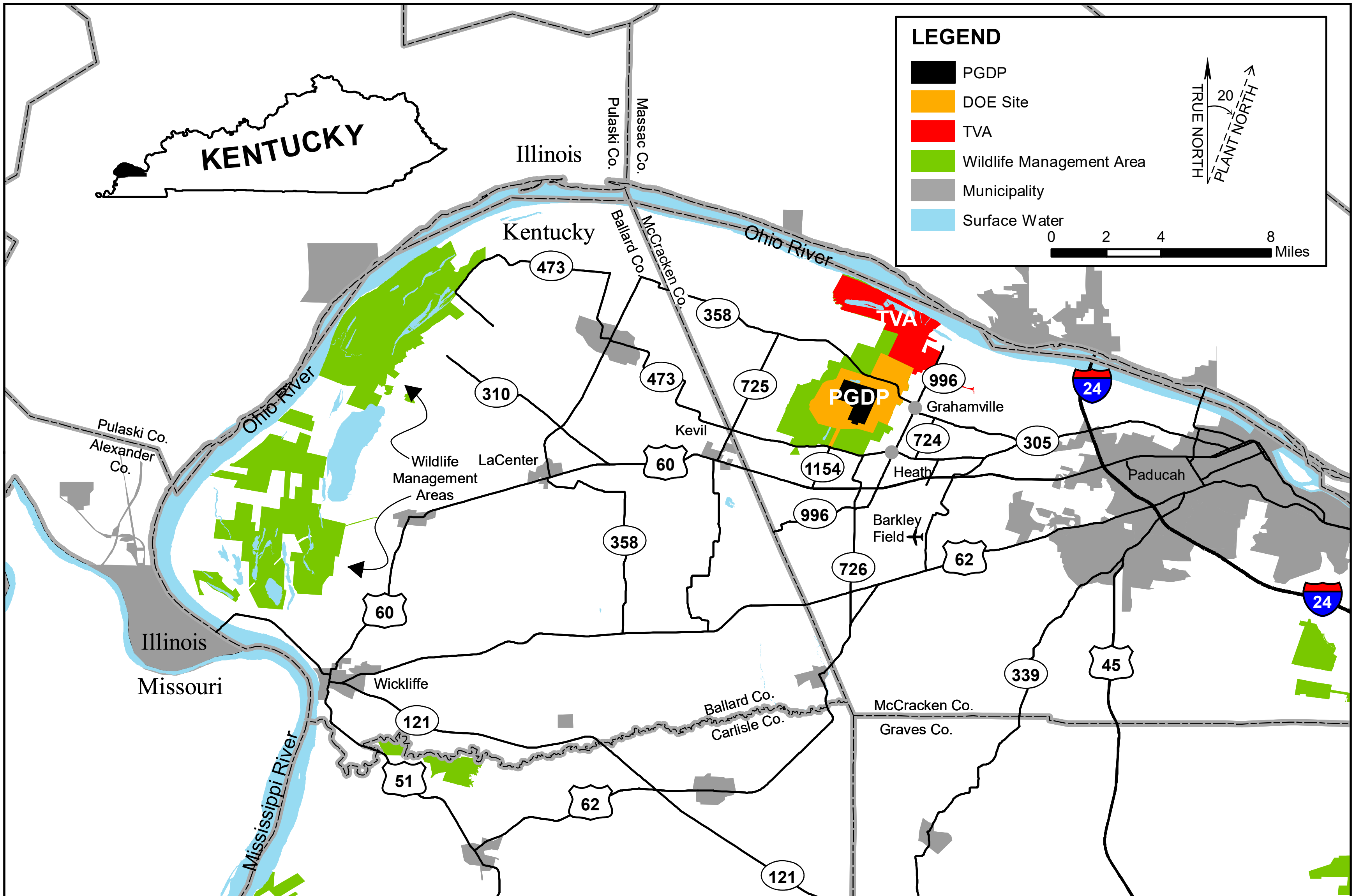

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Figure 1.1. Location of the Paducah Site

loams that are poorly drained, acidic, and have little organic content. Section 6.1 describes the local groundwater flow system at the Paducah Site.

Much of the Paducah Site has been affected by human activity. Vegetation communities on the reservation are indicative of old field succession with grassy fields, field scrub-shrub, and upland mixed hardwoods. The open grassland areas, most of which are managed by WKWMA personnel, are mowed periodically or burned to maintain early successional vegetation, which is dominated by members of the Compositae (flowering plants) family and various grasses. Corn, millet, milo, and soybeans are commonly cultivated for wildlife forage (CH2M HILL 1992). Corn, soybeans, and sunflowers were cultivated for wildlife forage within the WKWMA in 2022.

Field scrub-shrub communities consist of sun-tolerant wooded species such as persimmon, maples, black locust, sumac, and oaks (CH2M HILL 1991). The undergrowth varies depending on the location of the woodlands. Wooded areas near maintained grasslands have an undergrowth dominated by grasses. Other communities have a thick undergrowth of shrubs, including sumac, pokeweed, honeysuckle, blackberry, and grape. Upland mixed hardwood communities feature a variety of upland and transitional species; dominant species include oaks, shagbark and shellbark hickory, and sugarberry (CH2M HILL 1991). The undergrowth varies from limited undergrowth for more mature stands of trees to dense undergrowth similar to that described for a scrub-shrub community.

Wildlife at the Paducah Site include species indigenous to hardwood forests, scrub-shrub, and open grassland communities. Rabbits, mice, opossum, vole, mole, raccoon, and deer frequent some nearby areas, and several groups of coyotes also live in areas around the Paducah Site. Aquatic habitats are used by muskrat and beaver. Results of the Site Investigation Phase 1 includes a list of representative species (CH2M HILL 1991). Birds include red-winged blackbirds, quail, sparrows, shrikes, mourning doves, turkeys, cardinals, meadowlarks, hawks, and owls. The Ohio River, which is 3.5 miles north of the Paducah Site, also serves as a major flyway for migratory waterfowl (DOE 1995a). Harvestable fish populations live in Bayou Creek, especially near the mouth of the creek at the Ohio River. Fish populations in Little Bayou Creek are in the minnow category (DOE 2022b).

A threatened and endangered species investigation identified federal-listed, proposed, or candidate species potentially occurring at or near the Paducah Site (COE 1994). Updated information is obtained regularly from federal and Commonwealth of Kentucky sources. Potential habitat for 15 species of federal concern exists in the study area. Thirteen of these species are listed as endangered under the Endangered Species Act of 1973, and two are listed as threatened, as shown in Table 2.5 in Section 2 of this report. While potential habitats for endangered species exist on DOE property, none of the federal-listed or candidate species have been found on DOE property at the Paducah Site.

1.3 Site Operations

DOE established the Portsmouth/Paducah Project Office (PPPO) on October 1, 2003, to provide focused leadership to the environmental management missions at the Portsmouth, Ohio, and Paducah, Kentucky, gaseous diffusion plants. The PPPO office opened in January 2004 in Lexington, Kentucky, which is located midway between the Kentucky and Ohio facilities. Although the PPPO Manager is based in the Lexington office, frequent and routine site interactions occur at both the Portsmouth and Paducah Sites. DOE also maintains a strong daily presence at both sites through its Portsmouth and Paducah Site Offices. The mission of the PPPO is to conduct the safe, secure, compliant, and cost-effective environmental cleanup of the Portsmouth and Paducah Sites on behalf of the local communities and the American taxpayers. In addition to stabilization, deactivation, and infrastructure management of the gaseous diffusion plants, DOE's PPPO mission, as stated here, is to accomplish the following at the Portsmouth and Paducah Sites:

- Environmental remediation
- Waste management
- Depleted uranium hexafluoride (DUF_6) conversion
- Decontamination and decommissioning

Figure 1.2 shows the entrance sign to the DOE Paducah Site. Figure 1.3 identifies the main Paducah Site facilities and important locations and features. Prime contractors working to support DOE missions at the Paducah Site include Mid-America Conversion Services, LLC (MCS), Swift & Staley Inc. (SST),[2] and FRNP. DOE operates two major programs at the Paducah Site: Environmental Management and the Uranium Program.

Figure 1.2. DOE Paducah Site entrance

The Environmental Management Program includes the Environmental Restoration; Facility Stabilization, Deactivation, Decontamination and Demolition, and Infrastructure Optimization; and Waste Management Projects. Chapter 3 includes additional information on these activities.

The mission of the Environmental Restoration Project is to ensure that releases from past operations at the Paducah Site are investigated and that appropriate response actions are taken to protect human health and the environment in accordance with the Federal Facility Agreement (FFA) (US EPA 1998).

The mission of the Facility Stabilization, Deactivation, and Infrastructure Optimization Projects is to remove radioactive and hazardous materials from the facility, safely shut down facility systems, and optimize infrastructure that will continue to support the Site.

The mission of the Waste Management Project is to characterize and dispose waste stored and generated on site in compliance with regulatory requirements and DOE orders.

The mission of Decontamination and Demolition is to tear down the former gaseous diffusion plant and its support facilities and dispose the demolition debris in compliance with regulatory requirements and DOE orders.

The major missions of the Uranium Program are to maintain safe, compliant storage of the DOE DUF_6 inventory until final disposition, to operate a facility for conversion of DUF_6 to a more stable oxide and hydrofluoric acid, and to manage the associated facilities and grounds.

[2] Swift & Staley Inc. is known as SST at the Paducah Site.

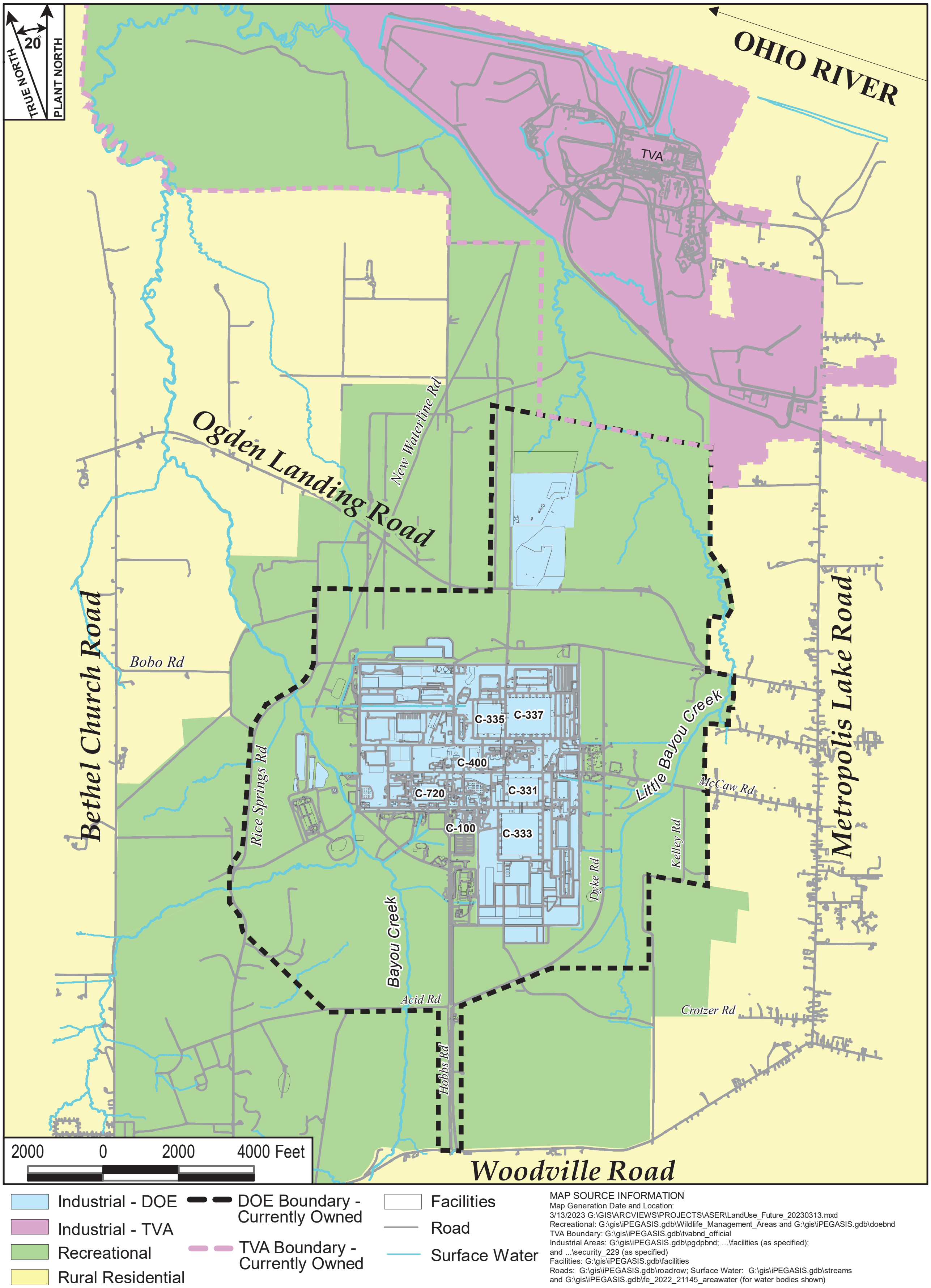


Figure 1.3. General map of the Paducah Site

2. Compliance Summary

This chapter provides a compliance summary for the Paducah Site with respect to environmental laws and regulations, DOE orders, and Executive orders. DOE and its contractors are responsible for environmental restoration; facility stabilization, deactivation, and infrastructure optimization; and waste management projects.

The US EPA Region 4 provides primary oversight of the CERCLA cleanup activities at the Paducah Site. KDEP also oversees CERCLA cleanup at the Paducah Site, as well as issuing regulatory permits and overseeing compliance with the applicable environmental laws and regulations for which they have implementation authority.

US EPA develops, promulgates, and enforces environmental protection regulations and technology-based standards based on statutes passed by Congress. In most instances, US EPA has delegated regulatory authority to KDEP when the Commonwealth of Kentucky program meets or exceeds US EPA requirements.

2.1 Environmental Protection and Waste Management

The following sections discuss environmental protection, waste management activities, and compliance with US EPA and KDEP environmental laws, regulations, and permits at the Paducah Site.

2.1.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA, commonly known as Superfund, was passed in 1980 and then amended in 1986 by the Superfund Amendments and Reauthorization Act. Under CERCLA, a site is investigated and remediated if it poses significant risk to human health or the environment.

The Superfund Amendments and Reauthorization Act amended CERCLA on October 17, 1986, to reflect US EPA's experience in administering the complex Superfund program. Important changes and additions included increasing the focus on human health problems posed by hazardous waste sites and encouraging greater participation by citizens in deciding how sites should be cleaned up. Section 3.5 describes DOE programs that engage citizens in cleanup decision-making for the Paducah Site.

DOE and US EPA Region 4 entered into an Administrative Consent Order in August 1988 under Sections 104 and 106 of CERCLA in response to the off-site groundwater contamination detected at the Paducah Site in July 1988. On May 31, 1994, the Paducah Site was placed on the US EPA National Priorities List, which includes sites across the nation designated by US EPA as the highest priority for remediation.

Section 120 of CERCLA requires federal agencies with facilities on the National Priorities List to enter into a FFA with US EPA. The FFA for the Paducah Site, which was signed February 13, 1998, by DOE, US EPA, and KDEP, established a decision-making process for remediation of the Paducah Site and coordinates CERCLA remedial action requirements with Resource Conservation and Recovery Act (RCRA) corrective action requirements. DOE, US EPA, and KDEP agreed to terminate the CERCLA Administrative Consent Order, and any additional, related activities would be continued under the FFA. The FFA defines the process for all remediation activities undertaken at the Paducah Site. It includes requirements for implementing investigations; selecting and implementing appropriate remedial and removal actions; and establishing priorities for the action and development of schedules, consistent with the priorities, goals, and objectives of the agreement.

Table 2.1 includes significant milestones completed under CERCLA and the FFA for 2022 at the Paducah Site.

Table 2.1. CERCLA FFA significant milestones completed in 2022

Document or activity	Date due	Date completed
Remedial Action Field Start for Solid Waste Management Unit 211-A Enhanced *In Situ* Bioremediation for Volatile Organic Compound Sources to the Southwest Groundwater Plume	N/A*	3/8/2022
Community Relations Plan under the Federal Facility Agreement, DOE/LX/07-2481&D1 (DOE 2022a)	6/30/2022	6/14/2022
Explanation of Significant Differences to the Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume, DOE/LX/07-2480&D1 (DOE 2022c)	N/A*	7/15/2022
Site Management Plan FY 2023, DOE/LX/07-2482&D1 (DOE 2022d)	11/15/2022	11/15/2022
Explanation of Significant Differences to the Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume, DOE/LX/07-2480&D2 (DOE 2022e)	12/1/2022	11/28/2022
Site Management Plan FY 2023, DOE/LX/07-2482&D2 (DOE 2022f)	12/25/2022	12/13/2022

*Document targeted by the federal and state regulatory agencies requirement update; no regulatory due date was established.

Acronyms:
N/A = not applicable
FY = fiscal year
FFA = Federal Facility Agreement

2.1.2 Emergency Planning and Community Right-to-Know Act

Also referred to as Title III of the Superfund Amendments and Reauthorization Act, the Emergency Planning and Community Right-to-Know Act (EPCRA) requires the reporting of emergency planning information; hazardous chemical inventories; and releases to the environment. The Paducah Site, as a federal facility, is subject to these reporting requirements.

EPCRA's primary purpose is to increase the public's knowledge of and access to information regarding chemical hazards in their communities. To ensure proper and immediate responses to potential chemical hazards EPCRA Sections 302–303 require notifying state and local agencies within 60 days of when the amount of a substance on the list of extremely hazardous substances first exceeds its established threshold planning quantity. Notifications also are required if a revision to the list results in the facility exceeding the revised threshold planning quantity or if changes at the facility are relevant to emergency planning. These notifications are required within 60 days and 30 days, respectively, of the facility becoming subject to the requirements. The Paducah Site did not receive shipments, have production amounts, or make changes relevant to emergency planning that triggered Sections 302–303 reporting for 2022. EPCRA Section 304 requires immediate notification of releases of hazardous or extremely hazardous substances, but because the Paducah Site had no releases at or above the minimum reportable quantities, Section 304 reporting was not required for 2022.

Sections 311–312 of EPCRA require businesses to report the safety data sheets, locations, and quantities of hazardous chemicals stored on site (if they exceed specific reporting thresholds) to state and local governments to help communities prepare to respond to chemical spills and similar emergencies. EPCRA Section 311 requires a one-time submittal of safety data sheets of hazardous chemicals present on site at or above the reporting threshold. No new hazardous chemicals met the reporting threshold at the Paducah Site in 2022. EPCRA Section 312 requires reporting the locations and quantities of the subject chemicals. The chemicals stored at the Paducah Site by DOE contractors in 2022, and included in an EPCRA 312 Report, were carbon, aluminum oxide, argon, cyclohexylamine, diesel fuel, calcium hydroxide, calcium oxide (Quicklime), carbon dioxide, chlorine, cryogenic and gaseous nitrogen, dichlorotetrafluoroethane (R-114), liquid and solid ferric sulfate, fuel oil (No. 2), gasoline, hydrofluoric acid, lead acid batteries, oil, Portland cement, potassium hydroxide, propylene glycol, quartz, sulfuric acid (nonbattery), uranium hexafluoride, and uranium oxide (uranium hexafluoride was reported as a discretionary because radioactive substances are not subject to reporting under EPCRA Sections 311 and 312 [52 Federal Register 38344-01, October 15, 1987]).

EPCRA Section 313 requires US EPA and each respective state to collect data annually on releases and transfers of certain toxic chemicals from industrial facilities and make the data available to the public. The Paducah Site submitted Section 313 Reports for hydrofluoric acid and chlorine for 2022. Table 2.2 summarizes the EPCRA reporting status for the Paducah Site for 2022.

Table 2.2. Status of EPCRA reporting

EPCRA section	Description of reporting	Status*
EPCRA Sections 302–303	Planning notification	Not required
EPCRA Sections 304	Extremely hazardous substance release notification	Not required
EPCRA Sections 311–312	Material safety data sheet/chemical inventory	Yes
EPCRA Sections 313	Toxic release inventory reporting	Yes

*An entry of yes, no, or not required is sufficient for the status.

Acronym:
EPCRA = Emergency Planning and Community Right-to-Know Act

2.1.3 Resource Conservation and Recovery Act

RCRA establishes regulatory standards for the characterization, treatment, storage, and disposal of solid and hazardous waste. Waste generators must follow specific requirements outlined in RCRA regulations for handling solid and hazardous wastes. Owners and operators of hazardous waste treatment, storage, and disposal facilities must obtain operating and post closure permits for waste treatment, storage, and disposal activities. The Paducah Site generates solid waste, hazardous waste, and mixed waste (hazardous waste mixed with radionuclides) and operates three permitted hazardous waste storage and treatment facilities: C-733 Waste Oil & Chemical Storage Facility, C-746-Q Hazardous & LLW Storage Facility, and C-752-A Waste Storage Facility. The closed C-404 Hazardous Waste Landfill must also meet the requirements of RCRA regulations and the Hazardous Waste Management Facility Permit.

The first RCRA Part A and Part B permit applications for storage and treatment of hazardous waste at the Paducah Site were submitted in the late 1980s. US EPA has authorized the Commonwealth of Kentucky to administer the RCRA-based program for treatment, storage, and disposal units. The current Hazardous Waste Management Facility Permit was issued by the Kentucky Division of Waste Management (KDWM) to DOE on February 21, 2020, and it expires on August 25, 2025.

MCS is registered as a small quantity generator and manages hazardous waste under RCRA, but as a small quantity generator they are not required to have a permit. On December 20, 2022, KDWM sent the Compliance Inspection Report for an inspection conducted at the DUF_6 Conversion Facility on December 15, 2022. The inspection found no issues and no violations and noted one positive observation on the compliance report.

DOE must report compliance issues as part of the annual Hazardous Waste Report submitted to KDWM. Two issues were reported in 2022. The first issue reported was that during generation of hazardous waste by disassembling various laboratory components, various waste streams were not properly containerized and moved to compliant storage by the end of the day. The waste consisted of silver tip fluorescent light bulbs, green tip fluorescent light bulbs, starters, circuit boards/computer parts, lithium batteries, and incandescent light bulbs. Once discovered, these wastes were properly containerized and moved to compliant storage. The second issue reported was a drum of air compressor oil that was characterized using process knowledge as low-level waste. Once it was received at the treatment, storage, and disposal facility (TSDF) the waste was resampled and found to contain tetrachloroethylene above the regulatory limits. Once verified, the waste was properly manifested and the TSDF was allowed to treat and dispose of the waste. No spills or releases to the environment were associated with these events.

2.1.4 Federal Facility Compliance Act

The Federal Facility Compliance Act, which was enacted in October 1992, waived federal facilities' immunity from fines and penalties for violations of hazardous waste management as defined by RCRA. It also provided for the development of site treatment plans for treating DOE mixed waste (low-level hazardous and radioactive waste), and for the approval of such plans by the Commonwealth of Kentucky. As a result of the complex issues associated with the treatment of mixed waste, and after considering stakeholder input, DOE and KDEP signed an Agreed Order/Site Treatment Plan on September 10, 1997. The Site Treatment Plan facilitates compliance with the Federal Facility Compliance Act. For the reporting period of January 1, 2022, to December 31, 2022, no mixed low-level waste was added to the Site Treatment Plan (DOE 2023a).

The Agreed Order requires that DOE implement a waste minimization and pollution prevention awareness program to minimize the amount of new waste generated at the Paducah Site each year. All projects at the Paducah Site are evaluated for waste minimization and pollution prevention opportunities. The following waste minimization and pollution activities at the Paducah Site are related to the Site Treatment Plan's waste management goals:

- Reducing the quantity of waste generated at their sources
- Draining, decanting, drying, dewatering, evaporating, and otherwise removing liquid from waste when possible
- Segregating, sorting, consolidating, and reducing the volume of like waste
- Reusing or recycling materials that otherwise would be managed as hazardous or radioactive mixed waste

Chapter 3 lists the waste minimization and pollution prevention activities at the Paducah Site.

2.1.5 National Environmental Policy Act

The National Environmental Policy Act (NEPA) requires federal agencies to evaluate the potential environmental impact of certain proposed activities and to examine alternatives to proposed actions. Compliance with NEPA, as administered by DOE's NEPA Implementing Procedures [10 *Code of Federal Regulations* (*CFR*) Part 1021] and the Council on Environmental Quality Regulations (40 *CFR* Parts 1500–1508), ensures that agencies consider environmental values and factors in planning and making decisions. In accordance with 10 *CFR* Part 1021, the Paducah Site conducts NEPA reviews for all proposed non-CERCLA actions and determines if they require the preparation of an environmental impact statement, an environmental assessment, or a categorical exclusion. The Paducah Site maintains records of all NEPA reviews.

Section II.E of the June 13, 1994, DOE Secretarial Policy Statement on NEPA states that separate NEPA documents for environmental restoration activities conducted under CERCLA are no longer required. Instead, the DOE CERCLA process incorporates NEPA values, which include environmental issues that affect the quality of the human environment. Documenting NEPA values in CERCLA documents allows decision makers to consider the potential effects of proposed actions on the human environment.

Chapter 3 discusses environmental restoration, waste disposition, and deactivation and decommissioning actions conducted under CERCLA.

In 2019, PPPO initiated an environmental assessment of the impacts associated with transporting and disposing of waste and excess materials to support deactivation and other non-CERCLA activities. The environmental assessment analyzed the potential impacts of managing and disposing of 5,050,000 cubic feet of waste and excess materials over the next 12 years. On July 27, 2020, DOE issued the Finding of No Significant Impact (DOE 2020). On September 15, 2021, PPPO finalized a supplemental analysis that assessed the potential impacts of a new treatment facility and transfer facility for disposition of waste and materials (DOE 2021a). No new impacts were identified.

PPPO initiated a supplemental environmental impact statement in 2018 to assess the environmental impacts of transporting and disposing of uranium oxide in DOE inventory resulting from DUF_6 conversion. After a public comment period, the statement was finalized and made available to the public on April 24, 2020 (DOE/EIS-0359-S1, DOE/EIS-p0360-S1).

2.1.6 Toxic Substances Control Act

The Toxic Substances Control Act was enacted in 1976 with two purposes: to ensure US EPA obtains information on the production, use, and environmental and health effects of chemical substances or mixtures; and to provide the means by which US EPA can regulate chemical substances and mixtures such as polychlorinated biphenyls, asbestos, chlorofluorocarbons, and lead.

The Paducah Site complies with polychlorinated biphenyls regulations (40 *CFR* Part 761) and the Modification to the February 20, 1992, Compliance Agreement between DOE and US EPA for the Toxic Substances Control Act (US EPA 1992). The Compliance Agreement between DOE and US EPA was modified on September 25, 1997, then modified again on May 30, 2017 (BJC 1998, US EPA 2017). Prominent revisions to the 2017 agreement included creating an annual meeting between PPPO and US EPA; generating an integrated schedule and a long-term schedule to support the annual meeting; altering the frequency and timing of air sampling in the process buildings; updating the approach to the regulatory one-year storage requirement for polychlorinated biphenyls and polychlorinated biphenyls items; and modifying the management of building demolition waste, building slabs, building demolition waste to be processed for disposal, and other polychlorinated biphenyls waste removed prior to a building's demolition. Major activities performed in 2022 are documented in the annual compliance agreement report for the PGDP and the polychlorinated biphenyls annual document (FRNP 2023a, FRNP 2023b).

2.2 Radiation Protection

The Paducah Site is subject to radiation protection statutes, regulations, and DOE standards designed to protect the health and safety of the public, the workforce, and the environment. The following sections discuss the Site's compliance with radiation protection and radioactive waste management requirements. The Paducah Site maintains and implements programs and procedures to ensure compliance with the relevant laws and regulations described in the following sections. See Chapter 4 for additional information about radiation protection.

2.2.1 Atomic Energy Act of 1954

To ensure proper management of radioactive materials, the Atomic Energy Act of 1954 and its amendments delegate roles and responsibilities for controlling radioactive materials and nuclear energy primarily to DOE, the US Nuclear Regulatory Commission, and US EPA. Through the Atomic Energy Act, DOE regulates the control of radioactive materials under its authority, including the treatment, storage, and disposal of low-level radioactive waste from its operations. Because sections of this Act authorize DOE to establish radiation protection standards for itself and its contractors, DOE published a series of regulations, including 10 *CFR* Part 820, *Procedural Rules for DOE Nuclear Activities*; 10 *CFR* Part 830, *Nuclear Safety Management*; and 10 *CFR* Part 835, *Occupational Radiation Protection*. Other DOE directives to protect public health and the environment from potential risks associated with radioactive materials include the current revisions of DOE Order 458.1, *Radiation Protection of the Public and Environment*, and DOE Order 435.1, *Radioactive Waste Management*. Paducah Site operations are subject to these regulations and directives.

ALARA, which means "as low as reasonably achievable," is an approach to manage and control releases of radioactive material to the environment and exposure to the workforce and to members of the public so that levels are as low as is reasonable, taking into account societal, environmental, technical, economic, and public policy considerations.

2.2.1.1 By-Product Material

The Paducah Site has no by-product material as defined by Section 11e.(2) of the Atomic Energy Act. Material defined as Section 11e.(3) or 11e.(4) by-product material in the Atomic Energy Act, such as sealed radioactive sources, is managed under 10 *CFR* Part 835.

2.2.2 DOE Order 458.1, *Radiation Protection of the Public and the Environment*

DOE Order 458.1 establishes requirements to protect the public and the environment against undue risk from radiation associated with radiological activities conducted under the control of DOE. This Order applies to all DOE elements and contractors performing work for DOE, as provided by law or contract, and as implemented by the appropriate contracting officer. DOE Order 458.1 was developed and issued under the authority of the Atomic Energy Act, as amended.

The objectives of DOE Order 458.1 include the following:

- To conduct DOE radiological activities so that exposure to members of the public is maintained within the dose limits established in this Order
- To ensure that potential radiation exposures to members of the public are as low as is reasonably achievable (ALARA)
- To control the radiological clearance of DOE real and personal property
- To ensure that DOE sites have the capabilities, consistent with the types of radiological activities conducted, to monitor routine and nonroutine radiological releases and to assess the radiation dose to members of the public
- To provide protection of the environment from the effects of radiation and radioactive material

Table 2.3 presents the standards (dose limits) for radiation protection of the public and the environment from DOE operations. While the public dose limit of 100 mrem/year (1 millisievert [mSv]/year) is the primary dose limit, other regulations control the dose that may be received through specific exposure pathways (see Appendix B for a discussion of exposure pathways). The air and water pathways are also regulated by US EPA as discussed in Sections 2.3 and 2.4 below. DOE Order 458.1 includes dose limits to protect aquatic and terrestrial plants and animals near radiological activities on the Paducah Site. The Order also regulates the dose that could be received by a member of the public from activities such as management, storage, and disposal of radioactive waste, as well as its unrestricted release to the public or clearance of real and personal property.

Table 2.3. Radiation protection standards for the public and the environment from all routine DOE operations[a]

All pathways (DOE Order 458.1)		
Exposure of members of the public will not cause a total effective dose exceeding 100 mrem (1 mSv) in a year. [DOE Order 458.1, *Radiation Protection of the Public and the Environment*, Contractor Requirements Document (CRD) Attachment 1, Paragraph 2.b.]	Total effective dose[c]	
	mrem/year	*mSv/year*
Routine public dose	100	*1*
Temporary public dose under special circumstances, with specific authorization and justification[b] (DOE Order 458.1, CRD Attachment 1, Paragraph 2.c.)	> 100, < 500	*> 1, < 5*
Air pathway dose constraints (40 *CFR* Section 61.92)		
Emissions of radionuclides shall not cause any member of the public to receive an effective dose equivalent of 10 mrem/year.	Effective dose equivalent[c]	
	mrem/year	*mSv/year*
	10	*0.1*
Water pathway dose constraints (40 *CFR* Section 141.66(d))		
The average annual dose equivalent to the total body or to any internal organ from beta particle and photon radioactivity from man-made radionuclides in drinking water shall not exceed 4 mrem/year.	Dose equivalent[c]	
	mrem/year	*mSv/year*
	4	*0.04*
Protection of biota (DOE Order 458.1, CRD Attachment 1, Paragraph 2.j.)		
Radiological activities must be conducted to protect populations of aquatic animals, terrestrial plants, and terrestrial animals.	Absorbed dose[c]	
	rad/day	*mGy/day*
Aquatic animal	1	*10*
Riparian animal	0.1	*1*
Terrestrial plant	1	*10*
Terrestrial animal	0.1	*1*
Radioactive waste dose constraint (DOE Order 458.1, CRD Attachment 1, Paragraph 2.h.)		
Exposure from radioactive waste management, storage, and disposal activities shall be ALARA and meet dose constraint.	Total effective dose[c]	
	mrem/year	*mSv/year*
Public dose constraint	25	*0.25*
Release and clearance of property (DOE Order 458.1 CRD Attachment 1, Paragraph 2.k.)		
Exposure from release of real (land and buildings) and personal property shall be controlled to be ALARA and meet dose constraints.	Total effective dose[c]	
	mrem/year	*mSv/year*
Public dose constraint from real property	25	*0.25*
Public dose constraint from personal property	1	*0.01*

[a] Routine DOE operations imply normal, planned activities and do not include actual or potential accidental or unplanned releases.
[b] DOE PPPO may request specific authorization from DOE Headquarters for a temporary public dose greater than 100 mrem/year (1mSv/year). The request must document the justification, alternative considered, and the application of the ALARA process.
[c] Dose units are those in the cited regulation, order, or standard.

Notes:
1. Excepts doses received from radon and its decay products in the air, from medical sources of radiation, by volunteers in medical research programs, from background radiation, and from occupational exposure under the Nuclear Regulatory Commission, Agreement State License, or to general employees under 10 *CFR* Part 835.
2. International dose units shown in *italics* are not provided in the order or rules, but are provided for information.

Acronyms:
ALARA = as low as reasonably achievable
CRD = Contractor Requirements Document
CFR = Code of Federal Regulations
DOE = US Department of Energy
mGy = milligray
mSv = millisievert
mrem = millirem
PPPO = Portsmouth/Paducah Project Office

These radiation standards are dose limits, but they do not represent DOE's expected dose to the public and the environment. DOE Order 458.1 requires the ALARA process be applied to all routine radiological activities to further reduce radionuclide releases and resulting doses as much as possible.

2.2.2.1 Authorized Limits at the Paducah Site

DOE uses Authorized Limits to establish concentrations or quantities of residual radioactive material that protect human health and the environment. Authorized Limits ensure that doses to the public meet DOE standards and are ALARA, groundwater is protected, no future remediation is needed, and no radiological protection requirements are violated.

The following pre-approved Authorized Limits were documented in CP2-ES-0103/FR5, *Environmental Radiation Protection Program for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, which was reviewed and approved by DOE in 2022.

- For radium-226 and radium-228 in soil—5 pCi/gram (0.2 Bq/gram) in excess of background levels, averaged over 100 m^2, in the first 15 cm depth of the surface layer of soil; and 15 pCi/gram (0.56 Bq/gram) in excess of background levels, averaged over any subsequent 15 cm subsurface layer of soil, plus an ALARA assessment. If both thorium-230 and radium-226 or both thorium-232 and radium-228 are present and not in secular equilibrium, the appropriate pre-approved Authorized Limit must be applied to the radionuclide with the higher concentration.
- Previously approved guidelines and limits [such as the surface activity guidelines (DOE Order 5400.5 Chg 2 and DOE 2002)] may continue to be applied and used as pre-approved Authorized Limits until they are replaced or revised by pre-approved Authorized Limits issued by DOE.
- Pre-approved Authorized Limits for Release and Clearance of Volumetric Radioactivity of Personal Property.

In addition to pre-approved Authorized Limits, the following Authorized Limits were documented in CP2-ES-0103/FR5, *Environmental Radiation Protection Program for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*, which was reviewed and approved by DOE in 2022:

- Release limits for hydrofluoric acid and calcium fluoride from DUF_6 conversion
- C-746-U Landfill Authorized Limits approval and implementation requirements
- Authorized Limits for the DOE-owned property outside the limited area in Paducah, Kentucky, approval and implementation requirements
- Authorized Limits for lube oil and dielectric fluids that allow for incineration at Veolia Environmental Services in Port Arthur, Texas, and Clean Harbors Environmental Services, Inc. in Deer Park, Texas
- Authorized Limits for Freon allow for incineration at Clean Harbors Aragonite in Dugway, Utah; Clean Harbors El Dorado in El Dorado, Arkansas; and Veolia North America Port Arthur in Beaumont, Texas
- Authorized Limits for Paducah and Portsmouth Personal Property Being Dispositioned Through the Bulk Survey for Release Process for Disposal to the Carter Valley Landfill in Tennessee.

2.2.3 DOE Order 435.1, *Radioactive Waste Management*

DOE Order 435.1 establishes requirements for managing high-level waste, transuranic waste, and low-level waste, including the radioactive component of mixed waste (high-level waste, transuranic waste, and low-level waste containing chemically hazardous constituents) in a safe manner that protects the worker, public health, and the environment. DOE Order 435.1 is a cradle-to-grave approach for managing waste that includes requirements for generating, storing, treating, and disposing of waste and for regulating and monitoring facilities during operations and after closure.

Radioactive waste is also managed to meet the requirements of other DOE orders, standards, and regulations, including 10 *CFR* Part 835, *Occupational Radiation Protection*; DOE Order 441.1B, W*orker Protection Program for DOE (Including the National Nuclear Security Administration) Federal Employees*; and DOE Order 458.1, *Radiation Protection of the Public and the Environment*. For facilities undergoing CERCLA removal actions or CERCLA remedial actions, DOE Order 435.1 may not be considered applicable or relevant and appropriate as defined in CERCLA Section 121(d) or 40 *CFR* Part 300.

The Paducah Site manages low-level and transuranic waste, if produced, in compliance with DOE Order 435.1, using a number of storage and disposal units. Procedures for managing these wastes ensure compliance with this Order.

2.3 Air Quality and Protection

The Paducah Site is subject to air quality and protection statutes, regulations, and rules designed to protect the health and safety of the public and the environment. The following sections discuss the Site's compliance with US EPA and KDEP requirements.

2.3.1 Clean Air Act

The Paducah Site complies with the Clean Air Act and its amendments, subsequent federal regulations, and Commonwealth of Kentucky rules by implementing programs, procedures, and permit requirements. Authority for enforcing compliance with the Clean Air Act and its amendments reside with US EPA Region 4, the Kentucky Division for Air Quality, or both. The Paducah Site has two programs that require air permits. The Environmental Remediation, Waste Management, and Decontamination and Decommissioning missions (identified as the Deactivation and Remediation Project) are combined under one air permit, and the DUF_6 conversion mission has a separate air permit.

The Deactivation and Remediation Project has identified the potential emission of hydrogen fluoride, a hazardous air pollutant, in excess of 10 tons per year. Kentucky Division for Air Quality therefore considers the project a major source and requires it to maintain a Title V Air Permit.

Activities performed as part of CERCLA projects, such as groundwater treatment systems, are not subject to the Title V Air Permit. Instead, the substantive requirements of the Clean Air Act for emissions associated with these CERCLA actions are applied to the actions as applicable or relevant and appropriate requirements. Groundwater pump-and-treat systems at the Paducah Site remove trichloroethene and other volatile organic compound contamination from the groundwater by air stripping. For the Northwest Plume Groundwater Treatment System, the off-gas from the air stripper then passes through a carbon adsorption system to remove the trichloroethene before it discharges to the atmosphere. For the Northeast Plume Containment System, concentrations of trichloroethene are low enough that a carbon adsorption system is not required to keep emissions below regulatory levels.

The DUF_6 Conversion Facility has the potential to emit more than 10 tons per year of hydrogen fluoride, but the DUF_6 air permit limits potential hydrogen fluoride emissions to less than 10 tons per year. The DUF_6 Conversion Facility has agreed to the operating limitations to maintain the potential hydrogen fluoride emissions. As a result, Kentucky Division for Air Quality considers the DUF_6 Conversion Facility to be a conditional major source that requires a Conditional Major Operating Air Permit.

2.3.2 National Emission Standards for Hazardous Air Pollutants Program

Airborne emissions of radionuclides from the Paducah Site are regulated under 40 *CFR* Part 61, Subpart H, known as the National Emission Standards for Hazardous Air Pollutants regulations. DOE also manages radionuclide air emissions according to the National Emission Standards for Hazardous Air Pollutants Management Plan for Emission of Radionuclides (FRNP 2019). Radionuclide sources at the Paducah Site in 2022 were the deactivation projects for PGDP; DUF_6 Conversion Facility; groundwater pump-and-treat systems (Northeast Plume Containment System and Northwest Plume Groundwater Treatment System); and fugitive and diffuse sources, which include building ventilation, uranium transfers, transport and disposal of waste, demolition of contaminated facilities, decontamination of contaminated equipment, and environmental remediation activities. DOE maintains ambient air monitoring data to verify a low emission rate of radionuclides in ambient air in accordance with the National Emission Standards for Hazardous Air Pollutants Management Plan. Ambient air data were collected at nine locations surrounding the Paducah Site to measure radionuclides emitted from Site sources, including fugitive emissions. Chapter 4 discusses the ambient air results in further detail.

2.3.3 Hydrofluorocarbon Phasedown

Hydrofluorocarbons are greenhouse gases with very high global warming potentials and are used as refrigerants in fire suppression systems and certain scientific and electrical equipment. On October 1, 2021, US EPA began the implementation of hydrofluorocarbon phasedown requirements.

At the Paducah Site, hydrofluorocarbons are not used for industrial processes and are only used for comfort cooling/heating. Hydrofluorocarbon refrigerants used at the Paducah Site are compliant with current regulations in 40 *CFR* Part 82 and any volumes removed as a result of maintenance activities are logged, properly contained, and recycled or disposed. Approximately 585 pounds of hydrofluorocarbon refrigerants were purchased for the Paducah Site in 2022.

Future purchases of refrigerants will consider acceptable alternatives that have lower global warming potentials.

2.4 Water Quality and Protection

The Paducah Site is subject to water quality and protection statutes, regulations, and rules designed to protect the health and safety of the public and the environment. The following sections discuss the Site's compliance with US EPA and KDEP requirements.

2.4.1 Clean Water Act

The Clean Water Act was established primarily through the passage of the Federal Water Pollution Control Act Amendments of 1972. The Clean Water Act set up four major programs for controlling water pollution: regulating point-source and storm water discharges into waters of the United States; controlling and preventing spills of oil and hazardous substances; regulating discharges of dredge and fill materials into waters of the United States; and providing financial assistance to construct publicly owned sewage treatment works.

2.4.1.1 Kentucky Pollutant Discharge Elimination System

The Clean Water Act applies to all nonradiological DOE discharges to waters of the United States. At the Paducah Site, the regulations are applied through Kentucky Pollutant Discharge Elimination System

(KPDES) permits for effluent discharges to Bayou Creek and Little Bayou Creek. In September 2017, the Kentucky Division of Water (KDOW) renewed KPDES Permit Number KY0004049 for Outfalls 001, 002, 004, 006, 008, 009, 010, 011, 012, 013, 015, 016, 017,[3] 019, and 020. The KPDES permit calls for monitoring to indicate the effects of discharges to these streams. Discharge monitoring reports are issued monthly and quarterly. The KPDES permit also requires the development and implementation of a best management practices plan to prevent or minimize the potential release of pollutants. These best management practices include requirements for operations and are implemented through the Paducah Site EMS and work control.

During 2022, the Paducah Site had one KPDES permit exceedance (Table 2.4). The KPDES permit requires quarterly toxicity testing for some permitted outfalls. One exceedance for toxicity was experienced at KPDES Outfall 010. The toxicity failure occurred in September 2022 as part of the required, permitted quarterly testing. Follow-up testing was completed for the toxicity failure as required by the permit and produced passing results. KDOW was notified of the toxicity failure and passing results in accordance with KPDES permit reporting requirements. Because the follow-up test produced passing results, no further action was required by the permit. A Notice of Violation, dated May 11, 2023, was received for the Outfall 010 toxicity exceedance.

Table 2.4. KPDES exceedances in 2022

Outfall	Parameter	Number of permit exceedances	Number of samples taken	Number of compliant samples	Percent compliance	Month of exceedance
010	Toxicity	1	4*	3	75	September

*Does not include two invalid toxicity results due to laboratory quality control issues.

Acronym:
KPDES = Kentucky Pollutant Discharge Elimination System

Preparation of the KPDES Permit Renewal Application was undertaken beginning in 2021 and was finalized in early 2022. As a result of these efforts, the KPDES Permit Renewal Application was transmitted to KDEP on February 10, 2022. Although the KPDES permit expired on August 30, 2022, the permit was administratively continued since the KPDES Permit Renewal Application was submitted more than 180 days prior to its expiration. KDEP issued the new KPDES permit for the Paducah Site on December 9, 2022. The new permit became effective on February 1, 2023; the new permit expires at midnight on January 31, 2028. The new permit named MCS as co-permittee at Outfalls 013 and 017. New permit requirements, in addition to the previous requirements, include phosphorus reporting at five outfalls; new limits for mercury, total residual chlorine, oil and grease, and temperature at some outfalls; and new limits for total suspended solids at all outfalls.

2.4.2 CERCLA Outfall

Activities performed as part of CERCLA projects, such as groundwater treatment systems, are not subject to the administrative requirements under Clean Water Act. Instead, the substantive requirements of the Clean Water Act for discharges associated with these CERCLA actions are applied to the actions as applicable or relevant and appropriate. The *Operation and Maintenance Plan for the Northeast Plume Containment System Interim Remedial Action at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* requires testing at CERCLA Outfall 001 (DOE 2021b). The Environmental Monitoring Plan lists sampling parameters and frequencies (FRNP 2022a).

[3] Permit Number KY0004049 also includes MCS as a permittee for Outfall 017.

2.4.3 Storm Water Management and the Energy Independence and Security Act of 2007

The Energy Independence and Security Act (EISA) requires new construction projects greater than 5,000 square feet to maintain the predevelopment hydrology or restore it after construction. The Paducah Site will comply with this requirement by ensuring storm water flow will be maintained and managed at predevelopment levels during the construction of an energy-efficient building. Besides meeting EISA requirements, the Paducah Site audits energy and water usage. These audits typically cover the building shell, lighting, possible deployment of occupancy sensors, and leaking of old water fixtures. The findings of these audits are assessed and prioritized based on the mission of the Paducah Site. The Site Sustainability Plan includes a list of previous audits (SST 2022).

2.4.4 Safe Drinking Water Act

The Paducah Site supplies its facilities with on-site potable water from the Ohio River. Potable water is used mostly for showering, cleaning, etc., and can also be consumed by employees. The Paducah Site also provides employees with commercially-supplied bottled water for drinking. This system is regulated by the Safe Drinking Water Act, which sets requirements for water testing, treatment, and disinfection, as well as distribution system maintenance and operator training. In 2022, FRNP operated and managed the water treatment system in accordance with the Safe Drinking Water Act. FRNP maintains a water withdrawal permit from KDOW for up to 30 million gallons per day. Water is pumped from the Ohio River and treated for distribution on site.

FRNP operates a nontransient, noncommunity water system regulated by KDOW. KDOW's requirement to submit monitoring plans to demonstrate compliance with regulations applies to this water system. FRNP monitors sampling locations in the nontransient, noncommunity water system in accordance with these plans and submits the results to KDOW.

KDOW conducted a Drinking Water Sanitary Survey of the C-611 water treatment plant on April 13, 2022, and April 27, 2022. A capacity development assessment was done as part of the survey. There were no deficiencies found.

2.5 Other Environmental Statutes

This section discusses the Paducah Site's compliance with applicable environmental statutes, regulations, and Executive orders.

2.5.1 Endangered Species Act

The Endangered Species Act of 1973, as amended, provides for the designation and protection of endangered and threatened animals and plants and protects the ecosystems on which such species depend. At the Paducah Site, proposed projects are reviewed in conjunction with the EMS or the CERCLA process to determine if activities have the potential to impact these species. If necessary, project-specific field surveys are performed to identify threatened and endangered species and their habitats, and mitigating measures are designed as needed. When appropriate, DOE initiates consultation with the US Fish and Wildlife Service and Kentucky Department of Fish and Wildlife Resources before implementing a proposed project.

Table 2.5 includes 15 federal-listed species that have been identified as potentially occurring at or near the Paducah Site. None of the threatened or endangered species have been reported as sighted on DOE property, although the potential exists for a summer habitat for the Indiana bat, Northern long-eared bat, and Gray bat at certain areas of the property. No DOE projects at the Paducah Site during 2022 adversely impacted any of these identified species or their potential habitats.

Table 2.5. Federal-listed species potentially occurring near the Paducah Site*

Group	Common name	Scientific name	Endangered species act status
Mammals	Gray bat	*Myotis grisescens*	Endangered
	Indiana bat	*Myotis sodalis*	Endangered
	Northern long-eared bat	*Myotis septentrionalis*	Threatened
Clams	Clubshell	*Pleurobema clava*	Endangered
	Fanshell	*Cyprogenia stegaria*	Endangered
	Fat pocketbook	*Potamilus capax*	Endangered
	Northern riffleshell	*Epioblasma torulosa rangiana*	Endangered
	Orangefoot pimpleback	*Plethobasus cooperianus*	Endangered
	Pink mucket	*Lampsilis abrupta*	Endangered
	Purple cat's paw	*Epioblasma obliquata*	Endangered
	Rabbitsfoot	*Quadrula cylindrica*	Threatened
	Ring pink	*Obovaria retusa*	Endangered
	Rough pigtoe	*Pleurobema plenum*	Endangered
	Sheepnose mussel	*Plethobasus cyphyus*	Endangered
	Spectaclecase	*Cumberlandia monodonta*	Endangered

*All listed species are identified as either an endangered or threatened species that is known or potentially located near the Paducah Site in McCracken County, Kentucky, by the US Fish and Wildlife Service (FWS 2023).

2.5.2 Impacts of Invasive Species

Executive Order 13751, *Safeguarding the Nation from the Impacts of Invasive Species*, calls on government agencies to take steps to prevent the introduction and spread of invasive species and to support efforts to eradicate and control invasive species that are established. Zebra mussels are an invasive species that can be found in the two intake supply lines used by the Paducah Site water treatment plant. This invasive species is controlled by draining one intake supply line at a time, allowing the mussels to die, then backwashing the drained line and flushing out the mussels. DOE takes steps to minimize the spread of invasive plant species at the Paducah Site through routine Site maintenance such as mowing and spraying for weeds.

2.5.3 Migratory Bird Treaty Act

The 2013 Memorandum of Understanding on Migratory Birds between DOE and the US Fish and Wildlife Service regarding Executive Order 13186, *Responsibilities of Federal Agencies to Protect Migratory Birds*, direct federal agencies to take certain actions to further implement the Migratory Bird Treaty Act of 1918, which is applicable to the Paducah Site. DOE takes measures to minimize impacts to migratory birds by avoiding disturbance of active nests. Work control documents implement this restriction.

2.5.4 Floodplain Management and Protection of Wetlands

Title 10 *CFR* Part 1022 establishes procedures for complying with Executive Order 11988, *Floodplain Management*, and Executive Order 11990, *Protection of Wetlands*. DOE takes steps to minimize or eliminate any impacts to wetlands. No projects in this area were active at the Paducah Site during 2022.

2.5.5 National Historic Preservation Act

The National Historic Preservation Act of 1966 is the primary law governing a federal agency's responsibility to identify and protect historic properties that are defined as cultural resources included in or eligible for inclusion in the National Register of Historic Places. Historic properties include buildings of historic significance and archeological sites. PGDP buildings were assessed in the Cultural Resources Survey (BJC 2006a). Archeological resources will be addressed as undisturbed land is developed for Paducah Site use or if undisturbed sites are considered to be impacted by DOE operations.

The Cultural Resources Management Plan identified a historic district eligible for the National Register of Historic Places (BJC 2006b). The PGDP Historic District contains 101 contributing properties and is eligible for the National Register of Historic Places under National Register Criterion A for its military significance during the Cold War and for its role in commercial nuclear power development. The PGDP Historic District encompasses the area of the process buildings; switchyards; C-100 Administration Building; cooling towers and pump houses; security facilities; water treatment facilities; storage tanks; and support, maintenance, and warehouse buildings. The Cultural Resources Management Plan includes a map showing the location of these structures, along with the rationale for designating the area as an eligible historic district.

2.5.6 Asbestos Program

Numerous facilities at the Paducah Site contain asbestos materials. Compliance programs for managing asbestos include identifying asbestos materials, monitoring, abatement, and disposal. Procedures and program plans delineate the scope, roles, and responsibilities for maintaining compliance with applicable US EPA, Occupational Safety and Health Administration, and Kentucky regulatory requirements.

2.5.7 Solid Waste Management

The Paducah Site disposes of a portion of its solid waste at its contained landfill facility, the C-746-U Solid Waste Contained Landfill, under Solid Waste Permit SW07300014, SW07300015, and SW07300045. Construction of the first five cells, or units, of the C-746-U Landfill began in 1995 and was completed in 1996. The operation permit received from KDWM in November 1996 allows for 23 cells. Disposal of waste at the landfill began in February 1997. Operating and groundwater reports for the C-746-U Landfill are submitted quarterly to KDWM. The Landfill is permitted to accept all nonhazardous solid waste, including residential, commercial, institutional, industrial, and municipal waste; shredded tires; nonhazardous spill cleanup residue generated at the Paducah Site; and any materials that meet the Authorized Limits. Construction of Phases 6 and 7 of the Landfill began on April 24, 2019, and was completed in August 2019. A Construction Progress Report was submitted to KDWM on September 9, 2019, and, after comments were addressed, KDWM approved the Construction Progress Report on September 27, 2019. A minor permit modification approved on May 21, 2021, by KDWM addresses leachate generation and storage capacity for Phases 6 and 7.

During 2022, DOE placed approximately 2,028 tons of solid waste in the C-746-U Landfill using the C-746-U Landfill Authorized Limits. The C-746-U Landfill waste acceptance criteria includes established volume and surface Authorized Limits that govern disposal. Authorized Limits for the C-746-U Landfill were established in 2003 and have been maintained since that time. The latest revision was approved by DOE in 2019 (DOE 2019a). Waste streams disposed of in the C-746-U Landfill during 2022 include building demolition debris, asbestos-containing materials, and other dry active waste generated during deactivation activities. Table 2.6 summarizes Authorized Limit disposal at the C-746-U Landfill during 2022 and the cumulative totals since Authorized Limit disposal began in May 2003.

Table 2.6. C-746-U Landfill Authorized Limit disposal through 2022

	Cumulative activity from 2022 disposal	Total activity from disposal 5/21/2003 to 12/31/2022		
Isotope	**Activity (curies)**	**Activity (curies)**	**Source term limit (curies)[a]**	**Percent utilized[b]**
Americium-241	4.36E-04	1.01E-02	79	0.01
Cesium-137	1.13E-04	1.16E-02	43	0.03
Neptunium-237	3.09E-04	1.41E-02	12	0.12
Plutonium-238	6.00E-05	2.32E-03	88	0.00
Plutonium-239/240	1.13E-03	2.43E-02	162	0.02
Technetium-99	3.70E-02	1.36E+00	117	1.16
Thorium-228	3.77E-04	7.38E-02	9	0.82
Thorium-230	7.06E-03	2.68E-01	230	0.12
Thorium-232	3.70E-04	7.37E-02	9	0.82
Uranium-234	1.78E-02	4.58E-01	360	0.13
Uranium-235	9.66E-04	2.24E-02	15	0.15
Uranium-238	3.07E-02	5.74E-01	360	0.16
				Total % 3.53

Notes:
1. Waste streams added (2022) 0
2. Mass disposed of (2022) 2,028 tons
3. Mass disposed of (2003–2022) 136,788 tons

[a] This column contains the maximum source term limit if it is the only isotope present and is reduced when there is a mixture of radionuclides.

[b] Percent utilized is the percentage of total activity disposed, divided by the disposal inventory limit, per isotope. The total percentage shown represents the sum of fractions for the source term of the landfill.

2.6 Sustainability

DOE and its contractors implement numerous sustainability requirements, including Executive Order 13423, *Strengthening Federal Environmental, Energy, and Transportation Management*; Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*; the *National Energy Conservation Policy Act*; the Energy Policy Acts of 1992 and 2005; and the EISA of 2007, largely through DOE Order 436.1, *Departmental Sustainability*.

2.6.1 Departmental Sustainability

DOE Order 436.1, *Departmental Sustainability*, was enacted May 2, 2011. The Paducah Site currently has no buildings that meet the Guiding Principles of High Performance and Sustainable Buildings stated in the Order. No large renovation projects are viable at this time for buildings at the Paducah Site, but the Site continues to implement small upgrades as opportunities arise such as maintenance replacements of heating, ventilation, and air conditioning units.

The Paducah Site acquired four new mobile units to house personnel and accommodate break, training, shower, and storage necessities. The new trailers allow for a reduced site footprint and enable the further deactivation of buildings at the Paducah Site. The restroom and shower facilities have water fixtures that use auto-shutoff sink and shower hardware to minimize water usage. Light-emitting diode fixtures that meet American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) 90.1 standards are used in the office and shower trailers.

The Paducah Site has taken measures to reduce water usage at the site, including conversion of the fire sprinkler systems in C-331, C-335, C-310, C-709, and C-720 facilities to a dry-hybrid fire system. This allowed the high-pressure fire water tower and system to be isolated, which saves approximately

5,000,00 gallons per year. The Paducah Site has also repaired intake water lines from the Ohio River. A leaking valve in one of the intake water lines was repaired in early 2023 and a lower capacity pump was installed. This lower capacity pump now pumps only enough water to meet the site's needs without pumping excess water that would be discharged to Bayou Creek. Other leaks in the on-site water supply lines have been repaired, resulting in the mitigation of water leakage totaling approximately 4,800,000 gallons per year.

The Paducah Site initiated planning and construction of a new Emergency Operation Center, which will be approximately 3,600 ft^2. The Emergency Operation Center will allow for the reduction of personnel footprint that will allow for the further deactivation of buildings at the Paducah Site. The Emergency Operation Center will utilize water fixture hardware to minimize water usage. The light-emitting diode light fixtures, water heater, and heating, ventilation and air conditioning system that are compliant to ASHRAE 90.1 standards will be utilized. The building is designed with insulating concrete forms and will provide a minimum insulating factor of R22.

The Paducah Site is in the process of constructing a new C-209 Protective Force Building (7,771 ft^2) at the site. The building will be a one-story office, locker room, exercise room, and armory building. Fire water and domestic water, as well as a sanitary sewer tie-in, will be provided to the PGDP utilities via existing systems. Electrical power will be provided by a local utility company. Light-emitting diode lights and occupancy sensors will be utilized. Electric heating, ventilation and air conditioning exhaust systems will be provided. The building provides, as applicable, optimized energy performance, water conservation, and indoor environmental quality according to the Guiding Principles for Sustainable Federal Buildings and Associated Instructions, The Council on Environmental Quality, February 2016. This includes metering for the water and electric, low water consumption plumbing fixtures, ventilation and lighting controls, and energy usage of 30% better than the ASHRAE 90.1.

2.6.2 Federal Leadership in Environmental, Energy, and Economic Performance

On December 8, 2021, President Joe Biden signed Executive Order 14057, *Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability*, which requires that federal agencies lead by example to achieve a carbon pollution-free electricity sector by 2035 and net-zero emissions economy-wide by no later than 2050. To support its goals to meet these requirements, DOE submitted a Site Sustainability Plan identifying the Paducah Site's progress toward sustainability goals in December 2022 (SST 2022). Chapter 3 details the objectives of the Site Sustainability Plan.

2.7 Other Major Environmental Issues and Actions

The following sections summarize environmental release reporting and permits for the Paducah Site.

2.7.1 Green and Sustainable Remediation

Green and sustainable remediation is the practice of using sustainable methods to reduce the environmental and social impacts of remedial cleanup and closure activities in a cost-effective way. It also offers opportunities to meet compliance obligations at lower overall cost and reduced environmental impact. The Paducah Site evaluates environmental aspects, such as energy use, water use, waste management, air pollution, and reuse of resources, when planning remediation activities.

2.7.2 Continuous Release Reporting

Section 103(a) of CERCLA requires that hazardous substance releases in excess of a reportable quantity be reported immediately to the National Response Center. Section 103(f)(2) provides relief from the Section 103(a) reporting requirement for hazardous substance releases that are continuous, stable in quantity and rate, and already have been reported. Notice of such releases must be given annually or when there is any statistically significant increase in the quantity of hazardous substance released. Releases of this nature typically are included in the Superfund Amendments and Reauthorization Act Title III reports and notifications listed in Section 2.7. There were no continuous releases in 2022.

2.7.3 Unplanned Reportable Quantity Releases

There was one unplanned release of material above a reportable quantity in 2022. In March 2022, more than one pound of potentially asbestos-containing material fell from a steam line onto a grassy area below, south of the C-728 Motor Cleaning Facility. The reportable quantity for asbestos is one pound. The area was controlled and the spill was cleaned up and verified the same day.

2.7.4 Enforcement and Compliance History Online

US EPA's Enforcement and Compliance History Online web tool provides environmental regulatory compliance and enforcement information for regulated facilities nationwide. FRNP monitors several facilities in the web tool that represent the Paducah Site. The facility names are listed in the web tool as US DOE Paducah Site, FRNP, and US Enrichment Corp Paducah Gaseous Diffusion Plant. The Facility Registry Service identification numbers are 110070378294, 110060257671, 110051926831, and 110009258980, respectively. The addresses for the facilities are identified as 5600 Hobbs Road, Kevil, Kentucky; 5511 Hobbs Road, Kevil, Kentucky; and, 5600 A Hobbs Road, Paducah, Kentucky, respectively.

2.7.5 Summary of Permits

Table 2.7 summarizes the Paducah Site environmental permits maintained by DOE in 2022.

Table 2.7. Permits maintained by DOE for the Paducah Site for 2022

Permit type	Issued by	Permit number	Issued to
State Agency Interest ID No. 3059			
Clean Water Act			
Kentucky Pollutant Discharge Elimination System	KDOW	KY0004049	DOE/FRNP/MCS
Permit to withdraw public water	KDOW	0900	FRNP
Water treatment registration	KDOW	Public Water System KY0732457	FRNP
Clean Air Act			
Conditional Major Operating Air Permit	KDAQ	F-21-018	MCS
Title V Air Permit	KDAQ	V-21-011 (09/21/2021 – 02/19/2022) V-21-011 R1 (02/20/2022 – 11/06/2022) V-21-011 R2 (11/07/2022 – 12/31/2022)	FRNP
RCRA—solid waste			
Residential Landfill (closed)	KDWM	SW07300014	DOE/FRNP
Inert Landfill (closed)	KDWM	SW07300015	DOE/FRNP
Solid Waste Contained Landfill (construction/operation)	KDWM	SW07300045	DOE/FRNP
RCRA—hazardous waste			
Hazardous Waste Management Facility Permit	KDWM	KY8-890-008-982	DOE/FRNP

Table 2.7. Permits maintained by DOE for the Paducah Site for 2022 (Continued)

Acronyms:
DOE = US Department of Energy
FRNP = Four Rivers Nuclear Partnership, LLC
ID = identification
KDAQ = Kentucky Division of Air Quality
KDOW = Kentucky Division of Water
KDWM = Kentucky Division of Waste Management
MCS = Mid-America Conversion Services, LLC
RCRA = Resource Conservation and Recovery Act

3. Environmental Programs and Activities

This chapter summarizes the environmental programs and activities at the Paducah Site, including environmental management, Site sustainability, waste management, environmental restoration and remediation, and public awareness.

3.1 Environmental Management System

DOE Order 436.1, *Departmental Sustainability*, requires the Paducah Site to develop and implement an EMS to protect air, water, land, and other natural or cultural resources that may be impacted by DOE operations.

The EMS integrates environmental protection, environmental compliance, pollution prevention, and continuous improvement in planning and execution throughout all work areas. The Paducah Site implements sound stewardship practices in the protection of land, air, water, and other natural or cultural resources potentially impacted by Site operations. The objectives are incorporated in the Integrated Safety Management System established by DOE Policy 450.4A, *Safety Management System Policy*.

Environmental protection programs at the Paducah Site conform to the six core elements of the International Organization for Standardization's ISO 14001:2015: leadership, planning, support, operation, performance evaluation, and improvement. By implementing the EMS, the Paducah Site can effectively protect workers, the surrounding communities, and the environment and also meet operating objectives that comply with legal and other requirements. Feedback is analyzed to determine the status of the program's implementation, integration, and effectiveness.

DOE contractors' environmental policy statements emphasize conserving and protecting environmental resources by incorporating pollution prevention and environmental protection in their daily conduct of business. The DOE contractors implement these policies through environmental cleanup, pollution prevention, and other programs described in this document and by integrating environmental protection, environmental regulatory compliance, and continuous improvement in daily planning and performance of work at the Paducah Site. The program manager for the DOE contract reviews the commitments in the policy and shares them with the rest of the DOE contractor management team. Employees and subcontractors learn about the policies through sitewide communication, EMS awareness training, and publications.

The EMS environmental stewardship scorecard evaluates the agency's environmentally preferable purchasing, EMS implementation, electronics stewardship, high performance sustainable buildings, and improvements in environmental compliance management. The scorecard for the Paducah Site in FY 2022 was green, which indicates standards for EMS implementation have been met.

DOE and its contractors are committed to enhancing environmental stewardship and reducing any impacts Paducah Site operations may cause to the environment. The Environmental Monitoring Program at the Paducah Site consists of effluent monitoring, environmental surveillance, and air monitoring around the plant. Requirements for routine environmental monitoring programs were established to measure and monitor effluents from DOE operations and continue to examine the effects of those operations on the environment and public health through measurement, monitoring, and calculation. FRNP implements the Environmental Monitoring Program for the Paducah Site, as documented in the Environmental Monitoring Plan (FRNP 2022a).

In addition to monitoring documented in the Environmental Monitoring Plan, MCS monitors radionuclide air emissions as required by their air permit. Subsequent chapters of this report discuss the results of these monitoring programs in detail.

3.2 Site Sustainability Program

In accordance with DOE Order 436.1 and Executive Order 14057, this report provides information on the requirements and responsibilities of managing sustainability on the Paducah Site. These include ensuring DOE carries out its missions in a sustainable manner that addresses national energy security and global environmental challenges while advancing sustainable, reliable, and efficient energy for the future; initiating wholesale cultural change to factor sustainability and greenhouse gas reductions in all of DOE's corporate management decisions; and ensuring that DOE achieves the sustainability goals established in its Site Sustainability Plan, pursuant to any applicable laws, regulations, Executive orders, sustainability initiatives, and related performance scorecards.

Table 3.1 is adapted from the Paducah Site FY 2023 Site Sustainability Plan from the web-based DOE Sustainability Dashboard. Site sustainability plans are organized by overarching categories, rather than by goals, to reduce redundancies and streamline reporting.

Table 3.1. DOE sustainability goal summary table

DOE goal	Current FY efforts	Planned efforts	Overall risk of nonattainment
Energy Management			
Reduce energy use intensity (Btu per gross square ft) in goal-subject buildings.	The Paducah Site had usage increases in electricity and natural gas in FY 2022. Increases in electricity and natural gas are due to the return to normal operations since the COVID-19 nationwide pandemic. The site did see a reduction in potable water usage during FY 2022.	The Paducah Site plans on reducing the site footprint where possible and continues to implement energy-saving projects including: utilizing light-emitting diode lighting upgrades where applicable; implementing space utilization practices and consolidating employees; and maximizing teleworking where applicable. The site plans to demolish 16 small structures/trailers which represents a footprint reduction of approximately 3,912 square ft.	Given the baseline and subsequent mission at the Paducah Site, the overall risk of nonattainment is medium. For DUF_6, the risk of nonattainment is high since electrical consumption and natural gas usage will continue with the operation of the facility.

Table 3.1. DOE sustainability goal summary table (continued)

DOE goal	Current FY efforts	Planned efforts	Overall risk of nonattainment
EISA Section 432 continuous (4-year cycle) energy and water evaluations.	The Paducah Site conducted condition asset surveys with supplemental energy and water checks.	The Paducah Site will use the condition asset surveys with supplemental energy and water checks to meet the EISA Section 432 energy and water evaluations.	Given the subsequent mission at the Paducah Site, the overall risk of nonattainment is low with EISA Section 432 evaluations being completed.
Meter individual buildings for electricity, natural gas, steam, and water where cost-effective and appropriate.	Most PGDP facilities were built in the early 1950s, and many facilities are not metered individually for any utilities. The Paducah Site will install and track meters for use of power, natural gas, water, and other fuels, when repairs are made to the utility service for a building/group of buildings, such that installation of the meters are practicable to DOE. New meters will be installed on any new construction if utilities are used.	The Paducah Site has identified those meters that have been added or deleted during the contract period. New office facilities will have electrical meters, and new shower/restroom facilities supplied by plant utilities will have electric and water meters added to the system.	Given the baseline and subsequent mission at the Paducah Site, the overall risk of nonattainment is medium.
Water Management			
Reduce potable water use intensity (gal per gross square ft).	Potable water usage decreased after the shutdown of the C-631 cooling tower.	As planned equipment, systems, and facility operations cease, potable water usage will continue to decrease.	Given the baseline and subsequent mission at the Paducah Site, the overall risk of nonattainment is medium.
Reduce nonpotable freshwater consumption (gal) for industrial, landscaping, and agricultural.	The Paducah Site does not have any Industrial, Landscaping, and Agriculture (ILA) water.	The Paducah Site does not have any ILA water and there are no plans for future use of ILA water.	The Paducah Site does not anticipate using any ILA water.
Waste Management			
Reduce nonhazardous solid waste sent to treatment and disposal facilities.	The Paducah Site will continue diverting nonhazardous solid waste from treatment and disposal.	The Paducah Site will continue existing recycle activities and will initiate new recycling opportunities as they become available.	Nonattainment risk is high due to the differing work scopes at the Paducah Site.

Table 3.1. DOE sustainability goal summary table (continued)

DOE goal	Current FY efforts	Planned efforts	Overall risk of nonattainment
Reduce construction and demolition materials and debris sent to treatment and disposal facilities.	The Paducah Site will continue to divert demolition materials and debris as opportunities are available.	The Paducah Site will continue actively diverting construction and demolition materials as opportunities are available.	Given the subsequent mission at the Paducah Site, the overall risk of nonattainment is low.
Fleet Management			
Reduce petroleum consumption.	Current performance is tracked in General Services Administration (GSA) Drive-Thru system.	Opportunities to reduce petroleum consumption will continue to be tracked and reviewed for opportunities for improvements.	Nonattainment risk is medium due to the differing work scopes of the site.
Increase alternative fuel consumption.	Current performance is tracked in GSA Drive-Thru system.	Opportunities to increase E85 usage will continue to be tracked and reviewed on a monthly basis.	Nonattainment risk is low due to close monitoring of fuel reports to detect noncompliance of alternative fuel usage.
Acquire alternative fuel and electric vehicles.	Current performance is tracked in GSA Drive-Thru system.	Opportunities to increase alternative fuel and electric vehicle usage will continue to be tracked and reviewed.	Medium risk of non-attainment due to alternative fuel vehicles availability during acquisition.
Clean and Renewable Energy			
Increase consumption of clean and renewable electric energy.	The Paducah Site continues to operate nine air monitoring stations powered by solar panels, which save over 2,800 kilowatt-hour (kWh) per unit per year. DOE PPPO purchased Renewable Energy Certificates for the Paducah Site during FY 2021. Two solar-powered light-emitting diode lights are being used on-site to provide lighting to a storage Connex. Four solar-powered energy packs for portable cameras are utilized for project activities. Three solar-powered portable ambient air samplers in support of continuous air monitoring in various locations are used.	DOE PPPO has purchased Renewable Energy Certificates in the past and may continue in the future.	Given the subsequent mission at the Paducah Site, the overall risk of nonattainment is low.

Table 3.1. DOE sustainability goal summary table (continued)

DOE goal	Current FY efforts	Planned efforts	Overall risk of nonattainment
Increase consumption of clean and renewable non-electric thermal energy.	DOE PPPO has purchased Renewable Energy Certificates in the past and may continue in the future.	DOE PPPO has purchased Renewable Energy Certificates in the past and may continue in the future.	Given the subsequent mission at the Paducah Site, the overall risk of nonattainment is low.
Sustainable Buildings			
Increase the number of owned buildings that are compliant with the Guiding Principles for Sustainable Buildings.	No existing Paducah facilities meet this criterion.	Due to the age of PGDP facilities, it will be difficult to implement the goal; however, the Paducah Site will implement as appropriate. There is no estimate to meet this goal at this time.	Given the subsequent mission at the Paducah Site, the overall risk of nonattainment is high. As part of the mission existing buildings are being deactivated.
Acquisition and Procurement			
Promote sustainable acquisition and procurement to the maximum extent practicable, ensuring all sustainability clauses are included as appropriate.	The Paducah Site assesses contract actions to maximize the supply or use of products and services that are energy-efficient, water efficient, bio-based, environmentally preferable, non-ozone depleting, that contain recycled content, and nontoxic or less toxic alternatives, as appropriate.	The Paducah Site assesses contract actions to maximize the supply or use of products and services that are energy-efficient, water-efficient, bio-based, environmentally preferable, non-ozone depleting, that contain recycled content, and nontoxic or less toxic alternatives, as appropriate.	Given the subsequent mission at the Paducah Site, the overall risk of nonattainment is low.
Efficiency and Conservation Measure Investments			
Implement life-cycle cost-effective efficiency and conservation measures with appropriated funds and/or performance contracts.	Finalized shutdown of C-531, one of the switchyards at the Paducah Site.	The Paducah Site will implement life-cycle cost-effective efficiency measures where applicable.	Given the subsequent mission at the Paducah Site, the overall risk of nonattainment is low.

Table 3.1. DOE sustainability goal summary table (continued)

DOE goal	Current FY efforts	Planned efforts	Overall risk of nonattainment
Electronic Stewardship and Data Centers			
Electronics stewardship from acquisition and operations to end of life.	During FY 2022, the Paducah Site purchased 75 notebooks, 19 desktop computers, 120 monitors, 547 mobile phones, and 6 copiers that met the Electronic Product Environmental Assessment Tool (EPEAT) Gold requirements.	To continue to acquire electronics-related assets that follow EPEAT guidelines, as appropriate and when available. Attempt to recycle as much obsolete electronics as possible to reduce landfill footprint and to reuse precious metals.	Risk of nonattainment is low due to the maintenance of adequate inventory controls and continuous surveying of all property to identify excess. It is the Paducah Site's policy to use a certified Responsible Recycling (R2) agency.
Increase energy and water efficiency in high-performance computing and data centers.	The Paducah Site is pursuing new heating, ventilation, and air conditioning systems for the C-100 server room to improve energy and water efficiency in the room.	Will review server and power infrastructure and pursue options to improve efficiency by replacement of older equipment and continuing efforts to virtualize the server environment. The Paducah Site uses a non-water based fire suppression system in the server room.	Risk of nonattainment is medium. The Paducah Site is designing a new data center.
Adaptation and Resilience			
Implement climate adaptation and resilience measures.	The Paducah Site Emergency Management Program addresses all hazardous events including natural phenomena (e.g., severe weather, earthquakes) and man-made and technological emergencies through emergency plans, implementing procedures, and facility Emergency Actions Plans.	Annual protective action drills will continue to be completed as scheduled.	Given the subsequent mission at the Paducah Site, the overall risk of non-attainment is low with a robust emergency management program already in place.

Table 3.1. DOE sustainability goal summary table (continued)

DOE goal	Current FY efforts	Planned efforts	Overall risk of nonattainment
Multiple Categories			
Reduce Scope 1 and 2 greenhouse gas emissions.	The Paducah Site had usage increases in electricity and natural gas in FY 2022. Increases in electricity and natural gas are due to return to normal operations after the COVID-19 nationwide pandemic. However, overall electrical usage reductions continue to trend downward from the FY 2015 baseline year. Through these reductions, Greenhouse Gas (GHG) Scope 1 and 2 emissions will be reduced.	The Scope 1 and 2 GHG goal will be extremely difficult, if not impossible, to achieve given the FY 2008 baseline and current status of the Paducah Site. Anticipate continued reductions with utility optimization projects, space consolidation, and reductions to site footprint.	Electrical usage has been reduced overall. Through these reductions, GHG Scope 1 and 2 emissions will be reduced.
Reduce Scope 3 greenhouse gas emissions.	During FY 2022, the Paducah Site continued implementing a consolidated 4-day/10-hour workweek schedule with a decrease in commuter mileage due to consolidated work schedules and teleworking mitigation activities.	The Scope 3 GHG goal will be extremely difficult, if not impossible, to achieve given the FY 2008 baseline and current status of the Paducah Site. Anticipate continued 4-day/10-hour workweek consolidated schedule.	There is a high risk of nonattainment at the Paducah site due to the FY 2008 baseline.

Acronyms:
DOE = US Department of Energy
EISA = Energy Independence and Security Act
EPEAT = Electronic Product Environmental Assessment Tool
FY = fiscal year
GHG = Greenhouse Gas
GSA = General Services Administration
ILA = industrial, landscaping, and agriculture
PGDP = Paducah Gaseous Diffusion Plant
PPPO = Portsmouth/Paducah Project Office

When enrichment operations at the Paducah Site ended in FY 2014 and previously leased facilities were returned to DOE, the Environmental Management footprint increased from 722,390 gross square feet in 2008 to 8,174,722 gross square feet in 2014. As a result, the Site's utility consumption increased significantly compared to the baseline values established in FY 2008, which affects the attainment of planned goals.

3.3 Environmental Management and Waste Management Activities

Environmental and waste management activities at the Paducah Site include the Waste Minimization/Pollution Prevention Program; the DUF_6 Cylinder Program; and stabilization, deactivation, and infrastructure optimization projects. The following sections describe these critical efforts.

3.3.1 Waste Minimization and Pollution Prevention

The Waste Minimization/Pollution Prevention Program at the Paducah Site provides guidance and objectives for minimizing waste generation. The program is set up to comply with RCRA and the Pollution Prevention Act, as well as applicable Commonwealth of Kentucky and US EPA rules, DOE Orders, Executive orders, and the Site Treatment Plan. All Paducah Site projects are evaluated for waste minimization and pollution prevention opportunities. In 2022, recycled materials included oils, paper, toner cartridges, nonradiological scrap metal, aluminum cans, light bulbs, batteries, tires, plastics, cardboard, and used electronics. The program strives to minimize waste using source reduction, segregation, reuse of materials, recycling, and procurement of recycled-content products. Program goals and objectives include the following:

- Eliminate or reduce the amount and toxicity of all waste generated at the Site.
- Comply with federal and state regulations and DOE requirements for waste minimization.
- Reuse or recycle materials when possible.
- Identify waste reduction opportunities.
- Integrate waste minimization and pollution prevention technologies in ongoing projects.
- Coordinate recycling programs.
- Track and report results.

The Paducah Site's waste minimization and pollution prevention efforts are reported in DOE's Sustainability Dashboard. As part of these efforts, SST offers excess reusable items to the Paducah Area Community Reuse Organization. During 2022 the Paducah Site diverted 46.4 percent of its waste, including paper, scrap metal, used oil and coolant, oily absorbent media, cardboard, plastic, excess chemicals, electronic items, light bulbs, and batteries from disposal in municipal landfills.

In 2022, the Paducah Site recycled 69,848 pounds of various batteries, 510 pounds of various light bulbs, 10 pounds of waste mercury items, and 469 pounds of unpunctured aerosol cans as outlined in the Site Treatment Plan. In addition, 21,020 pounds of activated carbon that would have required disposal was sent off site for regeneration and subsequent reuse (DOE 2023a). This list does not include all recycling efforts at the Paducah Site, only the potential hazardous waste that was diverted.

3.3.2 Depleted Uranium Hexafluoride Cylinder Program

A byproduct of the uranium enrichment process, DUF_6 is a solid at ambient temperatures and is stored in large metal cylinders. At the end of 2022, the Paducah Site managed an inventory of 50,924 DUF_6 cylinders in its cylinder storage yards.

The mission of the DUF_6 Cylinder Program is to safely store the DOE-owned DUF_6 inventory until its ultimate disposition. DOE has an active cylinder management program that includes cylinder and cylinder yard maintenance, routine inspections, and other program activities such as cylinder corrosion studies. The program maintains a cylinder inventory database that houses all cylinder inspection data.

The DUF_6 Conversion Facility converts the inventory of DUF_6 to triuranium octoxide, a more stable form of uranium, and hydrofluoric acid, which is sold for commercial use. During 2022, MCS converted approximately 2624.87 metric tons of DUF_6. Section 4.9 discusses the off-site shipment of these conversion products.

3.3.3 Facility Stabilization, Deactivation, and Infrastructure Optimization

Stabilization and deactivation projects at the Paducah Site involve isolating utilities, removing and compliantly disposing hazardous materials from facilities, and downgrading radiological facilities to make them ready for demolition. Significant Paducah Site accomplishments in 2022 included the removal of process gas equipment to support construction of a material sizing area; completion of fieldwork to deactivate the C-333-A Feed Vaporization Facility; continued efforts to characterize and deactivate process gas systems within the C-333 Process Building; continued progress with removal of hazardous materials, asbestos, and transite; and the isolation of recirculating cooling water and steam to the facility.

3.4 Environmental Restoration and Remediation

The environmental remediation program executes environmental investigations and implements environmental response actions. It also supports deactivation and decommissioning of facilities, projects designed to demonstrate or test advancements in remedial technologies, and other projects related to actions that protect human health and the environment.

Significant environmental remediation accomplishments at the Paducah Site in 2022 included the following:

- Completed the C-400 Complex Operable Unit Remedial Investigation/Feasibility Study field work, including waste disposition.
- Submitted and received federal and state regulatory approval of the *Plant Industrial Area Vapor Intrusion Preliminary Risk Assessment Report, Paducah Gaseous Diffusion Plant*, DOE/LX/07-2471&D2 (DOE 2022g).
- Submitted and received federal and state regulatory approval of the *Community Relations Plan under the Federal Facility Agreement at the U.S. Department of Energy Paducah Gaseous Diffusion Plant*, DOE/LX/07-2481&D1 (DOE 2022a).
- Completed the field activities for SWMU 211-A Enhanced *In Situ* Bioremediation.
- Submitted and received federal and state regulatory approval of the *Explanation of Significant Differences to the Record of Decision for Solid Waste Management Units 1, 211-A, 211-B, and Part of 102 Volatile Organic Compound Sources for the Southwest Groundwater Plume at the Paducah Gaseous Diffusion Plant*, DOE/LX/07-2480&D2 (DOE 2022e).
- Submitted and received federal and state regulatory approval of the *Site Management Plan Paducah Gaseous Diffusion Plant, Paducah, Kentucky, Annual Revision—FY 2023*, DOE/LX/07-2482&D2 (DOE 2022f).

3.5 Public Awareness Program

DOE and its contractors are committed to enhancing public awareness and community and educational outreach. The Paducah Citizens Advisory Board and the DOE Paducah Environmental Information Center are two avenues through which DOE interacts with the public.

A comprehensive Community Relations Plan exists for DOE activities at the Paducah Site; however, out of an abundance of caution and to help slow the spread of COVID-19, some DOE programs may have been affected during 2022 (DOE 2022a). Some activities, such as community involvement and recent cleanup mission achievements, were publicized using media releases. The following sections discuss many of these DOE programs and their 2022 status.

3.5.1 Community and Educational Outreach

As part of its community outreach program, Paducah Site employees participated virtually in a campaign to support the Feds Feed Families program, which helps local food pantries keep their shelves stocked during the summer when they usually see a decrease in donations and an increase in community need. The program has traditionally been a canned goods drive; however, due to COVID-19 safety concerns, a digital campaign encouraged Paducah Site workers and DOE to pledge funds to one of several food pantries.

DOE and its contractors engage students through the annual DOE National Science Bowl. The West Kentucky Regional Science Bowl, designed as a quick-recall, fast-paced, question-and-answer contest, quizzes students on their knowledge of biology, chemistry, earth and space science, energy, mathematics, and physics. The 2022 regional competitions for Western Kentucky and Southern Illinois middle and high schools (see Figure 3.1) were held virtually in February 2022 due to COVID-19 safety protocols. Seventeen middle schools and 13 high schools participated in the event.

Figure 3.1. West Kentucky Regional Science Bowl

COVID-19 safety protocols cancelled some DOE programs for 2022, including the DOE Internship Program. This program typically lasts 10 weeks and offers college students practical experience working on projects that support the Paducah Site's deactivation and remediation operations.

DOE usually conducts plant tours and briefings for community members, leaders, new Citizens Advisory Board members, Paducah Area Chamber of Commerce representatives, senior DOE Headquarters officials, and congressional staff members. The tours highlight PGDP's unique history and honor former workers who met the nation's defense and energy needs for many years; however, the DOE Community Tours Program was cancelled for 2022 due to COVID-19 safety concerns.

The Middle School Groundwater Lessons program was postponed for 2022 due to the COVID-19 pandemic. This program invites local sixth-grade students to participate in mentoring designed to help them understand groundwater cleanup at the Paducah Site.

DOE launched a virtual museum for the Paducah Site. The site maintains an archive of information that can be used to communicate with stakeholders and the public about the history, local impact, and cleanup of the Paducah Site. Additional information about the Kentucky Research Consortium for Energy and Environment is available here.

3.5.2 Citizens Advisory Board

The Paducah Citizens Advisory Board is a site-specific advisory board chartered by DOE under the Federal Advisory Committees Act. The board has up to 15 members who represent the general public from Western Kentucky and Southern Illinois. The Citizens Advisory Board also includes liaison members representing US EPA Region 4, Kentucky Cabinet for Health and Family Services, and WKWMA. The board seeks to reflect the concerns of the communities affected by the environmental management of the Site. Additional information on the Citizens Advisory Board can be found here.

The Paducah Citizens Advisory Board works to achieve its mission through its subcommittee structure, and each year the board holds a planning meeting to determine how best to address its mission. Executive committee members participate in administrative meetings to prepare board members and subcommittees for the task of advising DOE. The educational series was developed to address project priorities selected by the board, with guidance from DOE (PGDP CAB 2017). The intended educational series for FY 2022 addressed the following topics: the Groundwater Success Story Board, a Paducah Area Community Reuse Organization update and the roles of the organization and Citizens Advisory Board in future use discussions, a DUF_6 area update and tour, and a board planning session. The Citizens Advisory Board was also briefed on the status of PFAS sampling at the Paducah Site. Meetings are typically open to the public and are publicly advertised. The March 2022 board meeting was conducted both virtually and in person. Board meetings returned to in-person only format after March.

3.5.3 Paducah Environmental Information Center

The public has access to the electronic version of the Paducah Site's administrative records and programmatic documents at the Paducah Environmental Information Center located at the Emerging Technology Center, Room 221, 5100 Alben Barkley Drive, Paducah, Kentucky. The Paducah Environmental Information Center is open Monday through Friday from 8:00 a.m. to 12:00 p.m. by appointment. The Paducah Environmental Information Center's phone number is (270) 554-3004.

Documents for public comment also are placed in the McCracken County Public Library, 555 Washington Street, Paducah, Kentucky. The library is open Monday through Thursday from 9:00 a.m. to 7:00 p.m., Friday and Saturday from 9:00 a.m. to 5:00 p.m., and Sunday from 1:00 p.m. to 5:00 p.m.

The Paducah Environmental Information Center and other public web pages related to DOE work at the Paducah Site can be accessed here and here.

4. Environmental Radiological Protection and Monitoring

Each year the Paducah Site estimates the potential radiological dose to the public from Site operations and effluents. Estimates are calculated to confirm that no individual could have received a dose that exceeded the limits established by DOE or US EPA for the protection of the public. This section includes estimates of the maximum potential dose to the public and to plants and animals (biota) from Paducah Site activities.

To help readers understand the information in this section, Appendix B, *Introduction to Radiation*, answers the following questions:

- What is radiation?
- What is a radionuclide?
- What are some radionuclides of concern?
- What is radioactivity and how is it measured?
- What is dose and how is it measured?
- How are radioactivity and dose reported?
- What is an exposure pathway?
- What radiation sources and doses are we exposed to?
- What are the potential health effects of radiation exposure?

2022 Highlights

The paragraphs below summarize the radiological dose a member of the public, known as the maximally exposed individual (MEI), could have received from the Paducah Site, assuming exposure from all relevant pathways. The largest contributor to the calculated dose is the direct radiation pathway, or external radiation. Atmospheric releases, incidental ingestion of surface water, and incidental ingestion of sediment contribute to the dose that could be received by the MEI. The ingestion of drinking water does not contribute to the MEI dose; however, it does contribute to the collective population dose in Cairo, Illinois. DOE assumes the groundwater pathway does not contribute to the dose from the Paducah Site because DOE ensures all potentially impacted residents can access a public water supply.

As in previous years, the estimated potential dose from the Paducah Site to the MEI was well below applicable US EPA standards and DOE public dose limits and represents a very small fraction of the estimated 620 mrem members of the public receive annually from natural and man-made sources.

Total dose from all pathways: The calculated dose of radiation a member of the public could receive from all pathways of exposure was 4.3E+00 mrem, which is approximately 4.3 percent of the DOE annual dose limit of 100 mrem.

Dose from the air pathway: US EPA regulates annual radionuclide air emissions and sets a limit of 10 mrem per year at the maximally exposed off-site receptor. The total annual dose from airborne emissions from the Paducah Site was 1.4E-03 mrem, or 0.014 percent of the US EPA limit.

Dose from the surface water pathway: Dose from the surface water pathway is evaluated by how much it contributes to the DOE total dose limit of 100 mrem per year from all relevant pathways. The estimated dose from incidental ingestion of surface water from the Paducah Site was 4.1E-02 mrem, which is 0.04 percent of the DOE annual dose limit of 100 mrem. Groundwater is not considered an exposure pathway because DOE provides public water to potentially impacted residents.

Dose from the sediment pathway: Like surface water, dose from the sediment pathway is evaluated by its contribution to the DOE total dose limit of 100 mrem per year from all relevant pathways. The estimated dose from incidental ingestion of sediment from the Paducah Site was 3.0E-02 mrem. This level is 0.03 percent of the DOE annual dose limit of 100 mrem.

Dose from the direct radiation pathway: Dose from direct radiation is also evaluated by its contribution to the DOE total dose limit of 100 mrem per year from all relevant pathways. The estimated dose from external radiation from the Paducah Site was 4.2E+00 mrem, which represents 4.2 percent of the DOE annual dose limit of 100 mrem and 16.8 percent of the 25 mrem radioactive waste public dose constraint. This pathway represents 97.7 percent of the dose to the public from Paducah Site operations.

Dose to Biota: Biota dose modeling indicates that the plants and animals living on or near the Paducah Site are not exposed to doses in excess of the DOE biota dose standard.

4.1 Environmental Radiological Program

Routine DOE operations at the Paducah Site result in releases of radioactive materials to the environment through atmospheric and liquid pathways. These releases may result in a radiation exposure to the public. In accordance with DOE Order 458.1, *Radiation Protection of the Public and the Environment*, DOE has an environmental surveillance program that includes radiological monitoring of pathways that may contribute to the overall dose to the public. Surveillance includes analyses of surface water, groundwater, sediment, external radiation, and ambient air. The goals of the environmental radiological program are as follows:

- To conduct radiological activities so that exposure to members of the public is within the dose limits established by DOE Order 458.1
- To control the radiological clearance of DOE real and personal property
- To ensure that potential radiation exposures to members of the public are ALARA
- To monitor routine and nonroutine radiological releases and to assess the radiation dose to members of the public
- To protect the environment from the effects of radiation and radioactive material

4.2 Radiological Dose

DOE Order 458.1 establishes 100 mrem per year above background levels as the total annual dose limit to a member of the public. This established limit is consistent with Nuclear Regulatory Commission and Kentucky Radiation Health Branch dose limits for the public. DOE operations at the Paducah Site contribute to the yearly public dose through radiological releases and external radiation. DOE controls emissions and effluents to maintain releases at levels that are ALARA. The DOE Consolidated Audit Program (DOECAP) Accreditation Program provides DOE sites with the assurance that a contracted commercial laboratory is fully capable of providing accurate data analysis. The DOECAP Accreditation Program requires third-party assessments, which assure that environmental sample analysis is performed using proven methods; provide valid, reliable, and defensible data; and manage waste streams responsibly. The assessments are conducted by one of three DOECAP Accreditation Program-approved third-party accreditation bodies and are assessed to the most recent version of the *Department of Defense*

(DoD)/Department of Energy (DOE) Consolidated Quality Systems Manual (QSM) for Environmental Laboratories (DoD 2017). To confirm that doses to the public and biota are below established limits (see Table 2.3), the Paducah Site calculates annual dose estimates using effluent release data, external radiation monitoring data, and environmental monitoring data combined with relevant site-specific data such as meteorological conditions and population characteristics. These dose calculations use various computer codes to model the environmental dispersion of radionuclides that originate from on-site activities. Background radiation of natural cosmic and terrestrial origin and radiation from man-made activity (including medical doses) are subtracted from radiological measurements to determine the Paducah Site dose to the public.

4.2.1 Dose Assessment Methodology

Radiological dose assessments are modeled for exposure pathways applicable to the Paducah Site using methods consistent with the requirements of DOE Order 458.1 and other guidance, including the *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant Paducah, Kentucky*, commonly referred to as the Risk Methods Document (DOE 2022b). First, measurements or estimates of radionuclide concentrations in liquid and air released from the Paducah Site are assembled for the calendar year. Afterward, models approved by US EPA and DOE (or factors derived from those models) are used to estimate the total effective dose to the MEI and the collective total effective dose to the population within a 50-mile radius of the Paducah Site.

To determine compliance with the DOE public dose requirements, the Paducah Site calculates potential off-site doses from Paducah Site air and liquid effluent releases of radioactive materials for the MEI and the population living within a 50-mile radius. DOE Order 458.1 states that the pathway and exposure assumptions for the MEI are to be reasonable and should neither underestimate nor substantially overestimate the dose. The MEI at the Paducah Site is established based on lifestyle assumptions for radiological exposure from each of the pathways for an individual who lives near the Paducah Site at the location where the highest concentration of radionuclides in air has been modeled; consumes milk, meat, and vegetables produced at that location; and spends time swimming in Bayou Creek or Little Bayou Creek. Dose is expected to represent an upper limit for exposure because certain activities, such as swimming in nearby creeks, are assumed to occur but are not expected.

The drinking water pathway (i.e., the ingestion of either groundwater or surface water originating at the Paducah Site) is not a valid exposure pathway because all persons potentially impacted by the Paducah Site have access to commercially-supplied bottled water for drinking. Surface water for irrigating crops is assumed to come from an uncontaminated source and not from either Bayou Creek or Little Bayou Creek because water flow in these creeks is too low for irrigation, compared to the Ohio River. Furthermore, Little Bayou Creek does not support aquatic life for consumption and few game-size fish could be caught from Bayou Creek, except during a backwater event when a large number of fish enter the creek from the Ohio River. Eating fish from the creeks is not included in dose for these reasons.

The dose to the general public from the drinking water pathway is calculated by assuming water is ingested at the nearest public water withdrawal location, which is Cairo, Illinois. If radionuclides are detected at the nearest public water withdrawal location, the calculation is background corrected by using a point in the Ohio River upstream of the Paducah Site. The MEI dose from incidental sediment and surface water ingestion pathways is based on assumptions for wading (i.e., sediment) and swimming (i.e., surface water) in Bayou Creek and Little Bayou Creek. Dose associated with airborne releases is calculated for the MEI located at the nearest neighbor to the plant.

4.2.2 Dose Summary

Table 4.1 summarizes the potential dose to the MEI and the estimated collective population dose. The monitoring results in this table demonstrate the continued effectiveness of radiological control measures practiced at the Paducah Site.

Table 4.1. Summary of potential radiological dose to the public from the Paducah Site, 2022

Pathway[a]	Dose to MEI (mrem)[b] (mrem × 0.01 = mSv)	Percent of DOE 100 mrem per year limit	Estimated collective population dose (person-rem) (person-rem × 0.01 = person-Sv)	Population within 50 miles
Atmospheric releases[c]	1.4E-03	0.0014	2.0E-02	~534,000
Ingestion of groundwater[d]	[d]	[d]	[d]	
Ingestion of drinking water[e]	0.0E+00	0.00	0.0E+00[f]	2,830
Incidental ingestion of surface water	4.1E-02	0.04	[g]	
Incidental ingestion of sediment	3.0E-02	0.03	4.4E-03[h]	150
Direct radiation	4.2E+00	4.2	6.3E-01[h]	150
All relevant pathways[a,b,i]	4.3E+00	4.3	6.5E-01	

[a] Pathways are defined in previous sections.
[b] Maximum allowable exposure from all sources is 100 mrem per year (DOE Order 458.1), which is consistent with 902 *KAR* 100:019, Section 10 (1)(a).
[c] Doses associated with atmospheric releases also include ingestion pathways considered in the Clean Air Act Assessment Package-1998 Personal Computer (CAP-88 PC) food chain modeling routines.
[d] Groundwater is not a viable pathway for the MEI because DOE provides public water to potentially impacted residents.
[e] Ingestion of drinking water is assessed from the nearest surface water intake, which is Cairo, Illinois.
[f] Population dose for ingestion of drinking water from Cairo, Illinois, is based on a representative assumption using the estimated population of Cairo, Illinois, only. No radionuclides were detected near the surface water collection inlet at Cairo, Illinois, (L306) during 2022; therefore, a dose of 0.0E+00 was assigned.
[g] Incidental ingestion of surface water in plant creeks and ditches is not applicable for calculating collective dose to residents who reside within 50 miles of the Paducah Site. Collective dose is not calculated for the incidental ingestion pathway because it is unlikely that a population of individuals would swim repeatedly in either Bayou Creek or Little Bayou Creek. Because this pathway is more likely to involve individuals, it is more suitable for the MEI dose calculation.
[h] Population dose for direct radiation and incidental ingestion of sediment is based on a representative assumption using the estimated visitors hiking in WKWMA only.
[i] The dose to the MEI from all relevant pathways is calculated by summing the dose from individual pathways. The all-pathways dose is considered to be an upper bound of the expected dose to the MEI because no single individual would receive the sum of the calculated pathway doses due to the dose being calculated for exposure at varying locations and any individual's varying activity patterns.

Acronyms:
CAP-88 PC = Clean Air Act Assessment Package-1988 Personal Computer
DOE = US Department of Energy
KAR = Kentucky Administrative Regulations
MEI = maximally exposed individual
mrem = millirem
mSv = millisievert
rem = roentgen equivalent man
Sv = Sievert
WKWMA = West Kentucky Wildlife Management Area

4.3 Air Monitoring and Estimated Dose

DOE operations result in airborne releases from various sources, including CERCLA remedial actions. Radionuclide sources evaluated at the Paducah Site in 2022 included the C-310 Stack, Northwest Plume Groundwater Treatment System, Northeast Plume Containment System Treatment Units, the DUF_6 Conversion Facility, building exhaust vents, and fugitive emissions.

4.3.1 Air Monitoring

Specific activities that could generate fugitive emissions include the transport and disposal of waste, decontamination of equipment, and most environmental remediation activities. Ambient air monitoring, which monitors fugitive emissions from all Paducah Site operations (including DUF_6 Conversion Facility operations), uses nine continuous air monitors surrounding the Paducah Site, including one that collects data from a background location. Figure 4.1 shows the locations of these air monitors. The FY 2022 and FY 2023 Environmental Monitoring Plans describe the radiological constituents analyzed for the Paducah Site (FRNP 2022a).

For radionuclides at the Paducah Site, the effective dose equivalent is assumed to equal the effective dose. January 2020 guidance from DOE's Office of Public Radiation Protection (AU-22) states, "AU-22 considers the reported CAP-88 PC dose to be a very close approximation of a modeled ED result and well within the uncertainty bounds of the dose estimate." The DOE guidance is available here.

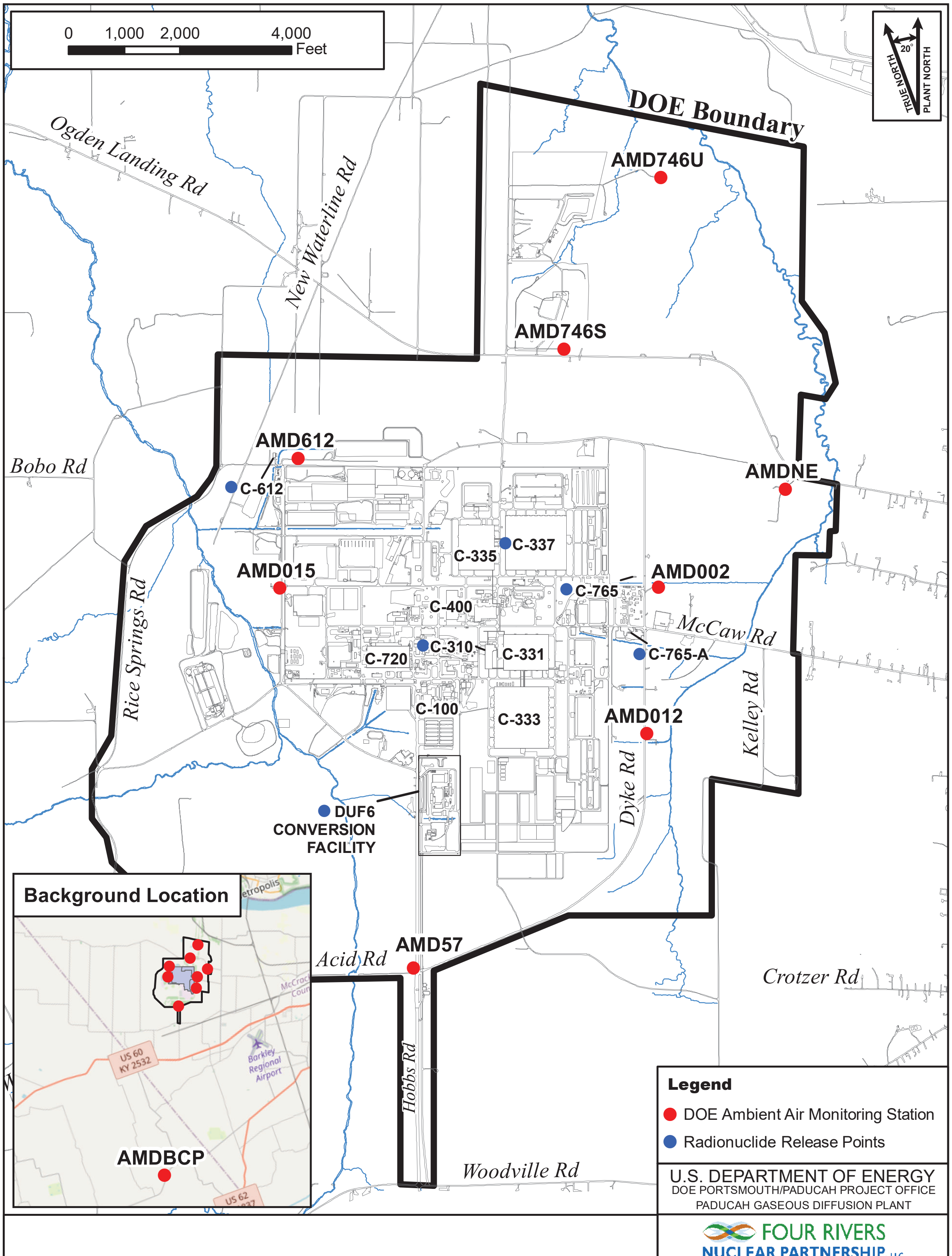
Airborne radionuclide emissions are regulated by US EPA under the Clean Air Act and its implementing regulations. DOE facilities are subject to 40 *CFR* Part 61, Subpart H, National Emission Standards for Hazardous Air Pollutants, which contains the national standards for emissions of radionuclides other than radon from DOE facilities. The applicable standard is a maximum of 10 mrem (0.1 mSv) effective dose equivalent to any member of the public in any year.

Table 4.2 shows the estimates of radionuclide atmospheric releases in curies, a unit of measure for radioactivity.

4.3.2 Air Estimated Dose

Airborne radioactive materials released in 2022 from the stacks and diffuse sources at the Paducah Site (see Table 4.2) were modeled using the US EPA-approved CAP-88 PC, Version 4.1.1, computer program. This air dispersion model estimates effective dose equivalents based on the ingestion, inhalation, air immersion, and ground surface pathways, including the consumption of vegetables, milk, and meat. Site-specific data for 2022 (radionuclide releases in curies per year) were entered in the CAP-88 PC program, along with on-site meteorological data. Table 4.3 provides the effective dose to the MEI for each individual point source in mrem received in a calendar year. Due to location differences, emission rates, and other factors, the MEI for each point source could differ from the MEI for the cumulative impacts from all sources.

The individual who would receive the maximum hypothetical cumulative dose from all pathways, known as the MEI, was calculated to receive an effective dose equivalent of 1.4E-03 mrem, which is below the National Emission Standards for Hazardous Air Pollutants standard of 10 mrem per year. Table 4.4 shows the collective effective dose to the entire population (~534,000 persons per 2010 US Census data) within



MAP SOURCE INFORMATION

Main Figure
Map Generation Date and Location-- G:\GIS\ARCVIEWS\PROJECTS\ASER\DOE_AMD_20230302.mxd
DOE Ambient Air Monitoring Station Layer-- G:\GIS\iPEGASIS.gdb\Locations
Streams Layer-- G:\GIS\iPEGASIS.gdb\streams
Roads Layer-- G:\GIS\iPEGASIS.gdb\roadrow
DOE Boundary Layer-- G:\GIS\iPEGASIS.gdb\doebnd
Facilities Layer-- G:\GIS\iPEGASIS.gdb\Facilities

Figure Inset
DOE Ambient Air Monitoring Station Layer-- G:\GIS\iPEGASIS.gdb\Locations
Limited Area Layer-- G:\GIS\iPEGASIS.gdb\limited_area
DOE Boundary Layer-- G:\GIS\iPEGASIS.gdb\doebnd
Basemap-- OpenStreetMap http://www.OpenStreetMap.org

Figure 4.1. Air monitoring locations and radionuclide release points

Table 4.2. Radionuclide atmospheric releases (in curies) for the Paducah Site

Radionuclide	Group A	Group B	Group C	Group D	Group E	Group F	Total Site Emissions
	Northwest Plume Groundwater Treatment System C-612	Northeast Plume Containment System Treatment Unit C-765	Northeast Plume Containment System Treatment Unit C-765-A	C-310 Stack	DUF_6 Conversion Facility	Seal Exhaust/ Wet Air Group	
Technetium-99	9.58E-05	7.43E-06	3.60E-06	0.00E+00	0.00E+00	1.69E-07	**1.07E-04**
Uranium-234	0.00E+00	0.00E+00	0.00E+00	3.44E-03	1.02E-07	4.60E-07	**3.44E-03**
Uranium-235	0.00E+00	0.00E+00	0.00E+00	7.21E-05	4.66E-09	2.43E-08	**7.21E-05**
Uranium-238	0.00E+00	0.00E+00	0.00E+00	2.55E-03	2.50E-07	2.42E-07	**2.55E-03**
Neptunium-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**
Plutonium-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**
Thorium-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	**0.00E+00**
Thorium-231	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.65E-08	0.00E+00	**3.65E-08**
Thorium-234	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.33E-06	0.00E+00	**3.33E-06**
Protactinium-234m	0.00E+00	0.00E+00	0.00E+00	0.00E+00	3.33E-06	0.00E+00	**3.33E-06**
Total	**9.58E-05**	**7.43E-06**	**3.60E-06**	**6.06E-03**	**7.05E-06**	**8.95E-07**	**6.18E-03**

Acronym:
DUF_6 = depleted uranium hexafluoride

Table 4.3. Dose calculations for airborne releases for 2022

Emission sources	Effective dose equivalent to the MEI for each source (mrem)	Dose to the MEI for the plant (mrem)
C-310 Stack	1.40E-03	1.40E-03
Seal Exhaust/Wet Air Group	3.2E-07	2.6E-07
Northwest Plume Groundwater Treatment System C-612	6.40E-05	2.30E-05
Northeast Plume Containment System Treatment Unit C-765	3.70E-06	1.50E-06
Northeast Plume Containment System Treatment Unit C-765-A	1.80E-06	7.50E-07
DUF_6 Conversion Facility	1.30E-07	9.20E-08
Total from All Sources		1.43E-03

Acronyms:
MEI = maximally exposed individual
mrem = millirem
DUF6 = depleted uranium hexafluoride

Table 4.4. Calculated radiation dose from airborne releases for the Paducah Site for 2022

Effective dose to MEI (mrem)	Percent of NESHAP 10 mrem/year limit	Collective effective dose (person-rem)
1.43E-03	0.014	1.99E-02

Acronyms:
MEI = maximally exposed individual
mrem = millirem
NESHAP = National Emission Standards for Hazardous Air Pollutants
rem = roentgen equivalent man

50 miles of the Paducah Site, as estimated by the CAP-88 PC program. The emissions are still below the regulatory limits and there was a decrease in airborne radionuclide emissions in 2022 (Table 4.5).

Table 4.5. Comparison of potential radiological dose for the atmospheric releases pathway

Atmospheric Releases[a]	2018	2019	2020	2021	2022
Dose to MEI in mrem[b] (mrem × 0.01 = mSv)	9.0E-05	8.5E-05	6.2E-05	4.9E-03	1.4E-03
Percent of DOE 100 mrem per year limit	0.00009%	0.000085%	0.000062%	0.0049%	0.0014%
Percent of NESHAP 10 mrem per year limit	0.0009%	0.00085%	0.00062%	0.049%	0.014%
Estimated Collective Dose in person-rem[a,b] (person-rem × 0.01 = person-Sv)	6.0E-04	5.0E-04	2.7E-04	5.5E-02	2.0E-02
Population within 50 miles[c]	~534,000	~534,000	~534,000	~534,000	~534,000

[a] Doses associated with atmospheric releases also include ingestion pathways considered in the CAP-88 PC food chain modeling routines.
[b] Maximum allowable exposure from all sources is 100 mrem per year (DOE Order 458.1), which is consistent with 902 *KAR* 100:019, Section 10(1)(a).
[c] Entire population within 50 miles of the Paducah Site.

Acronyms:
CAP-88 PC = Clean Air Act Assessment Package-1988 Personal Computer
DOE = US Department of Energy
MEI = maximally exposed individual
mrem = millirem
mSv = millisievert
NESHAP = National Emission Standards for Hazardous Air Pollutants
rem = roentgen equivalent man
Sv = Sievert

A detailed summary of this emissions data can be found in the National Emissions Standard for Hazardous Air Pollutants Annual Report for 2022 (FRNP 2023c).

4.4 Liquid Discharge Monitoring and Estimated Dose

The Paducah Site monitors effluent and surface water runoff for radiological constituents to protect human health and the environment.

4.4.1 Surface Water

Radioactive contaminants released to surface water may remain dissolved or suspended as particulates in surface water; may be deposited in sediment, on the ground, or on vegetation by irrigation; may be absorbed into plants and animals; or may infiltrate to the groundwater.

Derived concentration standard—A derived concentration value for a radionuclide in water that would result in a dose of 100 mrem in a year to a gender- and age-weighted reference person using DOE-approved dose coefficients and assuming continuous exposure.

Surface water leaving the Paducah Site includes precipitation runoff from cylinder yards, landfills, and effluent from Paducah Site processes such as the Northeast Plume Containment System, the C-611 Water Treatment Plant, the C-612 Northwest Plume Groundwater Treatment System, the C-613 Sedimentation Basin, and the C-615 Sewage Treatment Plant. Discharges from the Paducah Site flow into Bayou Creek and Little Bayou Creek, and both creeks then flow into the Ohio River.

DOE Order 458.1 requires DOE to control and manage radionuclides from its activities in liquid discharges and sets guidelines for allowable concentrations of radionuclides in effluents to protect public health. The Paducah Site achieves this protection by ensuring concentrations of radionuclides in effluents are ALARA. Ingestion limits for all radionuclides are calculated using the composite derived concentration standard value found in DOE-STD-1196-2022, *Derived Concentration Technical Standard*. The dose limits set by DOE Order 458.1 are the legal limits but are not DOE's expectation for dose to the public and the environment. DOE Order 458.1 requires application of the ALARA process to all routine radiological activities to reduce radionuclide releases and resulting doses.

The ingested water derived concentration standard value for a radionuclide is the concentration of the radionuclide in water that is calculated, or derived, to result in an annual dose of 100 mrem to a person. That is, if the person's entire annual drinking water intake contained a radionuclide at the derived concentration standard level, that person would receive 100 mrem. The derived concentration standard is different for each radionuclide because of differences in radiation type, radioactive energy, and half-life.

The Environmental Radiation Protection Program monitors effluent and surface water runoff for radiological constituents to observe potential contamination released to the receiving streams and tributaries from plant operations. Sampling locations were selected to support the analysis of site-specific radiation exposure pathways. Locations were prioritized for areas of public access, introduction of plant effluents to the environment, and verification of the effectiveness of the Paducah Site effluent control and monitoring. Figure 4.2 shows surface water monitoring locations.

Radionuclides were analyzed monthly at 14 surface water locations downstream of KPDES-permitted outfalls: K001ERPP, K002ERPP, K004ERPP, K008ERPP, K009ERPP, K010ERPP, K011ERPP, K012ERPP, K013ERPP, K015ERPP, K016ERPP, K017ERPP, K019ERPP, and K020ERPP.

Radionuclide analysis was performed quarterly at three Little Bayou Creek surface water locations: L10, L11, and L241. Radionuclides were analyzed quarterly at one Bayou Creek surface water location (L5) and at one North-South Diversion Ditch surface water location (L14DWN). Radionuclide analysis was performed quarterly at one reference location (L29A) and one location near the nearest public water withdrawal location in Cairo, Illinois (L306). Radionuclide analysis was performed annually at one reference location (L1) and one reference location for the public water source location in the Ohio River immediately downgradient of the plant (L30). Reference location L1 was chosen for comparisons of data generated as part of the Environmental Radiation Protection Program effluent and surface water runoff monitoring effort.

The surface water sampling locations with the maximum detectable radionuclides, were K015ERPP for thorium-230, K001ERPP for uranium-234, and K020ERPP for uranium-235 and uranium-238. Surface water runoff is sampled at the C-746-S, C-746-T, and C-746-U Landfills (L135, L136, L150, L154, and L351) to meet permit requirements; samples are analyzed for alpha and beta activity.

In addition to monitoring surface water under DOE orders, the KPDES permit, and the solid waste landfills permit, DOE conducted surface water monitoring as a separate program under CERCLA for effluent from the Northeast Plume Containment System via Outfall C001. This outfall was monitored for technetium-99, according to the *Remedial Action Work Plan for Optimization of the Northeast Plume Interim Remedial Action at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 2018). The highest surface water result in 2022 for technetium-99 (52.1 pCi/L) was at Outfall C001. Results from C001 are not used to calculate dose, however, because it is a direct discharge from a treatment system and this outfall does not represent a body of water that a person could enter. Relocating the two Northeast Plume extraction wells to optimize the interim remedial action (see Chapter 6) has placed the wells in an area where technetium-99 results observed in monitoring wells have been slightly higher than

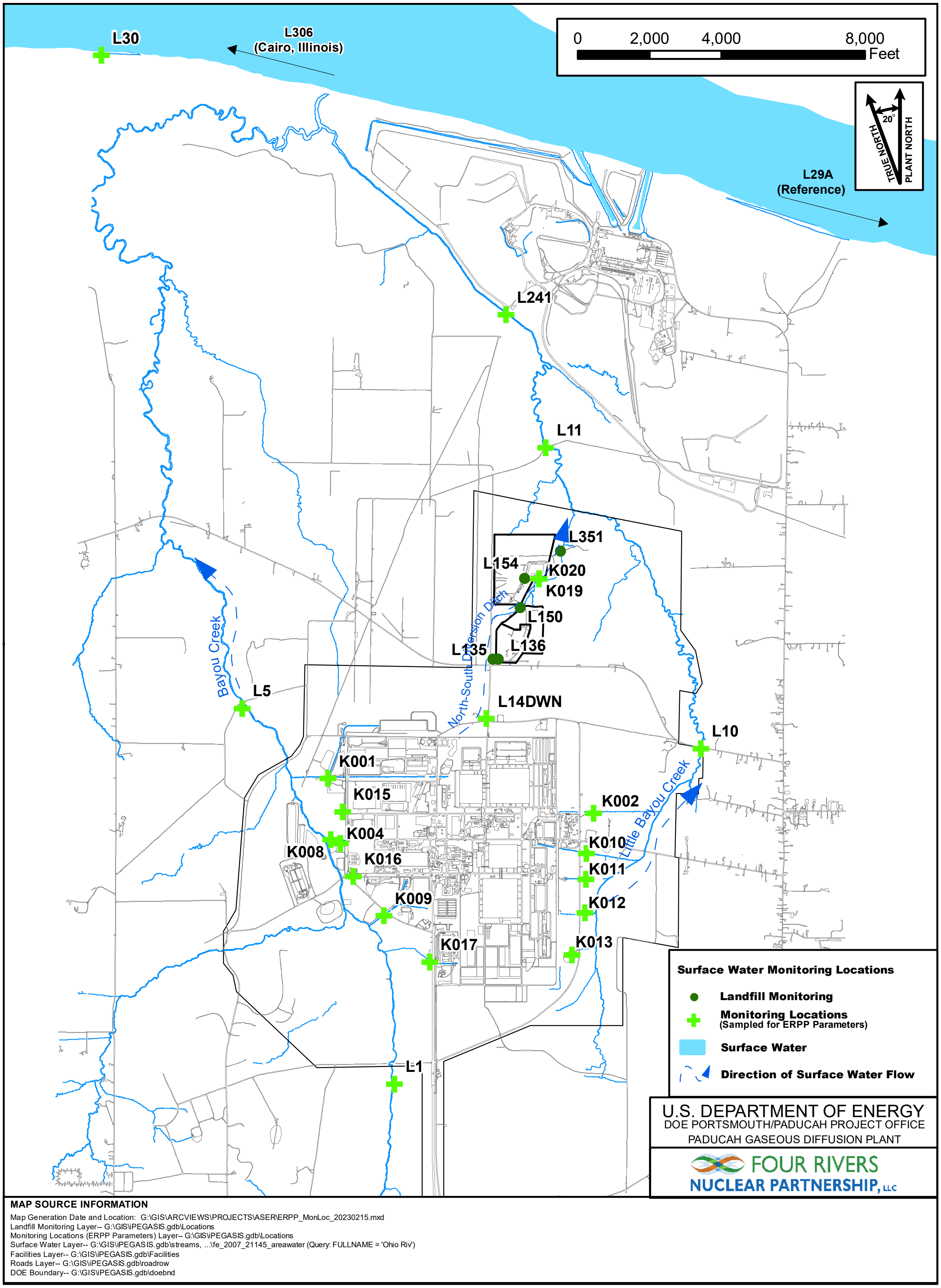


Figure 4.2. Surface water monitoring locations

technetium-99 results for monitoring wells near old extraction well locations. As such, a slight increase in technetium-99 in the extracted groundwater is not unexpected. DOE evaluated the presence of technetium-99 and determined that it did not pose a potential threat to human health or the environment in surface discharge, as documented in the *Record of Decision for Interim Remedial Action at the Northeast Plume at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (DOE 1995b). Additional monitoring results are available through the PPPO Environmental Geographic Analytical Spatial Information System (PEGASIS) website, which can be accessed here.

4.4.2 Drinking Water

Surface water from the Paducah Site is not consumed directly as drinking water; however, it eventually discharges into the Ohio River, which is used as a source of public drinking water. Cairo, Illinois, located approximately 30 miles from the Paducah Site at the confluence of the Ohio and Mississippi Rivers, is the closest drinking water system that uses water downstream of Paducah Site effluents. No radionuclides above background were detected in surface water samples collected near the surface water inlet at Cairo (L306) during 2022. There was no detectable alpha activity, and the maximum beta activity detected was 6.09 pCi/L in the surface water samples collected near the surface water inlet at Cairo (L306) during 2022.

4.4.3 Drinking Water Estimated Dose

The drinking water pathway dose was calculated for the general public assumed to consume water from the public drinking water supply at Cairo, Illinois (L306). Because no radionuclides above background were detected, a value of 0.0E+00 mrem was used in the dose calculation. This result is consistent with previous results cited in annual site environmental reports, as shown in Table 4.6.

Table 4.6. Comparison of potential radiological dose for ingestion of drinking water pathway

Ingestion of drinking water[a]	2018	2019	2020	2021	2022
Dose to MEI (mrem) (mrem × .01 = mSv)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Percent of DOE 100 mrem per year limit	0.00	0.00	0.00	0.00	0.00
Estimated collective population dose (person-rem)[b] (person-rem × .01 = person-Sv)	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Population within 50 miles	2,830	2,830	2,830	2,830	2,830

[a] Ingestion of drinking water is assessed from the nearest surface water intake at Cairo, Illinois.
[b] Population dose for ingestion of drinking water from Cairo, Illinois is based on a representative assumption using only the estimated population of Cairo, Illinois.

Acronyms:
DOE = US Department of Energy
MEI = maximally exposed individual
mrem = millirem
mSv = millisievert
rem = roentgen equivalent man
Sv = Sievert

Most of the individuals within a 50-mile radius of the Paducah Site do not obtain their daily drinking water from sources downstream of the Paducah Site; therefore, an estimated collective dose was calculated by multiplying the dose to the MEI from annual ingestion of drinking water from the Cairo, Illinois supply (prior to treatment) by the estimated number of Cairo, Illinois residents (2,830 persons according to the 2010 US Census data). This resulted in a representative collective dose of 0.0E+00 person-rem (roentgen equivalent man).

4.4.4 Incidental Ingestion of Surface Water

Dose to the MEI is based on incidental ingestion of surface water from swimming in Bayou Creek and Little Bayou Creek and their tributaries, including outfall locations. This scenario represents an upper limit for exposure because the dose is based on swimming, which is an unlikely activity for both Bayou Creek and Little Bayou Creek. For example, the manager of the WKWMA noted in an interview that any contact with water would be brief and would be limited to wading across creeks. A health assessment by the Agency for Toxic Substances and Disease Registry states, "…there is very little swimming, wading, or other human activity in Bayou and Little Bayou Creeks." Finally, the Kentucky Department of Fish and Wildlife Resources did not identify swimming (as compared to limited fishing and traversing incidental to hunting) as a recreational use of Little Bayou or Bayou Creeks in recreational usage information provided in 1995 or in the 2014 recreational usage update. The recreational usage information is found in Appendix E of the Risk Methods Document (DOE 2022b).

The method recommended in DOE-HDBK-1216-2015 Change Notice 1, *Environmental Radiological Effluent Monitoring and Environmental Surveillance*, was implemented to determine dose to the MEI for incidental ingestion of surface water. The ingestion assumptions, based on the Risk Methods Document, Table B.4, are that a hypothetical person may swim (at most) 45 days a year for 2.6 hours a day, with an incidental ingestion rate of 0.092 liters per hour, and be in different locations throughout the wildlife management area (DOE 2022b). Table A.10 of that document provides site-specific screening levels for receptors due to site-related radionuclides. Sample results from each surface water sample location were averaged for that location, and the average sample result was then used in the calculation to determine a dose at each surface water sample location. Results from reference location L1 were subtracted from other sample results to arrive at a dose associated with Paducah Site releases at each surface water sample location. When calculated reference location dose results were less than zero, a value of 0.0E+00 mrem was used for the reference result in the calculation to determine the annual dose minus background. When a calculated radionuclide's specific dose was less than zero, a value of 0.0E+00 mrem was used for that radionuclide specific result in the calculation to determine the annual estimated dose for incidental ingestion of surface water for each sample location. The sample location with the maximum estimated dose was assigned to the MEI. The 2022 surface water sample location with the maximum estimated dose was K020ERPP.

Table 4.7 summarizes the maximum detected radionuclides at the surface water sampling locations and KPDES-permitted outfalls mentioned previously.

Table 4.7. Maximum detected radionuclides in surface water samples

Radionuclide (pCi/L)	Maximum detected
Technetium-99	5.21E+01*
Thorium-230	3.94E+00
Uranium-234	2.59E+01
Uranium-235	2.38E+00
Uranium-238	6.83E+01

*Maximum level of technetium-99 was detected in location: C001. Data from C001 are not used for calculating dose of incidental ingestion of surface water because it is a direct discharge from a treatment system and not representative of waters that a person may swim in. There was no detectable technetium-99 in waters that a person may swim in.

4.4.5 Incidental Ingestion of Surface Water Estimated Dose

Dose from the surface water pathway is evaluated by its contribution to the DOE limit for the total dose from all pathways of 100 mrem per year. The estimated dose to the MEI from incidental ingestion of surface water releases from the Paducah Site was 4.1E-02 mrem. This level is 0.04 percent of the DOE annual dose limit of 100 mrem from all pathways to members of the public. This is consistent with previous results cited in annual site environmental reports, as shown in Table 4.8.

Table 4.8. Comparison of potential radiological dose for incidental ingestion of surface water pathway

Incidental ingestion of surface water	2018	2019	2020	2021	2022
Dose to MEI (mrem) (mrem × 0.01 = mSv)	6.7E-02	5.2E-02	1.6E-01	7.1E-02	4.1E-02
Percent of DOE 100 mrem per year limit	0.067	0.052	0.16	0.07	0.04
Estimated collective population dose (person-rem per year)* (person-rem × 0.01 = person-Sv)	*	*	*	*	*
Population within 50 miles	*	*	*	*	*

* Incidental ingestion of surface water in plant creeks and ditches is not applicable for calculation of collective population dose to residents who reside within 50 miles of the Paducah Site. Collective population dose is not calculated for the incidental ingestion pathway as it is unlikely that a population of individuals would swim repeatedly in either Bayou Creek or Little Bayou Creek. This pathway is more likely to involve individuals; therefore, it is more appropriate for the MEI dose calculation.

Acronyms:
DOE = US Department of Energy
MEI = maximally exposed individual
mrem = millirem
r mSv = millisievert
rem = roentgen equivalent man
Sv = Sievert

Collective dose is not calculated for the incidental ingestion of surface water pathway because it is unlikely that a population of individuals would repeatedly swim in either Bayou Creek or Little Bayou Creek. Because this pathway is more likely to involve individuals, it is more appropriate for the MEI dose calculation.

4.4.6 Landfill Leachate

Leachate collected from the C-746-U and C-746-S Landfills is sampled routinely and compared to DOE Order 458.1 limits. This data is used to determine programmatic management of landfill leachate. Leachate is treated and discharged through permitted outfalls at the Site, which are also monitored for compliance with permit limits. Additional monitoring results are available through the PEGASIS website, which can be accessed here.

4.4.7 Groundwater

DOE has numerous groundwater monitoring wells, which are described in Chapter 6. Groundwater wells that supplied drinking water to residents in the water policy area of the Paducah Site have been abandoned or taken out of service, and the houses are provided with public drinking water. As a result, groundwater is not an exposure route because it is not a source of drinking water. Because groundwater is not used as a drinking source, it is not considered in the calculation of the dose to the MEI. Similarly, groundwater as a drinking water source is not considered in the calculation of dose to the surrounding population.

4.5 Sediment and Soil Monitoring and Estimated Dose

Sediment is an important constituent of the aquatic environment. Radionuclides transported by water can adhere to suspended organic and inorganic solids or can be assimilated by plants and animals. Suspended solids, dead biota, and excreted waste matter settle to the bottom and become part of the organic substrata that support the bottom-dwelling community of organisms. As a result, sediments can have a significant impact on aquatic ecology by serving as a repository for radioactive substances that pass from bottom-feeding biota to higher levels of the food chain. A single sediment sample can represent information that would require many water samples, spaced over a period of time, to reconstruct. Sediment collects, concentrates, and stores specific kinds of contaminants at specific locations. Concentrations of contaminants in sediments represent the combined amounts of the contaminants accumulated in water over some preceding period of time.

4.5.1 Sediment Monitoring

Sediment sampling at the Paducah Site in 2022 included radiological and nonradiological constituents. Sediment sampling for nonradiological constituents is discussed in Chapter 5. Sampling locations, shown in Figure 4.3, were selected to facilitate the analysis of site-specific radiation exposure pathways and to indicate the accumulation of undissolved radionuclides in the aquatic environment.

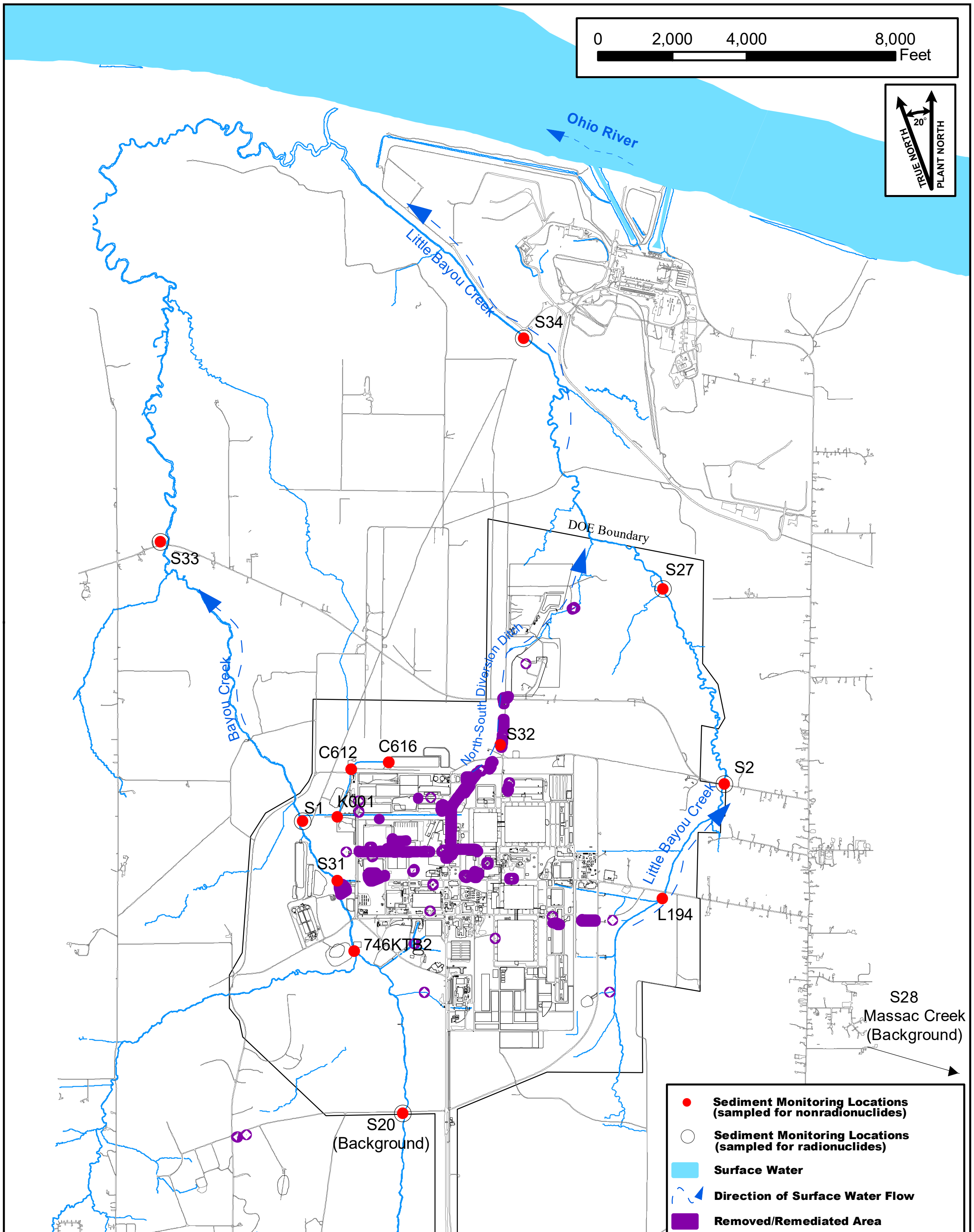
Sampling locations were selected to represent areas of public access, introduction of plant effluents to the environment, any unplanned release, and to verify the effectiveness of the Paducah Site's effluent monitoring. Areas removed or remediated as part of a 2010 removal action for contaminated sediment associated with the Surface Water Operable Unit are also noted in Figure 4.3 (DOE 2011).

Results from radiological analysis of the annual sediment samples are shown in Table 4.9 and may also be found on the PEGASIS website, which can be accessed here. The radiological results for 2022 are similar in magnitude to those from previous years. Location S20 provides background concentrations for radiological sediment sampling. Location S1 is on Bayou Creek within the DOE boundary surrounding the Paducah Site. Location S2 is downstream at Little Bayou Creek, near the DOE boundary. Location S27 is in Little Bayou Creek within the DOE boundary. Location S33 is in Bayou Creek, north of the DOE boundary, and Location S34 is in Little Bayou Creek, north of the DOE boundary.

Table 4.9. Radiological results for sediment sampling in picocuries per gram[a,b,c]

Parameter	S1	S1 (duplicate)	S1 (average)	S2	S20 (background)	S27	S33	S34
Alpha activity	7.72E+00	5.53E+00	6.63E+00	8.69E+00	7.15E+00	1.06E+01	1.00E+01	1.05E+01
Beta activity	1.28E+01	7.03E+00	9.92E+00	9.25E+00	1.31E+01	1.80E+01	1.19E+01	1.87E+01
Americium-241	-1.69E-02	-2.01E-02	-1.85E-02	-8.17E-02	1.08E-01	-1.41E-01	1.47E-01	-3.50E-02
Cesium-137	3.49E-02	9.76E-03	2.23E-02	7.56E-03	6.61E-02	-2.12E-02	4.37E-02	-5.58E-03
Neptunium-237	-3.80E-01	-2.10E-01	-2.95E-01	-9.82E-02	-2.06E-01	-1.49E-01	-1.75E-01	-2.24E-02
Plutonium-238	-4.30E-02	-1.19E-01	-8.10E-02	-6.76E-02	3.21E-02	-1.15E-01	2.64E-03	7.86E-02
Plutonium-239/240	5.06E-02	1.19E-01	8.48E-02	5.55E-02	9.39E-02	1.39E-01	-4.48E-02	2.42E-02
Technetium-99	3.72E+00	2.22E+00	2.97E+00	1.56E+00	-3.45E-01	-7.68E-02	1.52E+00	2.89E+00
Thorium-230	1.62E+00	5.31E-01	1.08E+00	7.66E-02	1.01E+00	1.30E+00	1.40E+00	1.03E+00
Total Uranium	3.20E+00	3.65E+00	3.43E+00	2.85E+00	9.77E-01	1.59E+00	2.72E+00	1.46E+00
Uranium-234	1.06E+00	1.35E+00	1.21E+00	8.59E-01	5.22E-01	6.58E-01	1.14E+00	6.26E-01
Uranium-235	2.21E-01	1.62E-02	1.19E-01	7.48E-02	-4.05E-02	4.01E-02	1.29E-01	-1.91E-02
Uranium-238	1.92E+00	2.28E+00	2.10E+00	1.92E+00	4.55E-01	8.90E-01	1.45E+00	8.38E-01

[a] Negative values are possible and observed regularly with radiological data.
[b] Negative results may be reported due to a statistical determination of the counts seen by a detector, minus a background count.
[c] Shaded values are less than the laboratory reporting limit.



MAP SOURCE INFORMATION

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Facilities Layer-- G:\GIS\iPEGASIS.gdb\Facilities
DOE Boundary Layer-- G:\GIS\iPEGASIS.gdb\doebnd

Figure 4.3. Sediment monitoring locations

4.5.2 Sediment Estimated Dose

In calculating dose to the MEI, it was assumed that exposure to contaminated sediment in Bayou Creek and Little Bayou Creek could occur during hunting and other recreational activities by incidentally ingesting the sediment. The ingestion assumption assumes that an individual, referred to as an adult recreational user, would wade at one creek location every other day during the hunting season (104 days per year) and ingest a small amount of sediment (100 milligrams per day) during each visit. A dose was then calculated using the methods in the Risk Methods Document, which includes the ingestion, inhalation, and external gamma pathways (DOE 2022b). Table A.8 of that document provides site-specific soil screening levels for receptors due to site-related radionuclides. Results from the background location, S20, are subtracted from other sample results to arrive at a dose associated with Paducah Site releases. When calculated background dose results were less than zero, a value of 0.0E+00 mrem was used for that background result in the calculation to determine the annual dose minus background. When a calculated radionuclide's specific dose was less than zero, a value of 0.00E+00 mrem was used for that radionuclide-specific result in the calculation to determine the annual estimated dose for incidental ingestion of sediment. Location S1 dose is calculated by averaging the dose from the S1 sample results and the S1 duplicate sample results. The sample location with the maximum estimated dose was assumed to represent the MEI dose received from this pathway. Table 4.10 presents the estimated annual dose for the incidental ingestion of sediment for each location sampled.

Table 4.10. 2022 annual dose estimates in millirem for incidental ingestion of sediment

Sample Location	Am-241	Cs-137	Np-237	Pu-238	Pu-239/240	Tc-99	Th-230	U-234	U-235	U-238	Total (mrem)
S20 (background)	1.12E-03	1.33E-02	0.00E+00	3.03E-04	9.63E-04	0.00E+00	8.78E-03	1.02E-03	0.00E+00	4.10E-03	2.96E-02
S1 (average)	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	9.25E-05	5.70E-04	1.33E-03	5.09E-03	1.48E-02	2.19E-02
S2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.86E-05	0.00E+00	6.58E-04	3.21E-03	1.32E-02	1.71E-02
S27	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.63E-04	0.00E+00	2.52E-03	2.66E-04	1.72E-03	3.92E-03	8.89E-03
S33	4.06E-04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.74E-05	3.39E-03	1.21E-03	5.54E-03	8.96E-03	1.96E-02
S34	0.00E+00	0.00E+00	0.00E+00	4.39E-04	0.00E+00	9.00E-05	1.74E-04	2.03E-04	0.00E+00	3.45E-03	4.36E-03

Acronyms:
Am = americium
Cs = cesium
mrem = millirem
Np = neptunium
Pu = plutonium
Tc = technetium
Th = thorium
U = uranium

Based on the dose estimates in Table 4.10, the maximum estimated dose was calculated at location S20, which is located on the southwest portion of the DOE Paducah Site boundary and is the background location used for the radiological sediment samples.

Prior to the 2018 annual site environmental report, collective dose for annual incidental ingestion of sediment was not estimated because it was not a plausible exposure for residents who resided within 50 miles of the Paducah Site. The pathway was more likely to involve individuals; therefore, it was better suited for the MEI dose calculation; however, to be consistent with the estimated collective dose for the direct radiation pathway, an estimated collective dose was calculated by multiplying the dose to the MEI from incidental ingestion of sediment by the total estimated number of visitors hiking in the WKWMA annually, as cited by the Risk Methods Document, which is 150 persons (DOE 2022b).

The estimated dose to the MEI from incidental ingestion of sediment was 3.0E-02 mrem. This level is 0.03 percent of the DOE annual dose limit of 100 mrem per year from all pathways to members of the public. The estimated collective population dose was 4.4E-03 person-rem. These results were consistent with previous results cited in annual site environmental reports, as shown in Table 4.11.

Table 4.11. Comparison of potential radiological dose for incidental ingestion of sediment pathway

Incidental ingestion of sediment	2018	2019	2020	2021	2022
Dose to MEI (mrem) (mrem × 0.01 = mSv)	5.4E-02	6.3E-02	6.1E-02	1.6E-01	3.0E-02
Percent of DOE 100 mrem per year limit	0.054	0.063	0.061	0.160	0.03
Estimated collective population dose (person-rem)* (person-rem × 0.01 = person-Sv)	8.1E-03	9.4E-03	9.2E-03	2.4E-02	4.4E-03
Population within 50 miles*	150	150	150	150	150

* Population dose for incidental ingestion of sediment is based on a representative assumption using the estimated visitors hiking in WKWMA only.

Acronyms:
DOE = US Department of Energy
MEI = maximally exposed individual
mrem = millirem
mSv = millisievert
rem = roentgen equivalent man
Sv = Sievert
WKWMA = West Kentucky Wildlife Management Area

4.6 External Radiation Monitoring and Estimated Dose

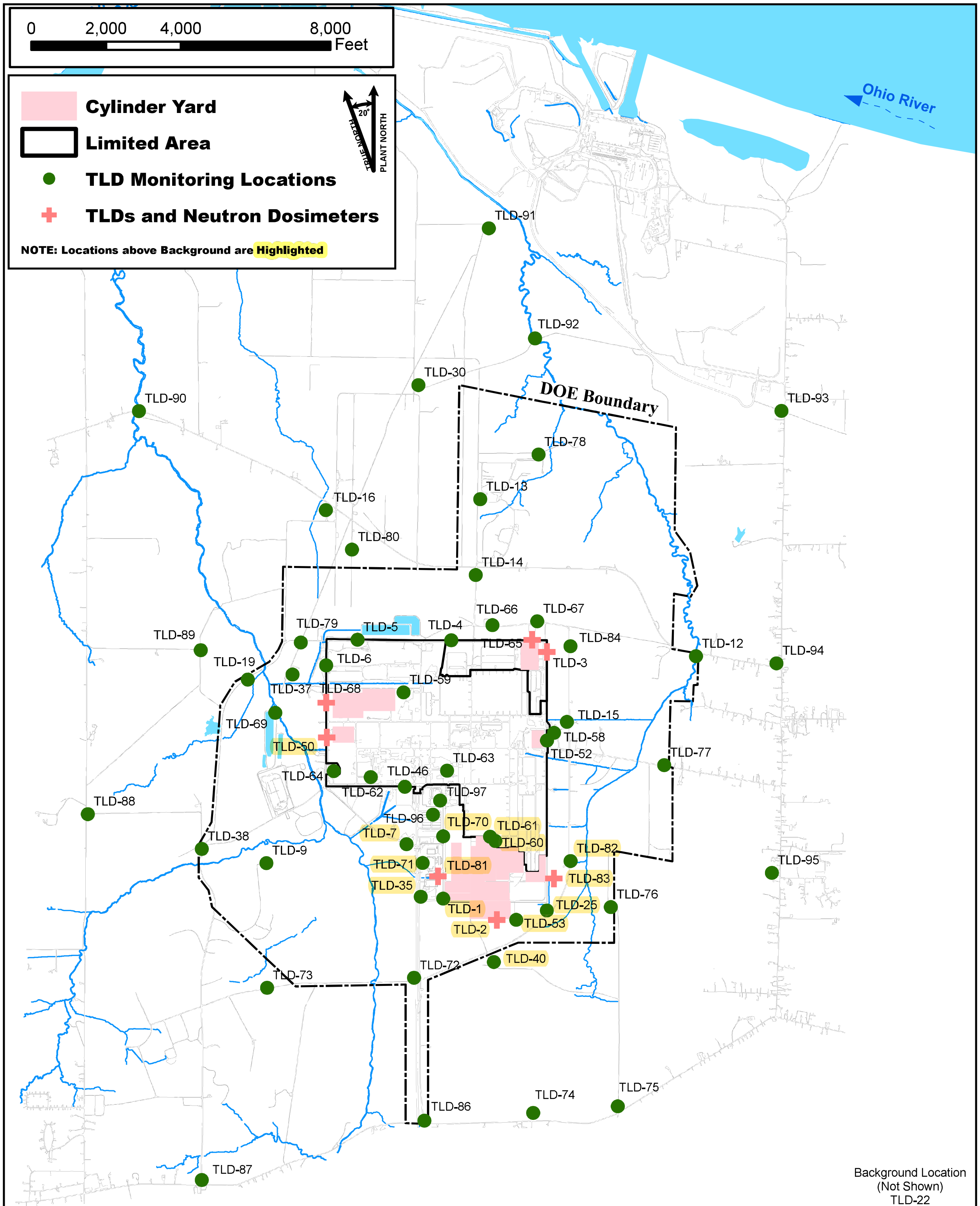
External radiation exposure from DOE's operations at the Paducah Site potentially contributes to the overall dose to the public. This report refers to this as the direct radiation pathway. External radiation exposure is defined as exposure attributed to radioactive sources outside the body, such as cosmic radiation. Sources of external radiation at the Paducah Site include the cylinder storage yards, the operations inside the cascade building, and small items such as instrument calibration sources. Cylinder storage yards have the greatest potential to contribute to the public dose because of their proximity to publicly accessible areas.

4.6.1 External Radiation Monitoring

The external radiation monitoring program is designed to provide data on external radiation exposure from DOE operations to members of the public. The primary factor in selecting the monitoring locations was the potential for a member of the public to be exposed to external radiation. Locations were also chosen for accessibility, representative exposure potentially received by members of the public, and area monitoring for individuals passing through the Paducah Site.

A surveillance network of environmental thermoluminescent dosimeters and optically stimulated luminescence dosimeters monitored locations inside the Paducah Site security fence and at the perimeter of the Paducah Site, in addition to outfalls, ditches, and background locations. Dosimeters were also placed in areas that historically received the highest radiation exposure. Figure 4.4 shows the dosimeter monitoring locations.

In 2022, the network used vendor-supplied thermoluminescent dosimeters that meet American National Standards Institute (ANSI) N545-1975, *Performance, Testing, and Procedural Specifications for Thermoluminescence Dosimetry (Environmental Applications)*, in 64 locations to measure external gamma radiation; and vendor-supplied optically stimulated luminescent dosimeters designed to meet ANSI N545-1975 and ANSI/Health Physics Society N13.37-2014 (Reaffirmed 2019), *Environmental Dosimetry-Criteria for System Design and Implementation*, in 7 locations to measure external neutron radiation. Vendor-supplied dosimeters were returned to the vendor so that the dosimeters could be processed following their internal processes, protocols, and quality control routines. Vendors then provided



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Map Generation Date and Location -- 1/10/2023 G:\GIS\ARCVIEWS\PROJECTS\ASER\2022 ASER \ASER.aprx Roads -- G:\GIS\iPEGASIS.gdb\roadrow
Streams -- G:\GIS\iPEGASIS.gdb\streams
Limited Area -- G:\GIS\iPEGASIS.gdb\limited_area
DOE Boundary -- G:\GIS\iPEGASIS.gdb\doebnd
Cylinder Yard -- G:\GIS\iPEGASIS.gdb\CylinderYards
TLDs, Neutron Dosimeters -- G:\GIS\iPEGASIS\TLDs

Figure 4.4. Dosimeter locations in the vicinity of the Paducah Site

reports of the results. The network of dosimeter locations, along with analysis of their data, monitored changes in external radiation measures over the year.

4.6.2 External Radiation Estimated Dose

The *2022 Annual External Radiation Monitoring Report Paducah Gaseous Diffusion Plant, Paducah, Kentucky* presents a detailed summary of monitoring results (FRNP 2023d). In 2022, 15 out of 64 monitoring locations showed results statistically above the background level. Fourteen of these fifteen locations were, historically, the areas with the highest measured results throughout the monitoring period. These locations were adjacent to or in close proximity of the uranium hexafluoride cylinder storage yards, which are not regularly accessible to the public. This means the potential external radiation dose calculated from these locations would not represent the actual public external radiation dose. The fifteenth location, TLD-40, was located outside the DOE boundary in the WKWMA, off Dyke Road.

DOE licenses a portion of the Paducah Site to the Kentucky Department of Fish and Wildlife Resources for recreational uses. There are no residences within this area but it is open to the public for recreational uses.

In 2022, the following two monitoring locations were readily accessible to members of the public: TLD-14 and TLD-40.

- TLD-14 is near Harmony Cemetery, north of the plant security fence and south of Ogden Landing Road. The monitoring results at this location indicated external radiation levels were statistically equivalent to the background radiation level.
- TLD-40 is outside the DOE boundary and within the WKWMA, off of Dyke Road. A member of the public would have received an external radiation effective dose of 1.8E+00 mrem at this location.

For 2022, the MEI scenario for a potential external radiation effective dose assumed a member of the public visited accessible areas of the Paducah Site, where potential exposure was highest, for a total of 80 hours per year. Under this scenario, a member of the public could receive 4.2E+00 mrem of external radiation. This is consistent with previous results cited in annual site environmental reports, as shown in Table 4.12.

Table 4.12. Comparison of potential radiological dose to the maximally exposed individual for the direct radiation pathway

Direct radiation pathway	2018	2019	2020	2021	2022
Dose to MEI (mrem) (mrem × 0.01 = mSv)	5.0E+00	3.0E+00	4.1E+00	3.6E+00	4.2E+00
Percent of DOE 100 mrem per year limit	5.0	3.0	4.1	3.6	4.2
Estimated collective population dose (person-rem) (person-rem × 0.01 = person-Sv)	7.5E-01	4.5E-01	6.1E-01	5.4E-01	6.3E-01
Population within 50 miles*	150	150	150	150	150

*Population dose for direct radiation is based on a representative assumption, using only the estimated number of visitors hiking in the WKWMA.

Acronyms:
DOE = US Department of Energy
MEI = maximally exposed individual
mrem = millirem
mSv = millisievert
rem = roentgen equivalent man
Sv = Sievert
WKWMA = West Kentucky Wildlife Management Area

An estimated external radiation effective collective dose for 2022 was calculated by multiplying the MEI dose by the total number of visitors hiking within the WKWMA annually (150 persons). This resulted in an estimated external radiation effective collective dose of 6.3E-01 person-rem. As shown in Table 4.12, this is consistent with previous results cited in annual site environmental reports.

4.7 Monitoring of Plants and Animals and Estimated Dose

Wildlife and farm-raised animal products, including meat, eggs, and milk may become contaminated when animals ingest contaminated water, sediment, or other animals, or through direct contact with contaminated areas. The subsequent ingestion of these products by humans can contribute to public dose. As discussed in Section 4.3, dose calculations estimate a portion of airborne radionuclides is deposited in soil, ingested by animals, and taken up by food crops. As a result, ground surface pathways include consumption of vegetables, milk, and meat. Irrigation and deposition through waterborne radionuclides are incomplete pathways because nearby residences use municipal water for household purposes.

4.7.1 Wildlife Monitoring

Wildlife from the DOE Paducah Site have been sampled in past years for nonradiological and radiological constituents. Deer were monitored annually for many years, and data were used to assess Paducah Site dose. During FY 2011, DOE performed an extensive review of data sets from 20 years of deer monitoring events. As a result of the 2011 review, DOE eliminated deer monitoring in 2012 because of a continued lack of detection results, as well as an overall downward trend in the concentration of contaminants in surface water, sediment, and groundwater found at the Paducah Site due to remediation efforts.

4.7.2 Wildlife Estimated Dose

This wildlife exposure route and associated dose is captured in the food chain models associated with the CAP-88 PC program.

4.7.3 Biota Monitoring

Radionuclides from both natural and man-made sources may be found in environmental media such as water, sediments, and soils. Contaminants may accumulate in animals from eating contaminated feed, drinking contaminated water, and breathing contaminated air, and in fish when they eat contaminated food and live in contaminated waters. Because plant and animal populations residing in or near, or taking food or water from these media may be exposed to a greater extent than humans, DOE prepared technical standard DOE-STD-1153-2019, *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota*. This standard provides methods and guidance for evaluating doses from ionizing radiation to populations of aquatic animals, riparian animals (those that live along banks of streams or rivers), terrestrial plants, and terrestrial animals.

Because both measured concentrations and bioconcentration factors associated with radionuclides of concern at the Paducah Site in animals and fish are low, DOE does not perform routine site-specific pathway assessments, including biota sampling. Biota in the watersheds have been sampled extensively in the past—to the point that further collection of aquatic organisms could negatively affect the aquatic community.

4.7.4 Biota Estimated Dose

DOE Order 458.1 requires that sites use DOE-STD-1153-2019 to evaluate dose to biota. The Paducah Site used the general screening phase described in this standard to determine if radiation doses to aquatic and terrestrial biota were in compliance with the specified dose limits (see Table 2.3.).

The RESRAD-BIOTA computer model (Version 1.8) is a calculation tool provided by DOE for implementing the technical standard. It compares existing radionuclide concentration data from environmental sampling with biota concentration guide (BCG) screening values to estimate maximum doses to biota.

Dose to biota was evaluated for Bayou Creek and Little Bayou Creek using the sampling locations shown in Figures 4.2 and 4.3. Data obtained from water sample location L5 and sediment sample location S1 were used to represent water and sediment, respectively, in Bayou Creek. Data obtained from water sample location L11 and sediment sample location S27 were used to represent water and sediment in Little Bayou Creek, respectively. Outfalls 019 and 020, which flow into Little Bayou Creek, were not considered due to their intermittent flow. Locations L11 and S27 also represent a section of Little Bayou Creek that is downstream of its confluence with the North-South Diversion Ditch. The creek at this point is more substantial and more likely to support aquatic life than upstream areas.

In accordance with the graded approach described in DOE-STD-1153-2019, a general screening phase from water and sediment sampling locations on Bayou Creek and Little Bayou Creek was conducted using the maximum radionuclide concentration data with no background subtraction. If the radionuclide concentration data was below the laboratory detection limit, then the maximum radionuclide concentration below the laboratory detection limit was used. Data were entered in the RESRAD-BIOTA computer model to calculate dose to biota from Paducah Site operations. The value for each radionuclide was divided by its corresponding BCG value to calculate a partial fraction for each radionuclide in each medium (water or sediment). Partial fractions for each medium were added to produce a sum of fractions. Each assessment identified the limiting organism (i.e., the organism that is most sensitive to the potential radiological dose). The sum of the fractions (or ratios) from each assessment was calculated and evaluated against the recommended biota dose rate criteria.

The sum of the fractions for the sediment-limiting organism in Bayou Creek was determined by summing the ratios for sediment in Table 4.13 where the limiting organism is noted as “yes.” In Table 4.13, only the riparian animal has ratios for sediment with the limiting organism noted as “yes.” Adding these numbers together equals 1.47E-03. The sum of the fractions for the water-limiting organism was determined by summing the ratios for water in Table 4.13 where the limiting organism is noted as “yes.” In Table 4.13, the aquatic animal and riparian animal have ratios for water with the limiting organism noted as “yes.” Adding these numbers together equals 1.89E-01. In order to determine the total sum of the fractions for the limiting organisms in Bayou Creek, the sum of the fractions for the sediment-limiting organism is added to the sum of the fractions for the water-limiting organism; the calculation would be 1.47E-03 + 1.89E-01 = 1.90E-01 or 0.190. Because 0.190 is less than 1.0, the dose to aquatic animal, riparian animal (i.e., animal that lives along the creek bank), terrestrial animal, and terrestrial plant does not exceed the recommended dose rate criteria and is in compliance with the DOE biota dose standard. Detailed information for Bayou Creek can be found in Table 4.13.

Table 4.13. Bayou Creek evaluation of dose to aquatic and terrestrial biota[a]

Aquatic animal									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	4.38E+02	0.00E+00	Yes	-1.69E-02	6.80E+05	-2.49E-08	No	-2.49E-08
Cs-137	2.71E+00	1.05E+03	2.58E-03	No	3.49E-02	4.93E+04	7.08E-07	No	2.58E-03
K-40	2.82E+01	2.90E+03	9.72E-03	No	N/A	5.79E+04	0.00E+00	No	9.72E-03
Np-237	3.15E-01	6.85E+01	4.60E-03	Yes	-2.10E-01	7.86E+04	-2.67E-06	No	4.60E-03
Pu-238	-1.22E-02	1.76E+02	-6.93E-05	Yes	-4.30E-02	3.95E+06	-1.09E-08	No	-6.93E-05
Pu-239[e]	1.28E-01	1.87E+02	6.84E-04	Yes	1.19E-01	7.05E+06	1.69E-08	No	6.85E-04
Tc-99	8.95E+00	2.47E+06	3.62E-06	No	3.72E+00	4.59E+05	8.10E-06	No	1.17E-05
Th-230	N/A	2.57E+03	0.00E+00	Yes	1.62E+00	2.74E+06	5.91E-07	No	5.91E-07
Th-234	2.29E+01	2.66E+05	8.61E-05	Yes	N/A	4.32E+04	0.00E+00	No	8.61E-05
U-234	-1.46E-01	2.02E+02	-7.23E-04	Yes	1.35E+00	3.03E+06	4.46E-07	No	-7.22E-04
U-235	4.37E-01	2.18E+02	2.00E-03	Yes	2.21E-01	1.10E+05	2.01E-06	No	2.01E-03
U-238	1.17E+00	2.24E+02	5.22E-03	Yes	2.28E+00	4.29E+04	5.31E-05	No	5.28E-03
Summed			**2.41E-02**				**6.23E-05**		**2.42E-02**

Table 4.13. Bayou Creek evaluation of dose to aquatic and terrestrial biota[a] (continued)

Riparian animal									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	1.46E+03	0.00E+00	No	-1.69E-02	5.15E+03	-3.28E-06	Yes	-3.28E-06
Cs-137	2.71E+00	4.27E+01	6.35E-02	Yes	3.49E-02	3.13E+03	1.12E-05	Yes	6.35E-02
K-40	2.82E+01	2.49E+02	1.13E-01	Yes	N/A	4.42E+03	0.00E+00	Yes	1.13E-01
Np-237	3.15E-01	1.16E+04	2.72E-05	No	-2.10E-01	7.63E+03	-2.75E-05	Yes	-3.68E-07
Pu-238	-1.22E-02	5.51E+02	-2.21E-05	No	-4.30E-02	5.73E+03	-7.50E-06	Yes	-2.96E-05
Pu-239[e]	1.28E-01	6.22E+02	2.06E-04	No	1.19E-01	5.87E+03	2.03E-05	Yes	2.26E-04
Tc-99	8.95E+00	6.67E+05	1.34E-05	Yes	3.72E+00	4.14E+04	8.99E-05	Yes	1.03E-04
Th-230	N/A	1.39E+04	0.00E+00	No	1.62E+00	1.04E+04	1.56E-04	Yes	1.56E-04
Th-234	2.29E+01	3.80E+06	6.03E-06	No	N/A	4.32E+03	0.00E+00	Yes	6.03E-06
U-234	-1.46E-01	6.84E+02	-2.13E-04	No	1.35E+00	5.27E+03	2.56E-04	Yes	4.27E-05
U-235	4.37E-01	7.37E+02	5.93E-04	No	2.21E-01	3.79E+03	5.83E-05	Yes	6.51E-04
U-238	1.17E+00	7.57E+02	1.55E-03	No	2.28E+00	2.49E+03	9.16E-04	Yes	2.46E-03
Summed			**1.79E-01**				**1.47E-03**		**1.80E-01**

Table 4.13. Bayou Creek evaluation of dose to aquatic and terrestrial biota[a] (continued)

Terrestrial animal									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	2.02E+05	0.00E+00	No	-1.69E-02	3.65E+25	-4.63E-28	No	-4.63E-28
Cs-137	2.71E+00	5.99E+05	4.52E-06	No	3.49E-02	3.65E+25	9.56E-28	No	4.52E-06
K-40	2.82E+01	1.93E+06	1.46E-05	No	N/A	3.65E+25	0.00E+00	No	1.46E-05
Np-237	3.15E-01	6.49E+06	4.85E-08	No	-2.10E-01	3.65E+25	-5.75E-27	No	4.85E-08
Pu-238	-1.22E-02	1.89E+05	-6.46E-08	No	-4.30E-02	3.65E+25	-1.18E-27	No	-6.46E-08
Pu-239[e]	1.28E-01	2.01E+05	6.37E-07	No	1.19E-01	3.65E+25	3.26E-27	No	6.37E-07
Tc-99	8.95E+00	1.54E+07	5.81E-07	No	3.72E+00	3.65E+25	1.02E-25	No	5.81E-07
Th-230	N/A	4.52E+05	0.00E+00	No	1.62E+00	3.65E+25	4.44E-26	No	4.44E-26
Th-234	2.29E+01	4.31E+06	5.31E-06	No	N/A	3.65E+25	0.00E+00	No	5.31E-06
U-234	-1.46E-01	4.05E+05	-3.60E-07	No	1.35E+00	3.65E+25	3.70E-26	No	-3.60E-07
U-235	4.37E-01	4.20E+05	1.04E-06	No	2.21E-01	3.65E+25	6.05E-27	No	1.04E-06
U-238	1.17E+00	4.06E+05	2.88E-06	No	2.28E+00	3.65E+25	6.25E-26	No	2.88E-06
Summed			**2.92E-05**				**2.49E-25**		**2.92E-05**

Table 4.13. Bayou Creek evaluation of dose to aquatic and terrestrial biota[a] (continued)

Terrestrial plant									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	6.80E+08	0.00E+00	No	-1.69E-02	3.65E+26	-4.63E-29	No	-4.63E-29
Cs-137	2.71E+00	4.93E+07	5.50E-08	No	3.49E-02	3.65E+26	9.56E-29	No	5.50E-08
K-40	2.82E+01	5.79E+07	4.87E-07	No	N/A	3.65E+26	0.00E+00	No	4.87E-07
Np-237	3.15E-01	7.86E+07	4.01E-09	No	-2.10E-01	3.65E+26	-5.75E-28	No	4.01E-09
Pu-238	-1.22E-02	3.95E+09	-3.09E-12	No	-4.30E-02	3.65E+26	-1.18E-28	No	-3.09E-12
Pu-239[e]	1.28E-01	7.05E+09	1.82E-11	No	1.19E-01	3.65E+26	3.26E-28	No	1.82E-11
Tc-99	8.95E+00	4.59E+08	1.95E-08	No	3.72E+00	3.65E+26	1.02E-26	No	1.95E-08
Th-230	N/A	2.74E+09	0.00E+00	No	1.62E+00	3.65E+26	4.44E-27	No	4.44E-27
Th-234	2.29E+01	4.32E+07	5.30E-07	No	N/A	3.65E+26	0.00E+00	No	5.30E-07
U-234	-1.46E-01	3.03E+09	-4.82E-11	No	1.35E+00	3.65E+26	3.70E-27	No	-4.82E-11
U-235	4.37E-01	1.10E+08	3.97E-09	No	2.21E-01	3.65E+26	6.05E-28	No	3.97E-09
U-238	1.17E+00	4.29E+07	2.73E-08	No	2.28E+00	3.65E+26	6.25E-27	No	2.73E-08
Summed			**1.13E-06**				**2.49E-26**		**1.13E-06**

Notes:
1. Summed total ratio for limiting organism: 1.90E-01.
2. Summed water ratio for limiting organism: 1.89E-01.
3. Summed sediment ratio for limiting organism: 1.47E-03.
4. N/A in this table indicates the radionuclide was not analyzed. Ratios were not included and not summed for radionuclides that were not analyzed.

[a] Bayou Creek was evaluated based on 2022 maximum radionuclide results for L5 and S1.
[b] BCG is the biota concentration guide value.
[c] All results were reported at concentrations less than the laboratory's reporting limit.
[d] Results for thorium-230, uranium-234, and uranium-238 were above the laboratory reporting limit. All other results were reported at concentrations less than the laboratory's reporting limit.
[e] Analytical data in PEGASIS are reported as plutonium-239/240.

Acronyms:
Am = americium
BCG = Biota Concentration Guide
Cs = cesium
K = potassium
N/A = not applicable
Np = neptunium
pCi/g = Picocuries per gram
pCi/L = Picocuries per liter
PEGASIS = PPPO Environmental Geographic Analytical Spatial Information System
Pu = plutonium
Tc = technetium
Th = thorium
U = uranium

The sum of the fractions for the sediment-limiting organism in Little Bayou Creek was determined by summing the ratios for sediment in Table 4.14 where the limiting organism is noted as "yes." In Table 4.14, only the riparian animal has ratios for sediment with the limiting organism noted as "yes." Adding these numbers together equals 5.66E-04. The sum of the fractions for the water-limiting organism was determined by summing the ratios for water in Table 4.14 where the limiting organism is noted as "yes." In Table 4.14, the aquatic animal and riparian animal have ratios for water with the limiting organism noted as "yes." Adding these numbers together equals 2.12E-02. In order to determine the total sum of the fractions for the limiting organisms in Little Bayou Creek, the sum of the fractions for the sediment-limiting organism is added to the sum of the fractions for the water-limiting organism; the calculation would be 5.66E-04 + 2.12E-02 = 2.18E-02 or 0.0218. Because 0.0218 is less than 1.0, the dose to aquatic animal, riparian animal (i.e., animal that lives along the creek bank), terrestrial animal, and terrestrial plant does not exceed the recommended dose rate criteria and is in compliance with the DOE biota dose standard. Detailed information for Little Bayou Creek can be found in Table 4.14.

Table 4.14. Little Bayou Creek evaluation of dose to aquatic and terrestrial biota[a]

Aquatic animal									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	4.38E+02	0.00E+00	Yes	-1.41E-01	6.80E+05	-2.07E-07	No	-2.07E-07
Cs-137	N/A	1.05E+03	0.00E+00	No	-2.12E-02	4.93E+04	-4.30E-07	No	-4.30E-07
Np-237	N/A	6.85E+01	0.00E+00	Yes	-1.49E-01	7.86E+04	-1.90E-06	No	-1.90E-06
Pu-238	N/A	1.76E+02	0.00E+00	Yes	-1.15E-01	3.95E+06	-2.91E-08	No	-2.91E-08
Pu-239[e]	N/A	1.87E+02	0.00E+00	Yes	1.39E-01	7.05E+06	1.97E-08	No	1.97E-08
Tc-99	2.51E+01	2.47E+06	1.02E-05	No	-7.68E-02	4.59E+05	-1.67E-07	No	9.99E-06
Th-230	1.96E+00	2.57E+03	7.63E-04	Yes	1.30E+00	2.74E+06	4.74E-07	No	7.63E-04
U-234	8.22E-01	2.02E+02	4.07E-03	Yes	6.58E-01	3.03E+06	2.17E-07	No	4.07E-03
U-235	4.21E-01	2.18E+02	1.93E-03	Yes	4.01E-02	1.10E+05	3.65E-07	No	1.93E-03
U-238	3.23E+00	2.24E+02	1.44E-02	Yes	8.90E-01	4.29E+04	2.07E-05	No	1.44E-02
Summed			**2.12E-02**				**1.91E-05**		**2.12E-02**

Table 4.14. Little Bayou Creek evaluation of dose to aquatic and terrestrial biota[a] (continued)

Riparian animal									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	1.46E+03	0.00E+00	No	-1.41E-01	5.15E+03	-2.74E-05	Yes	-2.74E-05
Cs-137	N/A	4.27E+01	0.00E+00	Yes	-2.12E-02	3.13E+03	-6.77E-06	Yes	-6.77E-06
Np-237	N/A	1.16E+04	0.00E+00	No	-1.49E-01	7.63E+03	-1.95E-05	Yes	-1.95E-05
Pu-238	N/A	5.51E+02	0.00E+00	No	-1.15E-01	5.73E+03	-2.01E-05	Yes	-2.01E-05
Pu-239[e]	N/A	6.22E+02	0.00E+00	No	1.39E-01	5.87E+03	2.37E-05	Yes	2.37E-05
Tc-99	2.51E+01	6.67E+05	3.76E-05	Yes	-7.68E-02	4.14E+04	-1.86E-06	Yes	3.58E-05
Th-230	1.96E+00	1.39E+04	1.41E-04	No	1.30E+00	1.04E+04	1.25E-04	Yes	2.66E-04
U-234	8.22E-01	6.84E+02	1.20E-03	No	6.58E-01	5.27E+03	1.25E-04	Yes	1.33E-03
U-235	4.21E-01	7.37E+02	5.71E-04	No	4.01E-02	3.79E+03	1.06E-05	Yes	5.82E-04
U-238	3.23E+00	7.57E+02	4.27E-03	No	8.90E-01	2.49E+03	3.57E-04	Yes	4.62E-03
Summed			**6.22E-03**				**5.66E-04**		**6.78E-03**

Table 4.14. Little Bayou Creek evaluation of dose to aquatic and terrestrial biota[a] (continued)

Terrestrial animal									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	2.02E+05	0.00E+00	No	-1.41E-01	3.65E+25	-3.86E-27	No	-3.86E-27
Cs-137	N/A	5.99E+05	0.00E+00	No	-2.12E-02	3.65E+25	-5.81E-28	No	-5.81E-28
Np-237	N/A	6.49E+06	0.00E+00	No	-1.49E-01	3.65E+25	-4.08E-27	No	-4.08E-27
Pu-238	N/A	1.89E+05	0.00E+00	No	-1.15E-01	3.65E+25	-3.15E-27	No	-3.15E-27
Pu-239[e]	N/A	2.01E+05	0.00E+00	No	1.39E-01	3.65E+25	3.81E-27	No	3.81E-27
Tc-99	2.51E+01	1.54E+07	1.63E-06	No	-7.68E-02	3.65E+25	-2.10E-27	No	1.63E-06
Th-230	1.96E+00	4.52E+05	4.34E-06	No	1.30E+00	3.65E+25	3.56E-26	No	4.34E-06
U-234	8.22E-01	4.05E+05	2.03E-06	No	6.58E-01	3.65E+25	1.80E-26	No	2.03E-06
U-235	4.21E-01	4.20E+05	1.00E-06	No	4.01E-02	3.65E+25	1.10E-27	No	1.00E-06
U-238	3.23E+00	4.06E+05	7.96E-06	No	8.90E-01	3.65E+25	2.44E-26	No	7.96E-06
Summed			**1.70E-05**				**6.92E-26**		**1.70E-05**

Table 4.14. Little Bayou Creek evaluation of dose to aquatic and terrestrial biota[a] (continued)

Terrestrial plant									
	Water				Sediment				Total
Radionuclide	Concentration (pCi/L)[c]	BCG (pCi/L)[b]	Ratio	Limiting organism	Concentration (pCi/g)[d]	BCG (pCi/g)[b]	Ratio	Limiting organism	Ratio
Am-241	N/A	6.80E+08	0.00E+00	No	-1.41E-01	3.65E+26	-3.86E-28	No	-3.86E-28
Cs-137	N/A	4.93E+07	0.00E+00	No	-2.12E-02	3.65E+26	-5.81E-29	No	-5.81E-29
Np-237	N/A	7.86E+07	0.00E+00	No	-1.49E-01	3.65E+26	-4.08E-28	No	-4.08E-28
Pu-238	N/A	3.95E+09	0.00E+00	No	-1.15E-01	3.65E+26	-3.15E-28	No	-3.15E-28
Pu-239[e]	N/A	7.05E+09	0.00E+00	No	1.39E-01	3.65E+26	3.81E-28	No	3.81E-28
Tc-99	2.51E+01	4.59E+08	5.47E-08	No	-7.68E-02	3.65E+26	-2.10E-28	No	5.47E-08
Th-230	1.96E+00	2.74E+09	7.15E-10	No	1.30E+00	3.65E+26	3.56E-27	No	7.15E-10
U-234	8.22E-01	3.03E+09	2.71E-10	No	6.58E-01	3.65E+26	1.80E-27	No	2.71E-10
U-235	4.21E-01	1.10E+08	3.83E-09	No	4.01E-02	3.65E+26	1.10E-28	No	3.83E-09
U-238	3.23E+00	4.29E+07	7.53E-08	No	8.90E-01	3.65E+26	2.44E-27	No	7.53E-08
Summed			**1.35E-07**				**6.92E-27**		**1.35E-07**

Notes:
1. Summed total ratio for limiting organism: 2.18E-02.
2. Summed water ratio for limiting organism: 2.12E-02.
3. Summed sediment ratio for limiting organism: 5.66E-04.
4. N/A in this table indicates that the radionuclide was not analyzed. Ratios were not included and not summed for radionuclides that were not analyzed.

[a] Little Bayou Creek was evaluated based on 2022 maximum radionuclide results for L11 and S27.
[b] BCG is the biota concentration guide value.
[c] Results for uranium-238 were above the laboratory reporting limit. All other results were reported at concentrations less than the laboratory's reporting limit.
[d] Results for thorium-230, uranium-234, and uranium-238 were above the laboratory reporting limit. All other results were reported at concentrations less than the laboratory's reporting limit.
[e] Analytical data in PEGASIS are reported as plutonium-239/240.

Acronyms:
Am = americium
BCG = Biota Concentration Guide
Cs = cesium
K = potassium
N/A = not applicable
Np = neptunium
pCi/g = Picocuries per gram
pCi/L = Picocuries per liter
PEGASIS = PPPO Environmental Geographic Analytical Spatial Information System
Pu = plutonium
Tc = technetium
Th = thorium
U = uranium

4.8 Unplanned Radiological Releases

There were no unplanned radiological releases at the Paducah Site in 2022.

4.9 Release of Property Containing Residual Radioactive Material

Real property is land and anything permanently attached to it, such as fences and buildings, and includes things attached to buildings such as lighting and plumbing fixtures. The Paducah Site has begun efforts to transfer real property, but clearance of real property has not yet taken place. As a result, this section addresses clearance of personal property (defined as any property other than real property) containing residual radioactive material, which is any radioactive material that remains in or on soil, air, water, equipment, or structures at a site after DOE activities have stopped.

DOE contractors use the processes, guidelines, and limits found in DOE Order 458.1 and associated guidance for the clearance of property with residual radioactive material. Release criteria for surface contamination limits, as specified in DOE Order 458.1, are used for the clearance of objects with the potential for surface contamination, while specific authorized limits have been derived to control whether items with potential volumetric radioactivity are released. Property that may contain residual radioactive material will not be cleared from the Paducah Site unless the property is demonstrated to be within acceptable limits. Property clearance requirements are governed by procedures established by each DOE contractor. Authorized limits for the Paducah Site are presented in Section 2.2.2.1. The type and quantity of releases for Paducah Site contractors are discussed below.

In 2022, Paducah Site contractors authorized (with concurrence from DOE) 1,498 releases of personal property that were surveyed for contamination. Several of these releases supported reuse and recycling efforts. These releases were in support of remediation contractor, infrastructure operations, and DUF_6 Conversion Facility operations and included heavy equipment, vehicles, mowers, miscellaneous equipment and parts, furniture, electronics, fire extinguishers containers, tanks, activated carbon, batteries, company-issued laundry, industrial hygiene samples, boxes of records, waste items, and items classified as excess. Approximately 1,040,080 pounds of Freon (R-114) were shipped for treatment in 2022 under DOE-approved Authorized Limits. The measurements and historical data associated with the materials supported the unconditional radiological release of the materials and equipment and indicated that levels were below the release criteria for surface contamination limits specified in 10 *CFR* Part 835 Appendix D, DOE Order 458.1, or other DOE-approved limits. If survey measurements exceeded 80 percent of the specified release limit, the measurements were independently verified.

The DUF_6 Conversion facility converts the inventory of DUF_6 to triuranium octoxide, a more stable form of uranium, and hydrofluoric acid. The hydrofluoric acid is sold for commercial use and shipped off-site. Each shipment must meet the authorized limit of less than 3 pCi/mL of total uranium activity. During 2022, approximately 502,665 gallons of hydrofluoric acid were shipped off site, and the total uranium activity of each shipment was below the detection limit of 1.06 pCi/mL. The measurements and historical data associated with the materials supported the unconditional radiological release of the materials and equipment and indicated that levels were below the release criteria for surface contamination limits specified in 10 *CFR* Part 835 Appendix D, DOE Order 458.1, or other DOE-approved limits. The DUF_6 Conversion Facility did not release any items above the minimum detectable activity, which is less than 50 percent of the release level, so no independent verifications were needed or performed.

5. Environmental Nonradiological Programs

The Paducah Site's environmental monitoring activities cover both radiological and nonradiological contaminants. Chapter 4 discusses radiological monitoring, and this chapter describes the results of the Paducah Site's monitoring of potential nonradiological contaminants in air, surface water, sediment, and biota.

5.1 Air Monitoring

No active emission points at the Paducah Site require nonradiological air monitoring.

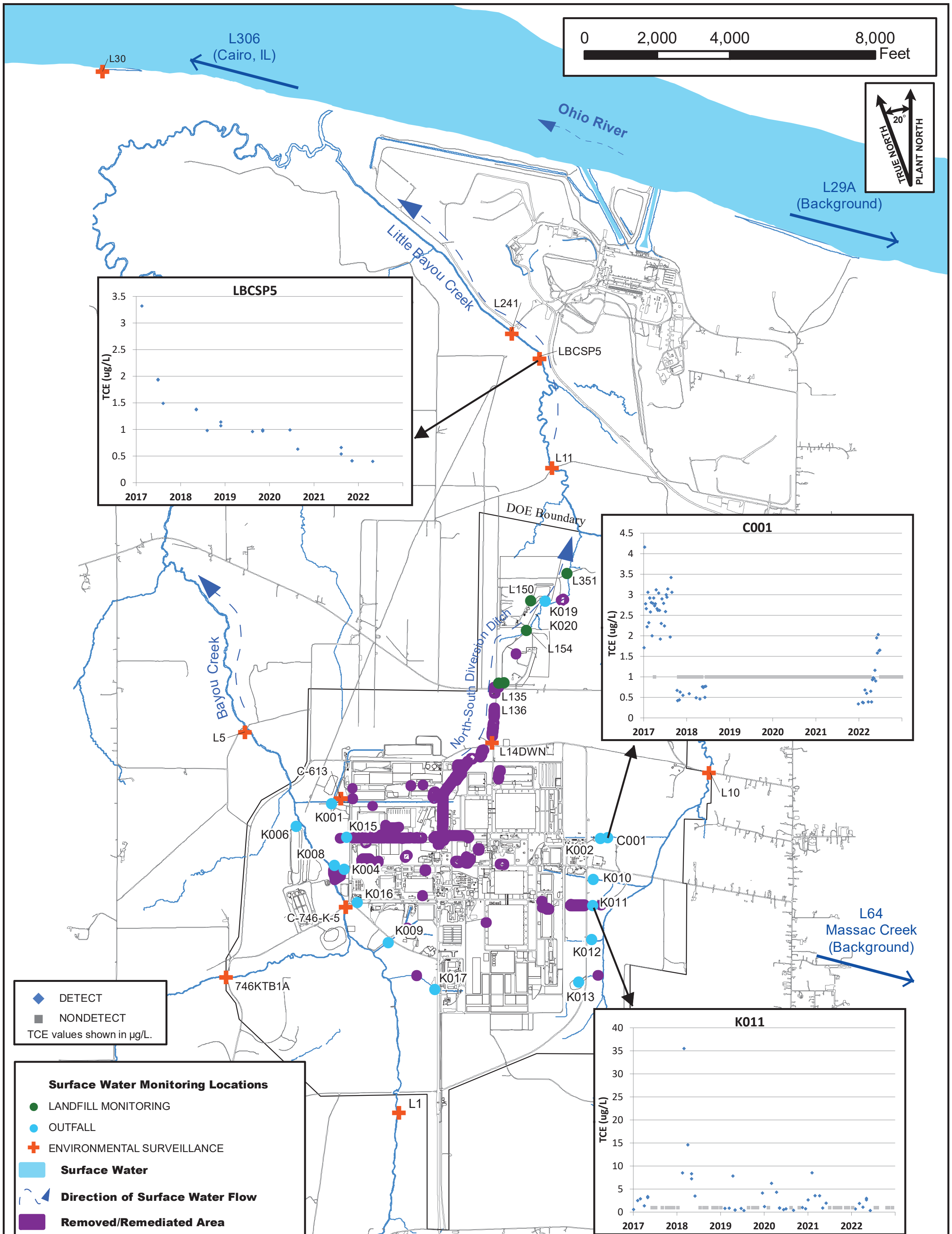
5.2 Surface Water Monitoring

The Paducah Site meets the Clean Water Act regulations through its KPDES permit for effluent discharges to Bayou Creek and Little Bayou Creek. The KDOW issued KPDES Permit No. KY0004049 to DOE and FRNP for Outfalls 001, 002, 004, 006, 008, 009, 010, 011, 012, 013, 015, 016, 017,[4] 019, and 020. In addition to the KPDES permit, a CERCLA outfall (C001) related to the Northeast Plume pump-and-treat operation discharges to surface water. Surface water from the C-613 Sedimentation Basin, a storm water control facility that collects storm water runoff from scrapyards in the northwestern portion of the Paducah Site, is measured for pH and total suspended solids (per the Northwest Storm Water Control Facility Operations and Maintenance Plan) prior to its discharge to Outfall 001 (DOE 2009). Samples are collected quarterly to confirm the pH and total suspended solids measurements. In addition, KDWM specifies in landfill permit SW07300014, SW07300015, and SW07300045 that surface runoff will be analyzed to ensure landfill constituents are not discharging into nearby receiving streams. Storm water discharge from the KDWM-permitted solid waste landfill is sampled under the KPDES permit.

Surface water monitoring locations at the Paducah Site and the monitoring program under which they are sampled routinely are shown in Figure 5.1 and Table 5.1, respectively. Figure 5.1 shows trends for trichloroethene results in selected surface water monitoring locations over the last five years. Table 5.1 also shows the reporting for each of these programs. Chapter 2 describes permit exceedances for 2022. Monitoring results are available through the PEGASIS website, which can be accessed here, and are summarized in Table 5.2.

This report does not include surface water sampling for project-specific decommissioning and environmental remediation projects or nonroutine sampling events.

[4] Permit Number KY0004049 also includes MCS as a permittee for Outfall 017.



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Landfill Monitoring Layer-- G:\GIS\iPEGASIS.gdb\Locations
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DOE Boundary Layer-- G:\GIS\iPEGASIS.gdb\doebnd

Figure 5.1. Surface water and seep monitoring locations with trichloroethene trends

Table 5.1. Summary of surface water monitoring at the Paducah Site

Program and reporting location	Locations (see Figure 5.1)
Effluent watershed monitoring program	
C-746-S and C-746-T Landfills surface water quarterly compliance monitoring reports: First Quarter 2022 (January–March) Second Quarter 2022 (April–June) Third Quarter 2022 (July–September)[b] Fourth Quarter 2022 (October–December)	L135, L136, L154[a]
C-746-U Landfill surface water quarterly compliance monitoring reports: First Quarter 2022 (January–March) Second Quarter 2022 (April–June) Third Quarter 2022 (July–September)[b] Fourth Quarter 2022 (October–December)	L150, L154[a], L351
KPDES discharge monitoring reports	K001, K002, K004, K006, K008, K009, K010, K011, K012, K013, K015, K016, K017, K019, K020
C-613 Northwest Storm Water Control Facility reported to KDWM via electronic mail	C-613
Environmental surveillance watershed monitoring program	
Surface water	746KTB1A, C746K-5, L1[c], L10[c], L11[c], L241[c], L29A[c], L30[c], L306[c], L5[c], L14DWN[c]
Seep	LBCSP5
Northeast Plume Effluent semiannual FFA progress reports: Second Half of FY 2022 (Data reported January–June 2022) First Half of FY 2023 (Data reported July–December 2022)	C001

[a] Location is listed for C-746-S, C-746-T, and C-746-U Landfills.
[b] No surface water samples were collected for L135, L136, L150, L154, and L351 during third quarter 2022 due to insufficient flow.
[c] Locations are sampled to support the Environmental Radiation Protection Program.

Acronyms:
FFA = Federal Facility Agreement
FY = fiscal year
KDWM = Kentucky Division of Waste Management
KPDES = Kentucky Pollutant Discharge Elimination System

Table 5.2. Ranges of detected analytes in 2022 surface water samples

Analyte	Range
Anions	
Chloride (µg/L)	1,010-37,300
Sulfate (µg/L)	2,890-136,000
Wet Chemistry Parameters	
Biochemical Oxygen Demand (µg/L)	3,740-32,300
Chemical Oxygen Demand (µg/L)	26,400-108,000
Dissolved Solids (µg/L)	72,900-456,000
Hardness—Total as $CaCO_3$ (µg/L)	27,900-240,000
Nonsettleable solids (µg/L)	400-43,600
Settleable solids (µg/L)	100-310,000

Table 5.2. Ranges of detected analytes in 2022 surface water samples (continued)

Analyte	Range
Suspended Solids (µg/L)	100–315,000
Total Organic Carbon (µg/L)	5,980-29,300
Total Solids (µg/L)	129,000-584,000
Volatile Organic Compounds	
Trichloroethene (µg/L)	0.35–2.98
Polychlorinated biphenyls	
PCB-1242 (µg/L)	0.0493-0.0493
PCB-1254 (µg/L)	0.0459-0.0984
PCB-1260 (µg/L)	0.0496-0.190
Total polychlorinated biphenyls (µg/L)	0.0493-0.281
Other Organics	
Oil and Grease (µg/L)	103-8,170
Metals	
Aluminum (µg/L)	45.9-1,510
Barium (µg/L)	49.5-71.7
Calcium (µg/L)	10,600-29,500
Copper (µg/L)	2.1-4.7
Iron (µg/L)	54.3-14,100
Lead (µg/L)	1.28-1.44
Magnesium (µg/L)	2,090-6,000
Manganese (µg/L)	47.2-138
Mercury (µg/L)	0.0595-0.0625
Nickel (µg/L)	0.622-2.78
Phosphorous (µg/L)	54.3-965
Potassium (µg/L)	2,590-8,770
Sodium (µg/L)	585-58,500
Uranium (µg/L)	0.068-222
Zinc (µg/L)	8.03-117

5.3 Sediment Monitoring

Sediment monitoring locations are shown in Figure 4.3. Additional monitoring results are available through the PEGASIS website, which can be accessed here. Sediment sampling is only conducted for radionuclides and polychlorinated biphenyls. Total polychlorinated biphenyls were detected in sediment during 2022 at levels from 2.28 µg/kg to 388 µg/kg. The potential risks and hazards from exposure to polychlorinated biphenyls at these concentrations are within CERCLA's acceptable risk range. US EPA's generally acceptable risk range is 10^{-4} to 10^{-6} for carcinogenic risk and below the hazard index of 1 for noncarcinogens (US EPA 1999). According to the Risk Methods Document, the no action level[5] for total polychlorinated biphenyls is 179 µg/kg, and the action level[6] is 17,900 µg/kg for the recreational user (DOE 2022b). The recreational user is used for comparison because it is the most reasonably anticipated scenario.

5.4 Biological Monitoring

Biological monitoring, which involves fish or benthic macroinvertebrate sampling, was not required in 2022 under the specifications listed in the KPDES permits. Aquatic or biological monitoring of

[5] The no action level is the concentration that represents the lesser of an excess lifetime cancer risk of 10^{-6} and a hazard index of 0.1.

[6] The action level is the concentration that represents the lesser of an excess lifetime cancer risk of 10^{-4} and a hazard index of 3.

Bayou Creek and Little Bayou Creek began in 1987. Current guidelines for monitoring are set forth in the most recent Watershed Monitoring Plan, which follows conditions in the KPDES permit (KY0004049) and best management practices (LATA Kentucky 2011). The permit initially required sampling of fish and benthic macroinvertebrates in the receiving creeks, as well as chronic and acute toxicity sampling at the KPDES outfalls. After years of collecting fish and benthic macroinvertebrate samples, a permit renewal issued by KDOW in 2009 eliminated the requirements for fish and benthic macroinvertebrate sampling because continued sampling may have a detrimental effect on the stream's ecology. The chronic and acute toxicity sampling remained a KPDES permit condition. DOE continued the benthic macroinvertebrate sampling efforts through 2010 to provide data for future ecological assessments but eliminated the sampling in 2011. Chronic and acute toxicity sampling, which are still required by the KPDES permit, are the two basic types of whole effluent toxicity testing. They describe the aggregate toxic effects of the whole effluent wastewater discharge as measured by an organism's response upon exposure to the sample. These tests replicate the total effect of environmental exposure of aquatic life to toxic pollutants in an effluent without requiring the identification of the specific pollutants.

Signs are posted along Bayou and Little Bayou Creeks to warn members of the public about the possible risks posed by recreational contact with these waters, stream sediments, and fish caught in the creeks.

5.5 Fire Protection Management and Planning

Fire protection management and planning at the Paducah Site follows the *Paducah Site Wildland Fire Management Plan Paducah Gaseous Diffusion Plant Paducah, Kentucky* (FRNP 2022b). The program includes fire prevention and hazard mitigation efforts including, training, work restrictions, combustible vegetation controls, safe facility location, and fire protection design considerations. If a wildland fire was to occur, a multiagency response would be activated to bring all available firefighting and related emergency response functions to bear and combat the fire promptly, minimizing the risk of fire exposure to the public, Paducah Site personnel, and critical facilities and programs.

FRNP is responsible for wildland fire management of all DOE owned property, except for the 1,973 acres licensed to WKWMA. West McCracken Fire Department is responsible for the area licensed to WKWMA.

5.6 Recreational Hunting and Fishing

Permitted recreational activities in WKWMA include turkey hunting, horseback riding, hiking, dog training and trials, hunting with a gun for small game, bow hunting for deer, mountain biking, and nature hiking. Additional information regarding hunting seasons and hunting and fishing limits is available from the Kentucky Department of Fish and Wildlife Resources website, which can be accessed here.

6. Groundwater Protection Programs

Groundwater monitoring at the Paducah Site is required by a combination of state and federal regulations, legal agreements with KDEP, and DOE Orders. More than 300 monitoring wells and residential wells are used to track the flow of groundwater and to identify and measure groundwater contaminants.

The results of the Paducah Site Investigation (Phase 1) in 1991 determined the primary off-site contaminants in the Regional Gravel Aquifer, which is the primary aquifer for local groundwater users, were trichloroethene and technetium-99 (CH2M HILL 1991). Trichloroethene was used until 1993 as an industrial degreasing solvent, and technetium-99 is a fission by-product contained in nuclear power reactor returns that were brought onsite through 1976 for the re-enrichment of uranium-235 (DOE 2001). Known or potential sources of trichloroethene and technetium-99 include former test areas, spills, leaks, buried waste, and leachate from contaminated scrap metal previously stored on site.

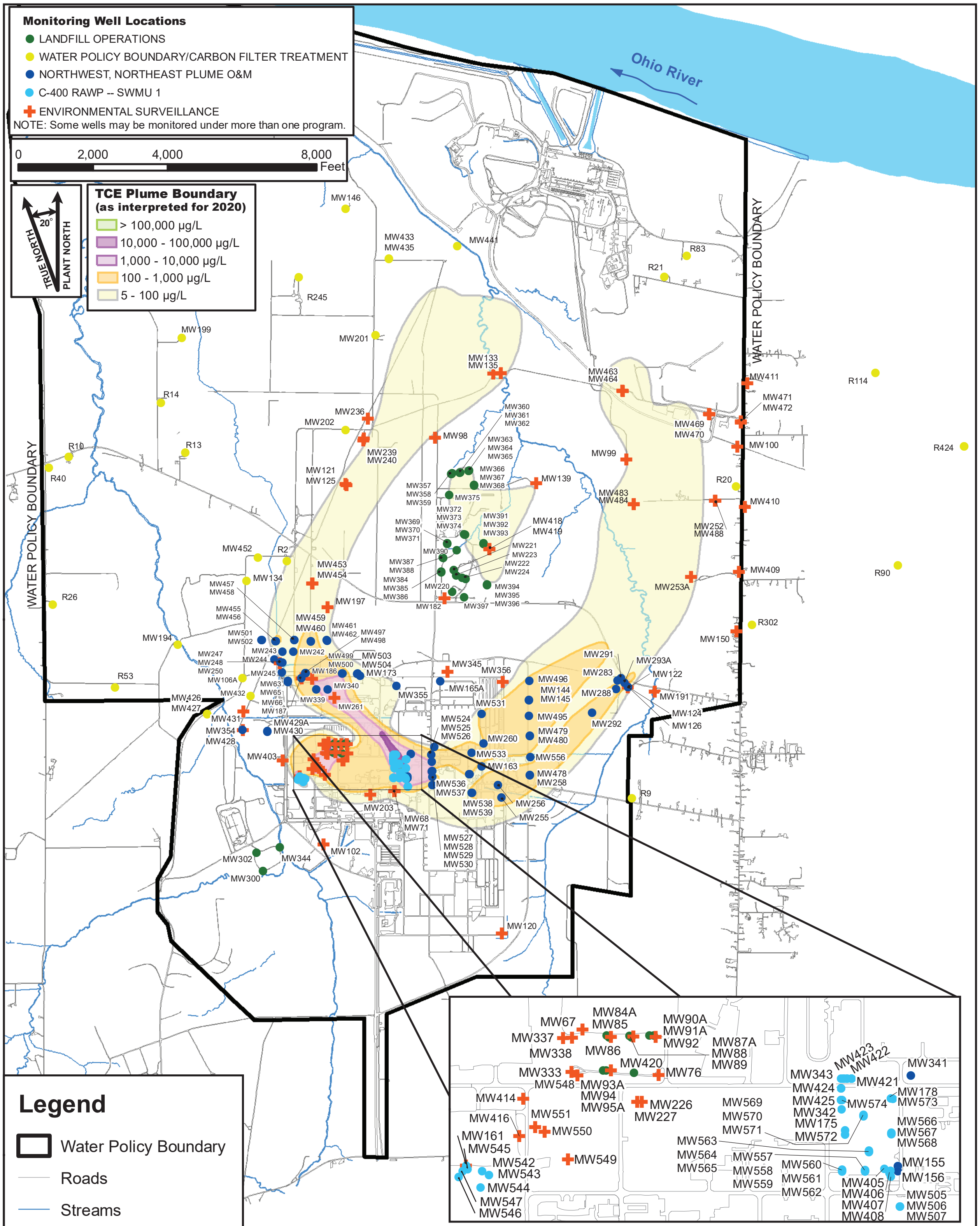
Investigations of the on-site source areas of trichloroethene at the Paducah Site are ongoing. The main source and highest concentration of trichloroethene contamination in the groundwater is near the C-400 Cleaning Building. Trichloroethene has a low solubility and a higher density than water and is included in a chemical group referred to as dense nonaqueous-phase liquids. Because of these characteristics, trichloroethene typically sinks through the subsurface and may form pools in less permeable layers of the subsurface, as well as in the base of an aquifer. The pooling makes treatment difficult because these pools constitute a continuous source of dissolved-phase contamination in the form of plumes deep within the aquifer.

Groundwater monitoring detects the nature and extent of contamination at the Paducah Site, including the types and concentrations of contaminants, and determines the movement of groundwater near the plant. Data obtained from groundwater monitoring supports the decision-making process for the ultimate disposition of the contaminants. Figure 6.1 shows monitoring wells sampled in 2022 and the trichloroethene plume associated with the Paducah Site (FRNP 2021a). See Section 6.3 for additional information on plumes associated with the Paducah Site. Visit the PEGASIS website, which can be accessed here, to view historical data for monitoring wells and groundwater locations at the Paducah Site.

6.1 Geology and Uses of Groundwater

The local groundwater flow systems at the Paducah Site (from shallowest to deepest) are the Terrace Gravel flow system, the Upper Continental Recharge System, the Regional Gravel Aquifer, and the McNairy flow system. Additional water-bearing zones monitored at the Paducah Site are the Eocene Sands and the Rubble Zone, which is the weathered upper portion of the Mississippian bedrock. Figure 6.2 illustrates these components.

Groundwater flow originates south of the Paducah Site within the Eocene Sands and the Terrace Gravel. Groundwater within the Terrace Gravel discharges to local streams and recharges the Regional Gravel Aquifer. The predominant groundwater flow through the Upper Continental Recharge System is downward, also recharging the Regional Gravel Aquifer. From the Site, groundwater generally flows northward in the Regional Gravel Aquifer toward the Ohio River, which is the local base level for the system. Groundwater in the McNairy system beneath the Paducah Site also flows northward to discharge into the Ohio River.



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Northwest, Northeast Plume O&M Layer-- G:\GIS\iPEGASIS.gdb\MWs_2022.shp
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Figure 6.1. Monitoring wells sampled in 2022

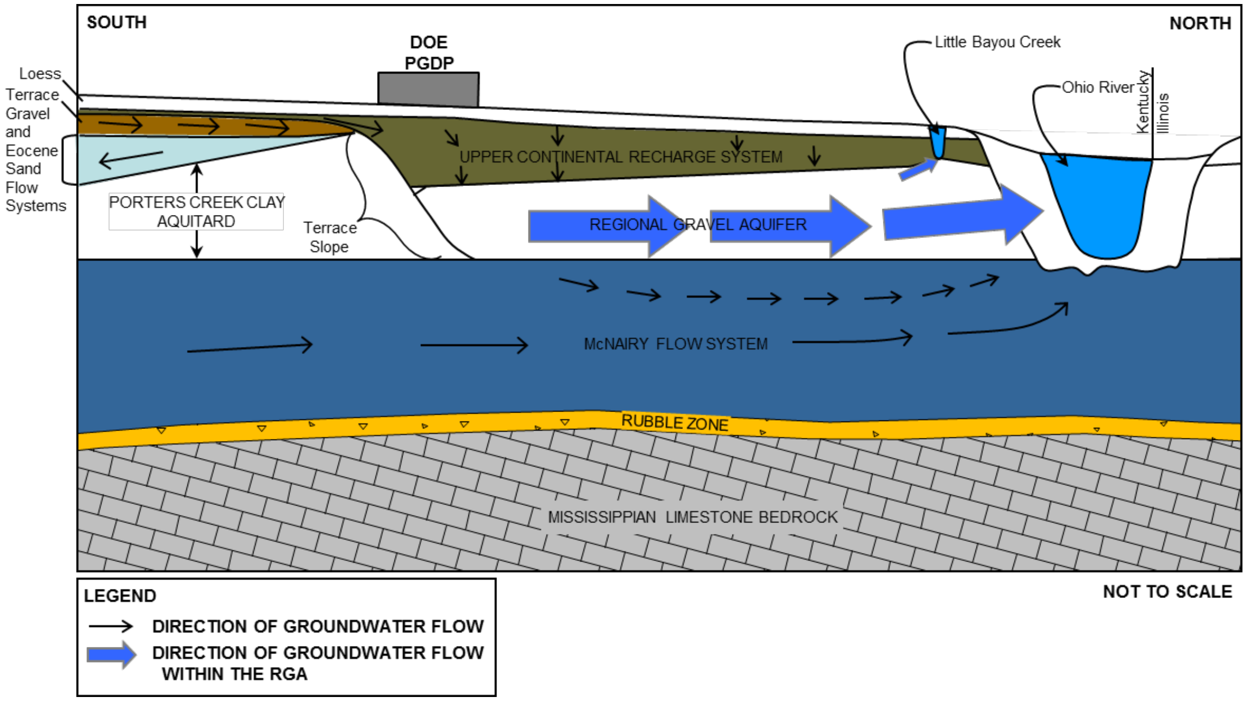


Figure 6.2. Paducah Site groundwater flow system and water-bearing zones

Additional information on the geology and hydrogeology of the Paducah Site can be found in the *Report of the Paducah Gaseous Diffusion Plant Groundwater Investigation Phase III* (MMES 1992). A revision of the sitewide groundwater flow model was completed in 2016 (DOE 2017).

The WKWMA and some lightly populated farmlands are in the immediate vicinity of the Paducah Site. Homes near the Paducah Site are sparsely located along rural roads. Two communities, Grahamville and Heath, lie within 2 miles east of the plant.

Historically, groundwater was the primary source of drinking water for residents and businesses near the plant area. In areas where the groundwater either is known to be contaminated or has the potential to become contaminated, DOE has provided water hookups to public water since 1994 and pays water bills for affected residences and businesses. An educational mailer was developed in 2016 and has been updated, as necessary, and mailed to residents and businesses annually since then in an effort to ensure that the public is aware of the groundwater contamination.

6.2 Groundwater Monitoring Programs

Monitoring wells are used extensively at the Paducah Site to assess the effect of plant operations on groundwater quality. The primary objectives of the Site's groundwater monitoring program are obtaining data to determine baseline and current conditions of groundwater quality and quantity; demonstrating compliance with and implementation of all applicable regulations and DOE orders; providing data to allow early detection of groundwater pollution or contamination; identifying existing and potential groundwater contamination sources and maintaining surveillance of these sources; and providing data for making decisions about waste disposal on land-based units and the management and protections of groundwater resources. The groundwater monitoring program consists of routine compliance and facility monitoring designed to ensure protection of public health and the environment.

Two documents outline the sitewide approach to groundwater monitoring: the Groundwater Protection Plan (FRNP 2021b) and the Paducah Site Environmental Monitoring Plan (FRNP 2022a). A total of 254 monitoring wells and residential wells were sampled in accordance with DOE orders and federal, state, and local requirements during 2022. Table 6.1 lists the monitoring programs that include well sampling. This table also shows the number of wells sampled in each flow system, each program (note that some wells are sampled under more than one program), and the reporting location for each program. Monitoring results are available through the PEGASIS website, which can be accessed here.

Table 6.1. Summary of groundwater monitoring at the Paducah Site for 2022

Program and reporting location	Number of wells[a]					
	Terrace Gravel/ Eocene Sands	Upper Continental Recharge System	Regional Gravel Aquifer	McNairy Flow System	Rubble Zone	Total
Groundwater monitoring program for landfill operations						
C-746-S and C-746-T Landfills wells quarterly compliance monitoring reports: First quarter 2022 (January–March) Second quarter 2022 (April–June) Third quarter 2022 (July–September) Fourth quarter 2022 (October–December)	0	4	14	0	0	18[b]
C-746-U Landfill wells quarterly compliance monitoring reports: First quarter 2022 (January–March) Second quarter 2022 (April–June) Third quarter 2022 (July–September) Fourth quarter 2022 (October–December)	0	7	12	0	0	19
C-404 Landfill wells (required by permit) semiannual C-404 groundwater monitoring reports: C-404 Hazardous Waste Landfill May 2022 Semiannual Groundwater Report (October 2021–March 2022) C-404 Hazardous Waste Landfill November 2022 Semiannual Groundwater Report (April 2022–September 2022)	0	4	5	0	0	9
C-404 Landfill wells (not committed)	0	0	17	0	0	17
C-746-K Landfill wells semiannual FFA progress reports: Second half of FY 2022 (data reported January–June 2022) First half of FY 2023 (data reported July–December 2022)	3	0	0	0	0	3
Northeast Plume operations and maintenance program semiannual FFA progress reports: (see links above)						
Quarterly optimization wells	0	0	36	0	0	36
Northwest Plume operations and maintenance program semiannual FFA progress reports: (see links above)						
Semiannual wells	0	0	28	0	0	28
Quarterly wells	0	0	5	0	0	5

Table 6.1. Summary of groundwater monitoring at the Paducah Site for 2022 (continued)

Program and reporting location	Number of Wells[a]					
	Terrace Gravel/ Eocene Sands	Upper Continental Recharge System	Regional Gravel Aquifer	McNairy Flow System	Rubble Zone	Total
C-400 Cleaning Building interim remedial action monitoring wells semiannual FFA progress reports: (see links above)						
Semiannual wells	0	0	8	0	0	8
Quarterly wells	0	0	29	0	0	29
Former Oil Landfarm Solid Waste Management Unit (SWMU) 1 monitoring wells Annual Site Environmental Report						
Semiannual wells	0	0	7	0	0	7
Water Policy Boundary monitoring program Annual Site Environmental Report						
Northwestern wells (quarterly)	0	0	22	0	0	22
Northeastern wells (annual)	0	0	7	0	0	7
Carbon filter treatment system Annual Site Environmental Report	0	0	1	0	0	1
Environmental surveillance groundwater monitoring program Annual Site Environmental Report						
Annual wells	0	3	28	0	1	32
Biennial wells	0	0	0	0	0	0
Semiannual wells	0	0	6	8	0	14
Quarterly wells	0	0	3	0	0	3
Geochemical wells	0	0	0	0	0	0

[a] Some wells are sampled under more than one program.
[b] Regional Gravel Aquifer wells MW369, MW370, MW372, and MW373 are sampled with the C-746-U Landfill sampling events; these four wells are not counted in the sampling event for the C-746-S&T Landfills but are reported in the Compliance Monitoring Reports for the C-746-U and C-746-S&T Landfills.

Acronyms:
FFA = Federal Facility Agreement
FY = fiscal year
MW = monitoring well
SWMU = solid waste management unit

6.3 Groundwater Monitoring Results

Groundwater monitoring at the Paducah Site supports programs for general environmental surveillance, current and inactive landfills, groundwater plume pump-and-treat operations, the C-400 Cleaning Building Interim Remedial Action monitoring, and area residential wells. The Environmental Surveillance Groundwater Monitoring Program is reviewed each year and modified, as appropriate, to continue to delineate the boundaries of the contaminant plumes over time. Groundwater monitoring results from all sampling efforts conducted by the Paducah Site are compiled in the Paducah Oak Ridge Environmental Information System (OREIS) database. Analytical results of interest may be requested by e-mailing PegasisAdmins@pad.pppo.gov and data can be viewed on the PEGASIS website, which can be accessed here. Table 6.2 summarizes detected analytes from monitoring well groundwater samples (typically station names that begin with MW) in 2022. Groundwater samples also were collected for PFAS in MW315 and MW330 in 2019. DOE committed to provide these results to US EPA and KDEP in the CERCLA Five-Year Review (DOE 2019b), which are presented in Section 6.4.

Table 6.2. Ranges of detected analytes in 2022 monitoring well groundwater samples

Analyte	Range
Volatile Organics (µg/L)	
1,1,2-Trichloroethane	0.43-1.21
1,1-Dichloroethane	0.34-10.9
1,1-Dichloroethene	0.36-140
1,2-Dichloroethane	0.5-1.39
2-Hexanone	2.93-2.93
Acetone	1.81-2.73
Benzene	1.44-3.08
Carbon tetrachloride	0.35-5.75
Chloroform	0.34-19.6
cis-1,2-Dichloroethene	0.34-1,620
Methylene chloride	0.51-2.67
Tetrachloroethene	0.34-3.83
Toluene	0.37-1.53
trans-1,2-Dichloroethene	0.36-2.35
Trichloroethene	0.34-47,700
Vinyl chloride	0.36-223
Semivolatile Organics (µg/L)	
Benz(a)anthracene	0.33-0.33
Polychlorinated biphenyls (µg/L)	
PCB-1242	0.0512-0.261
PCB-1254	0.0403-0.0834
PCB-1260	0.0426-0.0426
Polychlorinated biphenyls	0.0512-0.387
Radionuclides (pCi/L)	
Alpha activity	11.2-11.2
Beta activity	4.18-1,340
Radium-226	1.17-1.51
Radium-228	3.07-6.9
Technetium-99	8.66-25,400
Tritium	293-293
Uranium-234	0.883-0.833
Uranium-238	0.453-1.32
Wet Chemistry (µg/L)	
Alkalinity	71,600-182,000
Chemical Oxygen Demand (COD)	9,070-260,000
Cyanide	1.76-4.12
Dissolved Solids	120,000-531,000
Iodide	327-740
Silica	23,400-23,400
Total Organic Carbon (TOC)	338-11,600
Total Organic Halides (TOX)	3.48-304

Analyte	Range
Anions (µg/L)	
Bromide	67.3-953
Chloride	589-242,000
Fluoride	97.5-1,030
Nitrate as Nitrogen	53.7-9,340
Sulfate	3,940-677,000
Metals (µg/L)	
Aluminum	20-24,300
Arsenic	2.01-36
Barium	17.1-416
Beryllium	0.39-0.911
Boron	5.53-2,930
Calcium	5,430-190,000
Chromium	3.08-892
Cobalt	0.318-37.9
Copper	0.312-24.5
Iron	33.6-44,300
Lead	0.526-16.9
Magnesium	2,970-40,100
Manganese	1.01-6,390
Mercury	0.069-0.156
Molybdenum	0.203-5.8
Nickel	0.621-94.5
Potassium	80-17,600
Selenium	1.69-6.08
Silver	1.89-1.89
Sodium	9,410-136,000
Tantalum	1.01-2.22
Uranium	0.068-5.47
Uranium-235	0.00649-0.0259
Uranium-238	0.163-3.25
Vanadium	3.34-36.5
Zinc	3.36-43.1
Arsenic, Dissolved	2.08-36.1
Barium, Dissolved	16.5-397
Cadmium, Dissolved	0.353-0.353
Chromium, Dissolved	3.06-43.1
Mercury, Dissolved	0.16-0.16
Selenium, Dissolved	1.7-12.1
Uranium, Dissolved	0.08-4.47

The Paducah Site groundwater plume maps are used in planning to optimize the Site groundwater cleanup. These maps depict the general footprint of the trichloroethene and technetium-99 contamination in the Regional Gravel Aquifer and also convey the general magnitude and distribution of contamination within the plumes above the maximum contaminant level. For additional descriptions of the Paducah Site plumes, please see *Trichloroethene and Technetium-99 Groundwater Contamination in the Regional Gravel Aquifer for Calendar Year 2020 at the Paducah Gaseous Diffusion Plant, Paducah, Kentucky* (FRNP 2021a). Records of decision are in place under the Groundwater Operable Unit for the following projects:

- Solid Waste Management Unit 91 (DOE 1998)
- Northwest Plume (DOE 1993 and DOE 2010)
- Northeast Plume (DOE 1995b and DOE 2015)
- C-400 Cleaning Building source area (DOE 2005)
- Southwest Plume (DOE 2012)

The documents can be found here in the Paducah Environmental Information Center.

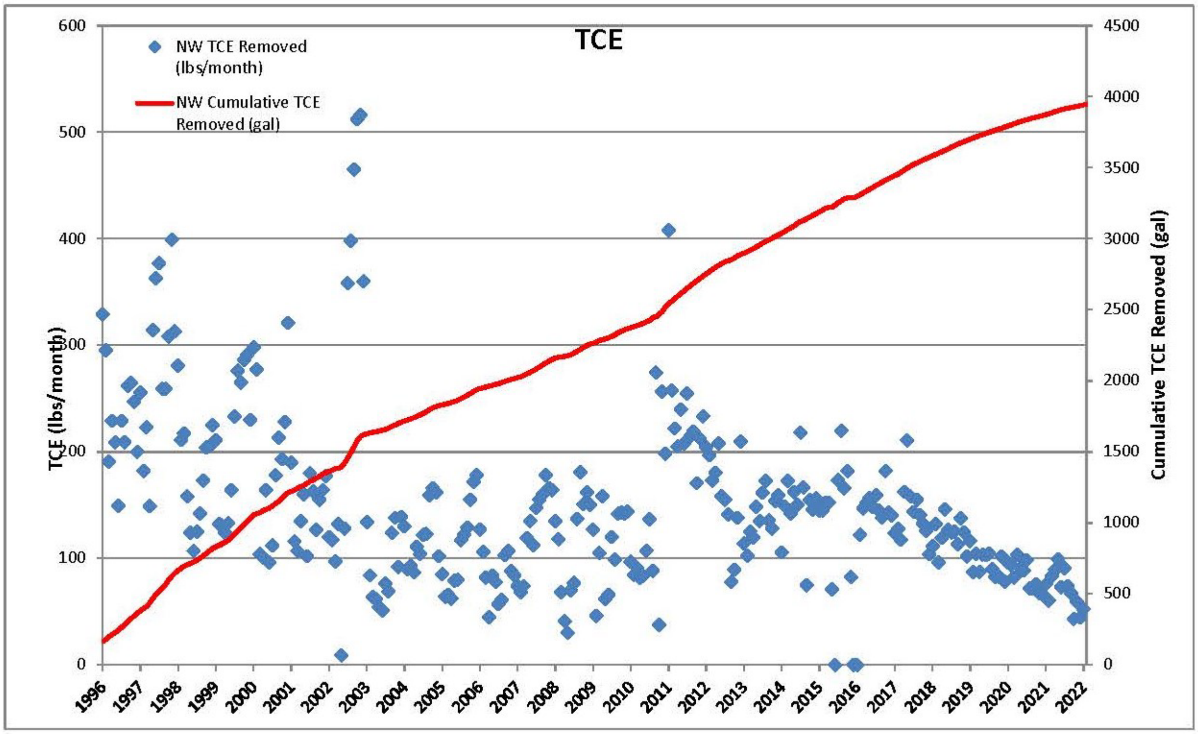
Table 6.3 lists the cumulative trichloroethene removed from liquid volatile organic compounds and volatile organic compounds on carbon recovered through 2022. The graphs shown in Figures 6.3 and 6.4 illustrate the cumulative trichloroethene removed from liquid by the Northwest Plume Groundwater Treatment System and the Northeast Plume Containment System, respectively, through 2022. Figure 6.5 shows the locations of groundwater contamination sources.

Table 6.3. Cumulative trichloroethene removed at Paducah

Source area	Cumulative trichloroethene removed (gallons)[a]	Cumulative trichloroethene removed (lb)[a]
Northwest Plume Pump-and-Treat	3,992[b]	48,343[b]
Northeast Plume Pump-and-Treat	371[b]	4,493[b]
C-400 Six-Phase Treatability Study	1,900	23,009
C-400 Phase I	535	6,479
C-400 Phase IIa and Phase IIb	1,137	13,769
Southwest Plume	24[c]	291[c]
Other sources (i.e., SWMU 91, LASAGNA)	246	2,979
Total	8,205	99,363

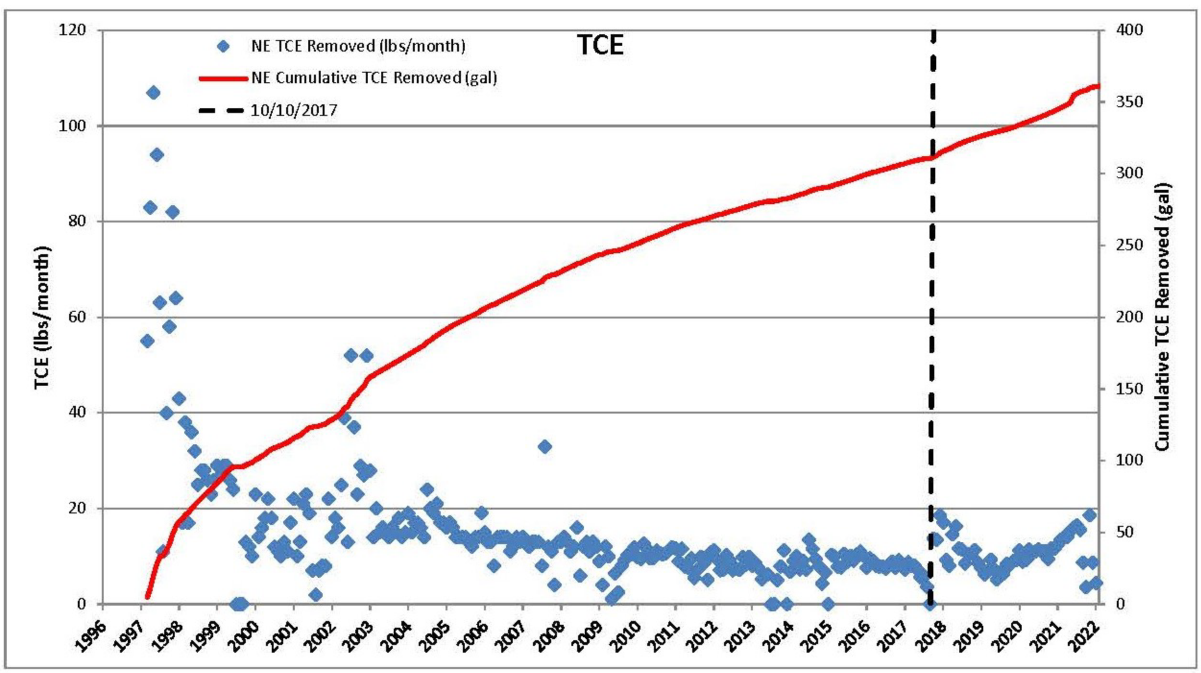
[a] Trichloroethene values may contain other volatile organic compounds.
[b] Cumulative through December 31, 2022.
[c] Removed during deep soil mixing operations.

Acronyms:
LASAGNA = Lasagna *in-situ* Remediation Technology
SWMU = solid waste management unit



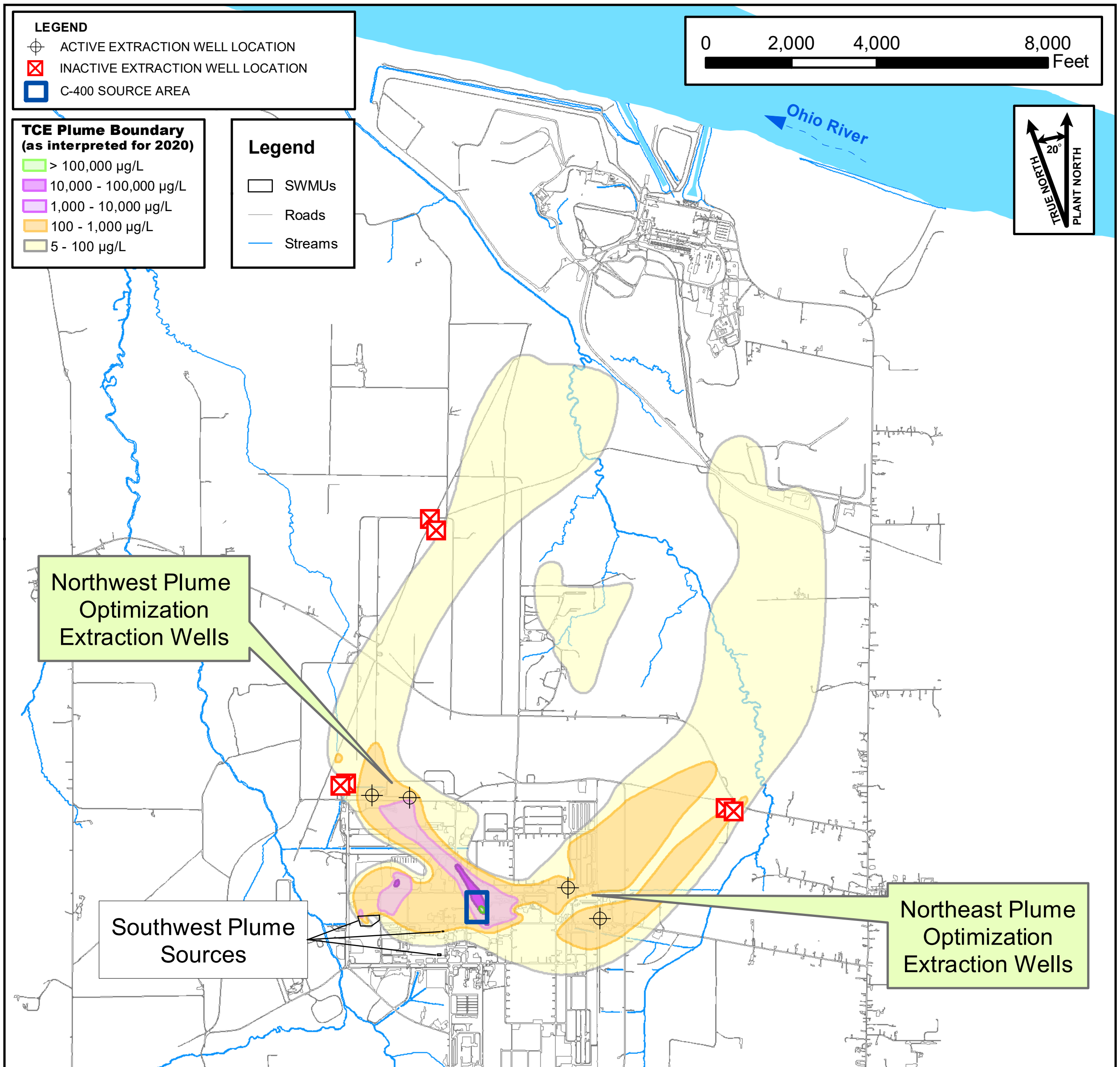
Source: DOE 2023b

Figure 6.3. Northwest Plume groundwater treatment system trichloroethene removed



Source: DOE 2023b

Figure 6.4. Northeast Plume containment system trichloroethene removed



MAP SOURCE INFORMATION
Map Generation Date and Location: G:\GIS\ARCVIEWS\PROJECTS\ASER\GWSources_20230720.mxd
Active Extraction Well Location Layer-- G:\GIS\iPEGASIS.gdb\Locations
Inactive Extraction Well Location Layer-- G:\GIS\iPEGASIS.gdb\Locations
Sources to the Southwest Plume Layer-- G:\GIS\iPEGASIS.gdb\SWMUs (Query: SWMU = '001') & G:\GIS\ARCVIEWS\PROJECTS\PLUMES\TCE_Plumes\drawings\areas of concern.dwg\Polyline
C-400 Source Area Layer-- G:\GIS\iPEGASIS.gdb\C400_Block
2020 Plume Layer-- G:\GIS\ARCVIEWS\PROJECTS\PLUMES\2020 Plumes\TCE_100000.shp, ...\TCE_10000.shp, ...\TCE_100.shp, ...\TCE_1000.shp, ...\TCE_5.shp
Roads Layer-- G:\GIS\iPEGASIS.gdb\roadrow
Surface Water Layer-- G:\GIS\iPEGASIS.gdb\streams, ...\fe_2022_21145_areawater (Query: FULLNAME = 'Ohio Riv')

Figure 6.5. Locations of groundwater contamination sources

The C-404 Hazardous Waste Landfill is subject to semiannual groundwater monitoring and statistical analyses of the data, in accordance with the Hazardous Waste Management Facility Permit.

The Kentucky Solid Waste Facility (401 *KAR* 47:030 § 6) maximum contaminant level exceedances for the C-746-S&T and C-746-U Landfills for 2022 are listed in Table 6.4. Groundwater monitoring is required on a quarterly basis.

Table 6.4. Summary of maximum contaminant level exceedances for C-746-S&T and C-746-U Landfills in 2022

Upper Continental Recharge System	Upper Regional Gravel Aquifer	Lower Regional Gravel Aquifer
C-746-S&T Landfills		
MW390: beta activity	MW387: beta activity MW391: trichloroethene MW394: trichloroethene	MW373: trichloroethene MW388: beta activity MW392: trichloroethene MW395: trichloroethene
C-746-U Landfill		
none	none	MW361: trichloroethene MW373: trichloroethene

Note:
Shading indicates a background monitoring well. This provides evidence of upgradient contamination.

Acronym:
MW = monitoring well

To support the evaluation of whether there is evidence that the C-746-U Landfill was contributing to groundwater contamination in the area of the landfill, the concentrations from monitoring well samples in the vicinity of the C-746-U Landfill of a broad range of parameters were screened against benchmarks, such as background concentrations and maximum contaminant levels. A Groundwater Assessment Report documented that there was no evidence indicating a release from the C-746-U Landfill (LATA Kentucky 2013). The data used to support this assessment were groundwater analyses of quarterly and semiannual monitoring for the period of 2002 through 2012 and the focused sampling of October 2006. The report found that the beta activity (associated with technetium-99) and trichloroethene in the wells are not landfill-related but originate upgradient of the C-746-S, C-746-T, and C-746-U Landfills.

Statistical analyses also are used to evaluate compliance monitoring wells at the C-746-S and C-746-T Landfill, the C-746-U Landfill, and the C-404 Hazardous Waste Landfill. Each report lists any statistical exceedance that is found. Reports for each landfill are listed in Table 6.1.

6.4 Emerging Contaminants

The release of PFAS into the environment is a topic of growing public health and environmental concern. PFAS are a class of man-made chemicals that have been manufactured and used in a variety of industries since the 1940s. Since then, thousands of chemical formulations have been developed and widely used in manufacturing and processing facilities due to their resistance to grease, water, oil, and heat. PFAS are often found in commercial products such as stain-resistant carpeting, water-resistant clothing, nonstick and grease-resistant food contact materials (e.g., cookware, food packaging), and aqueous film forming foams used in firefighting. These chemicals are very persistent in the environment and tend to bioaccumulate in food chains.

PFAS are exceptionally long-lasting due to the strength of the carbon-fluorine bond. Because of their breadth of use and environmental longevity, PFAS can be found in surface water, groundwater, soil, and air—from remote rural areas to densely-populated urban centers. A growing body of scientific evidence shows that exposure at certain levels to specific PFAS can adversely impact human health and other living things.

DOE has a unique historical relationship with PFAS, which were first produced on an industrial scale for use in uranium separation activities during the Manhattan Project. PFAS are found in commercial products (notably in firefighting foams) that have been used at DOE sites. DOE is actively researching historical and current uses in its production, research, and fire safety activities to identify applications that may have involved environmental release of PFAS.

In recognition of the need for a comprehensive departmental approach to PFAS, the Deputy Secretary of Energy issued a departmental policy (Policy) in September 2021 (Turk 2021). The Policy informs DOE's efforts to minimize or eliminate the use and release of PFAS; to assess, contain, reduce, and/or remove PFAS from the environment; and to protect workers and the public from exposure to PFAS as a result of DOE operations. The Policy also directs DOE to leverage the expertise of the National Laboratories to advance knowledge about PFAS, its fate and transport in the environment, and innovative research and technology approaches.

On March 22, 2019, the Kentucky Governor signed S.B. 104, banning the use of firefighting foam containing PFAS for training and testing purposes. This law went into effect on July 15, 2020. In August 2021, the Paducah Site replaced all aqueous film forming foams containing PFAS with a new biodegradable nonhazardous foam. The former supply of aqueous film forming foams (600 gallons) has been declared waste and is being properly stored until suitable treatment and disposal methods are identified.

The Paducah Site began investigating the history and on-site use of PFAS compounds in 2017. Interviews with Paducah Site staff, including the fire chief, indicated that aqueous film forming foams had not been used to fight a fire at the Paducah Site during the previous approximate 30-year time frame, but it had been used in fire training exercises at the Fire Training Area. A document and database search conducted in 2017 concluded that no PFAS sampling was ever completed at the Paducah Site.

In 2018, PFAS sampling at the Fire Training Area was added to the Paducah Site Environmental Monitoring Plan for sampling and analysis in 2019. At that time, there was no US EPA-approved analytical method for PFAS in groundwater, surface water, or wastewater; therefore, the most appropriate available method was used (a modified version of the drinking water method—US EPA Method 537.1). This method has subsequently been approved in specific media for certain PFAS compounds. Based on the most likely known potential source of PFAS contaminants, sampling of two groundwater monitoring wells was conducted in the Fire Training Area in August 2019 and September 2019. Samples were collected from MW315 (Upper Continental Recharge System) and MW330 (Regional Gravel Aquifer), which are approximately 75 feet from each other. The samples were analyzed for 18 PFAS compounds, and results were validated by an independent third party. Analytical results indicate detectable levels of PFAS contamination in groundwater in the vicinity of the Fire Training Area. These analytical results were added to the publicly available data repository (PEGASIS) on March 26, 2020, and are presented in Table 6.5.

In 2022, the Paducah Site began a project to evaluate for the presence of PFAS in environmental media, including potable water, at the site. Subsequently, in September 2022, DOE issued the *PFAS Strategic Roadmap: DOE Commitments to Action 2022–2025* (DOE 2022h), which requires DOE sites to perform initial testing of potable water produced by DOE-owned water treatment plants.

Consistent with the PFAS Screening Assessment Project Quality Assurance Project Plan, site standard sampling procedures and method-specific sample containers were used to collect potable water samples in Table 6.5.

Table 6.5 Paducah Site: per-and polyfluoroalkyl substances in groundwater

Analyte	First sampling event			Second sampling event		
	MW315	MW315 (Duplicate)	MW330	MW315	MW315 (Duplicate)	MW330
	8/22/2019	8/22/2019	8/22/2019	8/29/2019	8/29/2019	9/10/2019
Perfluorobutanesulfonate (PFBS)	10,000	10,100	15.8	5,720	4,880	21.9
Perfluorobutyric acid (PFBA)	886	850 J	6	850 J	605 J	7.88
Perfluorodecanesulfonate (PFDS)	843 U	844 U	1.67 U	86 U	86.6 U	1.73 U
Perfluorodecanoic acid (PFDA)	1.14 J	1.11 J	1.72 U	88.7 U	89.3 U	1.79 U
Perfluorododecanoic acid (PFDoA)	1.74 U	1.74 U	1.72 U	88.7 U	89.3 U	1.79 U
Perfluoroheptanesulfonate (PFHpS)	3,040	2,560	0.924 J	1,640	1,310	3.77
Perfluoroheptanoic acid (PFHpA)	1,370	1,300	2.71	1,420	1,200	3.56
Perfluorohexadecanoic acid (PFHxDA)	2 U	500 U	8.91 U	88.7 U	89.3 U	1.79 U
Perfluorohexanesulfonate (PFHxS)	63,200	59,600	44.7	38,100	42,400	89.3
Perfluorohexanoic acid (PFHxA)	14,000	12,300	22.2	11,800	9,940	29.3
Perfluorononanoic acid (PFNA)	870 U	871 U	1.08 J	88.7 U	89.3 U	1.26 J
Perfluorooctadecanoic acid (PFODA)	2 U	500 U	8.91 U	88.7 UJ	89.3 UJ	1.79 U
Perfluorooctanesulfonate (PFOS)	128,000	117,000	29.6	40,000	36,600	174
Perfluorooctanoic acid (PFOA)	5,230	5,190	7.38	3,890	3,520	10.7
Perfluoropentanoic acid (PFPeA)	2,570	2,560	6.96	2,380 J	1,830 J	7.27
Perfluorotetradecanoic acid (PFTeDA)	1.74 U	1.74 U	1.72 U	88.7 U	89.3 U	1.79 U
Perfluorotridecanoic acid (PFTrDA)	1.74 U	1.74 U	1.72 U	88.7 U	89.3 U	1.79 U
Perfluoroundecanoic acid (PFUdA)	1.74 U	1.74 U	1.72 U	88.7 U	89.3 U	1.79 U

Notes:
1. MW315 is an Upper Continental Recharge System well and MW330 is a Regional Gravel Aquifer well.
2. Concentrations are in units of nanograms/liter (ng/L), also commonly referred to as parts per trillion.
3. A duplicate is collected at the same time, using the same procedures, the same type of equipment, and in the same types of containers as the original samples. Duplicate samples also are preserved in the same manner and submitted for the same analyses as the original sample. Data from duplicate samples may be used to assess sampling variability in comparison to the original sample.
4. The first sampling event was conducted using polytetrafluoroethylene tubing and conventional bladder pumps.
5. The second sampling event was conducted using high-density polyethylene tubing and certified PFAS-free bladder pumps.
6. MW315 was purged 5 minutes prior to both sample collection events. MW330 was purged 12 minutes prior to the first sample collection and 11 minutes prior to the second event.
7. The analytical method used was a modified version of US EPA Method 537.1 and is noted in PEGASIS as 537.1M. This method is a liquid chromatography tandem mass spectroscopy method. This method is a referenced method by the *Department of Defense (DoD)/Department of Energy (DOE) Consolidated Quality Systems Manual (QSM) for Environmental Laboratories*; however, because the method is not an US EPA-promulgated method, qualifier code QSM-METH was assigned to the data set to indicate a possible uncertainty to the data set (DoD 2017).

Acronyms:
DoD = US Department of Defense
DOE = US Department of Energy
J = Estimated value.
PFAS = per- and polyfluoroalkyl substances
U = Analyte analyzed for, but not detected at or below, the lowest concentration reported.
US EPA = US Environmental Protection Agency

November 2022 (round 1) samples. A second sampling activity was conducted in January 2023 (round 2). For this sampling event, PFAS-specific collection procedures, including special sampler personal protective equipment, were developed and followed, and an experienced PFAS sampler was employed. These additional measures were included in the second round of sampling to minimize the potential for any cross-contamination from samplers, the equipment used, or sampling procedures. Method specific sample containers were used for both round 1 and round 2. Samples were collected directly from the water tap and analyzed using EPA Method 537.1.

Multiple PFAS were detected in Paducah Site potable water, and several results were assigned a "J" qualifier (estimated). Potable water sample results are summarized in Table 6.6. All results for perfluorooctanoic acid (yellow shading) and perfluorooctanesulfonate (orange shading) exceed the US EPA provisional health advisory levels (0.004 ng/L and 0.02 ng/L, respectively) and maximum containment level goals (i.e., 0 ng/L for both). Some results for perfluorooctanoic acid and perfluorooctanesulfonate exceed the draft maximum containment levels (i.e., 4 ng/L).

The Paducah Site permitted water treatment plant treats water sourced from the Ohio River for potable use across the site. The Paducah Site potable water results are consistent with 2021 ambient concentrations reported by the Ohio River Valley Water Sanitation Commission for the Ohio River and also as reported by a nearby municipal water supplier, Paducah Water, which also sources its water from the Ohio River at a location upstream of the Paducah Site intake. The Paducah Site potable water results, (which are similar to the PFAS concentrations in Ohio River water) and the Paducah Water results (which are similar to the Paducah Site result) indicate that the PFAS detections in Paducah Site potable water most likely originate from the Ohio River and are unrelated to the Paducah Site water treatment process and/or distribution system.

As emerging contaminants, federal and state agencies are developing reliable and consistent methods to characterize PFAS in the environment; developing guidance to facilitate cleanup of contaminated groundwater; researching methods for treatment and disposal of PFAS-containing materials, and are developing new tools and materials to communicate information about PFAS. US EPA maintains a website, which can be accessed here, that provides PFAS tools and resources, as well as outlines actions that US EPA is taking on the topic.

Paducah Site personnel continue to participate in the DOE Headquarters PFAS Working Group to provide input to and obtain DOE Headquarters' direction for other actions consistent with those outlined by US EPA and across the DOE complex. Additionally, PPPO participates on the DOE PFAS Coordinating Committee. The PFAS Coordinating Committee serves as a management-level counterpart to the PFAS Working Group and meets routinely to track progress related to PFAS issues; identify changes that may be needed to Departmental directives or regulations; discuss opportunities for DOE laboratories to identify breakthroughs and high-value opportunities to advance PFAS knowledge; and clarify the additional resources needed to support research, testing, characterization, and possible remediation activities that are likely to soon be required.

As part of these group activities, DOE issued the previously mentioned DOE PFAS Roadmap. The roadmap is a strategic plan to understand PFAS uses and environmental releases, to manage and protect employee and public health and the environment, to leverage DOE expertise to enhance PFAS knowledge and technological solutions, and to communicate with regulators, communities, and stakeholders to ensure transparency to develop effective PFAS strategies. In October 2022, DOE also released its *Initial Assessment of Per- and Polyfluoroalkyl Substances (PFAS) at DOE-EM Sites* (DOE 2022i). This report summarizes DOE's current knowledge about PFAS uses and releases based on surveys performed at DOE sites across the country.

Table 6.6. Paducah Site: per- and polyfluoroalkyl substances in potable water

Sample location:	DW-036DWN	DW-036DWN	DW-036	DW-036	DW-037	DW-037	DW-038	DW-038 Duplicate (1/12/2023)
Sample date:	1/12/2023	11/8/2022	1/12/2023	11/8/2022	1/12/2023	11/8/2022	1/12/2023	1/12/2023
Sample ID:	DW036DWNPFAS1-23R	DW036DWNPFAS1-23	DW036PFAS1-23R	DW036PFAS1-23	DW037PFAS1-23R	DW037PFAS1-23	DW038PFAS1-23R	DW038PFAS1-23DR
Facility name:	C-611 Water Treatment Plant	C-611 Water Treatment Plant	C-611 Water Treatment Plant	C-611 Water Treatment Plant	C-611 Water Treatment Plant	C-611 Water Treatment Plant	C-755 Trailer Complex	C-755 Trailer Complex
Analyte/Units:	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L
Perfluoroundecanoic acid (PFUdA)	1.73 U	1.69 U	1.78 U	1.86 U	1.87 U	1.65 U	1.79 U	1.75 U
Perfluorotridecanoic acid (PFTrDA)	1.73 U	1.69 U	1.78 U	1.86 U	1.87 U	1.65 U	1.79 U	1.75 U
Perfluorotetradecanoic acid (PFTeDA)	1.73 U	1.69 U	1.78 U	1.86 U	1.87 U	1.65 U	1.79 U	1.75 U
Perfluorooctanoic acid (PFOA)*	**3.91**	**4.17**	**4.29**	**4.07**	**3.96**	**3.85**	**4.64**	**4.66**
Perfluorooctanesulfonate (PFOS)*	**6.03**	**4.85**	**7.53**	**4.37**	**6.66**	**5.68**	**6.98**	**7.52**
Perfluorononanoic acid (PFNA)	0.897 J	0.622 J	0.791 J	1.86 U	1.87 U	0.631 J	1.22 J	1.19 J
Perfluorohexanoic acid (PFHxA)	2.16	3.09	2.57	2.73	1.98 J	2.66	2.35	2.53
Perfluorohexanesulfonate (PFHxS)	1.18 J	1.08 J	1.19 J	1.02 J	1.07 J	1 J	1.17 J	1.18 J
Perfluoroheptanoic acid (PFHpA)	1.32 J	1.31 J	1.26 J	1.29 J	1.09 J	1.13 J	1.38 J	1.6 J
Perfluorododecanoic acid (PFDoA)	1.73 U	1.69 U	1.78 U	1.86 U	1.87 U	1.65 U	1.79 U	1.75 U
Perfluorodecanoic acid (PFDA)	1.73 U	1.69 U	1.78 U	1.86 U	1.87 U	1.65 U	1.79 U	1.75 U
Perfluorobutanesulfonate (PFBS)	3.24	4.27 J	4.32	4.22 J	3.43	3.24 J	3.5	3.41
N-methylperfluoro-1-octanesulfonamidoacetic acid (NMeFOSAA)	3.45 U	3.39 U	3.56 U	3.73 U	3.74 U	3.29 U	3.58 U	3.49 U
N-ethylperfluoro-1-octanesulfonamidoacetic acid (NEtFOSAA)	3.45 U	3.39 U	3.56 U	3.73 U	3.74 U	3.29 U	3.58 U	3.49 U
Hexafluoropropylene oxide dimer acid (HFPO-DA)	1.73 U	0.783 J	1.78 U	0.912 J	1.87 U	0.991 J	1.79 U	1.75 U
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9-Cl-PF3ONS)	1.61 U	1.58 U	1.66 U	1.74 U	1.74 U	1.54 U	1.67 U	1.63 U
4,8-Dioxa-3H-perfluorononanoic acid (DONA/ADONA)	1.73 U	1.69 U	1.78 U	1.86 U	1.87 U	1.65 U	1.79 U	1.75 U
11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11-Cl-PF3OUdS)	1.63 U	1.59 U	1.68 U	1.76 U	1.76 U	1.55 U	1.68 U	1.65 U

Table 6.6. Paducah Site: per- and polyfluoroalkyl substances in potable water (continued)

Sample location:	DW-038	DW-038 Duplicate (11/8/2022)	DW-040	DW-040	QC 1 (1/12/2023)	QC 2 (1/12/2023)	QC (11/8/2022)
Sample date:	11/8/2022	11/8/2022	1/12/2023	11/8/2022	1/12/2023	1/12/2023	11/8/2022
Sample ID:	DW038PFAS1-23	DW038PFAS1-23D	DW040PFAS1-23R	DW040PFAS1-23	FB1DWPFAS1-23R	FB2DWPFAS1-23R	FB1DWPFAS1-23
Facility name:	C-755 Trailer Complex	C-755 Trailer Complex	C-615-G Sewage Lift Station	C-615-G Sewage Lift Station	N/A	N/A	N/A
Analyte/Units:	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L
Perfluoroundecanoic acid (PFUdA)	1.85 U	1.76 U	1.78 U	1.81 U	1.69 U	1.73 U	1.77 U
Perfluorotridecanoic acid (PFTrDA)	1.85 U	1.76 U	1.78 U	1.81 U	1.69 U	1.73 U	1.77 U
Perfluorotetradecanoic acid (PFTeDA)	1.85 U	1.76 U	1.78 U	1.81 U	1.69 U	1.73 U	1.77 U
Perfluorooctanoic acid (PFOA)*	**3.88**	**4.1**	**4.39**	**4.39**	**1.69 U**	**1.73 U**	**1.77 U**
Perfluorooctanesulfonate (PFOS)*	**4.61**	**4.85**	**7.1**	**4.65**	1.69 U	1.73 U	1.77 U
Perfluorononanoic acid (PFNA)	1.85 U	1.76 U	0.972 J	1.81 U	1.69 U	1.73 U	1.77 U
Perfluorohexanoic acid (PFHxA)	2.83	2.87	2.53	2.98	1.69 U	1.73 U	1.77 U
Perfluorohexanesulfonate (PFHxS)	1.13 J	1.11 J	1.03 J	1.07 J	1.54 U	1.57 U	1.61 U
Perfluoroheptanoic acid (PFHpA)	1.42 J	1.39 J	1.37 J	1.51 J	1.69 U	1.73 U	1.77 U
Perfluorododecanoic acid (PFDoA)	1.85 U	1.76 U	1.78 U	1.81 U	1.69 U	1.73 U	1.77 U
Perfluorodecanoic acid (PFDA)	1.85 U	1.76 U	1.78 U	1.81 U	1.69 U	1.73 U	1.77 U
Perfluorobutanesulfonate (PFBS)	4.1 J	4.5 J	3.61	4.13 J	1.5 U	1.54 U	1.58 U,J
N-methylperfluoro-1-octanesulfonamidoacetic acid (NMeFOSAA)	3.7 U	3.52 U	3.55 U	3.63 U	3.37 U	3.45 U	3.55 U
N-ethylperfluoro-1-octanesulfonamidoacetic acid (NEtFOSAA)	3.7 U	3.52 U	3.55 U	3.63 U	3.37 U	3.45 U	3.55 U
Hexafluoropropylene oxide dimer acid (HFPO-DA)	0.843 J	0.837 J	1.78 U	0.924 J	1.69 U	1.73 U	1.77 U
9-Chlorohexadecafluoro-3-oxanonane-1-sulfonic acid (9-Cl-PF3ONS)	1.72 U	1.64 U	1.66 U	1.69 U	1.57 U	1.61 U	1.65 U
4,8-Dioxa-3H-perfluorononanoic acid (DONA/ADONA)	1.85 U	1.76 U	1.78 U	1.81 U	1.69 U	1.73 U	1.77 U
11-chloroeicosafluoro-3-oxaundecane-1-sulfonic acid (11-Cl-PF3OUdS)	1.74 U	1.66 U	1.67 U	1.71 U	1.59 U	1.63 U	1.67 U

*Method detection limits for PFOS and PFOA are above the current US EPA "Lifetime Drinking Water Health Advisories for Four Perfluoroalkyl Substances," (FRL 9855-01-OW) (EPA 2022b).

Notes:

1. DW-036DWN is a tap at the C-611 water treatment plant, prior to water entering distribution system.
2. DW-036 is a tap at the C-611 water treatment plant laboratory (combined filter effluent).
3. DW-037 is a tap at the C-611 water treatment plant softener influent.
4. DW-038 is a tap at the C-755 trailer complex shower house janitor closet.
5. DW-040 is a tap at the C-615-G sewage lift station.
6. All results for perfluorooctanoic acid (PFOA) (yellow shading) and perfluorooctanesulfonate (PFOS) (orange shading) exceed their US EPA provisional health advisory levels (0.004 ng/L and 0.02 ng/L, respectively) and maximum contaminant level goals (i.e., 0 ng/L for both). Some results for PFOA and PFOS exceed their draft maximum contaminant levels (i.e., 4 ng/L).
7. Consistent with the PFAS Screening Assessment project Quality Assurance Project Plan, Paducah Site standard sampling procedures and equipment and method-specific sample containers were used for sample collection in November 2022; the potential for cross-contamination (e.g., introduction of either a positive or negative bias) during collection of potable water samples resulting from the use of standard sampling procedures and equipment is considered to be low. Data flags are a combination of lab qualifiers and data assessment codes. The quality control sample also does not indicate cross-contamination occurred during sampling. See also Rodowa et. al 2020; https://pubs.acs.org/doi/10.1021/acs.estlett.0c00036.
8. The January 2023 samples were collected using PFAS-specific procedures and equipment, including sampler personal protective equipment.
9. Samples analyzed by US EPA Method 537.1, Quality Control Criteria for EPA Method 537.1, are such that individual PFAS analytes have accuracy limits of ±30% of the true value.
10. Results are consistent with samples collected and published by others from the Ohio River near the Paducah Site as well as finished water samples from the local municipal water supply (Paducah Water) which sources its water from the Ohio River upstream of the Paducah Site.
11. The results do not indicate the addition of any PFAS from the Paducah Site water treatment process and/or distribution system.

Acronyms:

J = estimated value
N/A = not applicable
PFAS = per- and polyfluoralkyl substances
QC = quality control
U = compound analyzed for but not detected at or below the lowest concentration reported (method detection limit)
US EPA = United States Environmental Protection Agency

7. Quality Assurance

The Paducah Site maintains a Quality Assurance (QA)/Quality Control (QC) Program to verify the integrity of data generated by the Environmental Monitoring Program. Each aspect of the monitoring program, from sample collection to data reporting, must comply with quality requirements and assessment standards. Requirements and guidelines for the QA/QC Program at the Paducah Site are established by the following:

- DOE Order 414.1D, *Quality Assurance*
- EM-QA-001, Rev 1, *Environmental Management Quality Assurance Program*
- CP2-QA-1000, *Quality Assurance Program Description for the Paducah Gaseous Diffusion Plant, Paducah, Kentucky*
- Commonwealth of Kentucky and federal regulations and guidance from US EPA
- American National Standards Institute
- American Society of Mechanical Engineers
- American Society for Testing and Materials
- American Society for Quality Control

The QA/QC Program specifies organizational and program elements for equipment, design, documents, data, nonconformances, and records. DOE emphasizes planning, implementing, and assessing activities and implementing effective corrective actions as necessary. Project and subcontract documents specify program requirements to ensure they are included in project-specific planning documents such as QA plans.

The Paducah Site uses laboratories audited through the DOECAP. DOECAP annually audits the performance and qualifications of environmental analytical laboratories and commercial waste treatment, storage, and disposal facilities to support complex-wide DOE mission activities.

The environmental monitoring quality assurance project plan defines how each element of the Environmental Monitoring Program relates to key quality and data management requirements. The quality assurance project plan is an appendix to the Environmental Monitoring Plan (FRNP 2022a).

The Paducah Programmatic Quality Assurance Project Plan, which is based on the Uniform Federal Policy for Quality Assurance Project Plans, was implemented in 2013 and updated in 2022 (DOE 2022j). The following procedures further ensure quality:

- Field forms are maintained in accordance with CP3-RD-0010, *Records Management Process*.
- Communication and documentation between the sample management office and field sampling personnel are conducted according to CP4-ES-5007, *Data Management Coordination*.
- Sample labels and chain-of-custody forms are completed according to CP3-ES-2708, *Chain-of-Custody Forms, Field Sample Logs, Sample Labels, and Custody Seals*.
- Data assessment is conducted by a technical reviewer or their designee according to CP3-ES-5003, *Quality Assured Data*.
- Logbooks and data forms are prepared according to CP4-ES-2700, *Logbooks and Data Forms*.

The environmental monitoring quality assurance project plan and the procedures cited above cover data collected from January 2022 through December 2022. The plan also includes training requirements, sample custody, procedures, and instrument calibration and maintenance.

7.1 Field Sampling

Efforts to ensure the quality of field samples begin with planning for sampling activities and programs and continue in the field as measurements are taken and samples are collected according to the protocols specified for the specific sampling activity. The following sections describe elements crucial to field sample quality.

7.1.1 Data Quality Objectives and Sample Planning

From the start of any sampling program, data quality objectives play an important role in determining the number of samples, location of sampling sites, sampling methods, sampling schedules, and coordinating sampling and analytical resources to meet critical completion times. These sampling program criteria are documented in the Paducah Site Environmental Monitoring Plan (FRNP 2022a). This Plan is evaluated and modified each FY, as appropriate, using the data quality objectives methodology and following US EPA's data quality objectives guidance found here.

Each sampling location and sample collected are assigned a unique identification number. Each segment of the identification number sequence designates information on where the sample was collected. To implement the data quality objectives, an analytical statement of work for the analytical laboratory is generated from the Paducah Integrated Data System. Information from this system is used to populate the Project Environmental Measurements System (PEMS), an electronic database that manages and streamlines field-generated and laboratory-generated data. Information in PEMS includes sample identification numbers, sampling locations, sampling methods, analytical parameters, analytical methods, and sample container and preservative requirements. The information in PEMS is used to produce sample bottle labels and chain-of-custody forms for each sampling event.

7.1.2 Field Measurements

Field measurements for the groundwater and surface water monitoring program include water level measurements, pH, conductivity, flow rate, turbidity, temperature, dissolved oxygen, total residual chlorine, Eh (approximate), and barometric pressure. Environmental conditions, such as ambient temperature and weather, are recorded as well. Field measurements are collected, downloaded electronically, recorded on appropriate sample data forms or in logbooks, and then entered into PEMS.

7.1.3 Sampling Procedures

Samples are collected using procedures specific to the media (surface water, groundwater, sediment, or air filters), which are written to comply with US EPA-approved sampling methods. Information recorded during a sampling event consists of the sample identification number, station or location, date collected, time collected, and the person who performed the sampling. This information, which is documented in a logbook or sample data form, on a chain-of-custody form, and on the sample container label, then is entered directly in PEMS. Chain-of-custody forms are maintained from the point of sampling, and the samples are protected properly until they are placed in the custody of an analytical laboratory.

7.1.4 Field Quality Control Samples

The QC program for both groundwater and environmental monitoring activities specifies a minimum target rate for field QC samples of 1 per 20 environmental samples. Table 7.1 shows the types of field QC

Table 7.1. Types of quality control samples

Field QC samples	Laboratory QC samples
Field blanks[a]	Laboratory duplicates
Field duplicates	Reagent blanks
Trip blanks[a]	Matrix spikes[b]
Equipment rinseates[c]	Matrix spike duplicates
	Performance evaluations
	LCS

[a] Blanks = Samples of deionized water used to assess potential contamination from a source other than the media being sampled.
[b] Spikes = Samples that have been mixed with a known quantity of a chemical to measure overall method effectiveness during the analysis process, as well as possible sample/matrix interferences.
[c] Rinseates = Samples of deionized water that have been used to rinse the sampling equipment. The water is collected after completion of decontamination and prior to sampling. It is used to assess adequate decontamination of sampling equipment.

Acronyms:
LCS = Laboratory Control Sample
QC = quality control

samples that are collected and analyzed. Analytical results of field QC samples are evaluated to determine whether the sampling activities biased the sample results.

7.2 Analytical Quality Assurance

The following sections describe the methods and procedures that ensure the laboratory analysis of samples meet quality standards, as well as the criteria for selecting off-site laboratories to analyze samples from the Paducah Site.

7.2.1 Analytical Procedures

When available and appropriate for the sample matrix, methods from US EPA's SW-846 Compendium are used for sample analysis. When SW-846 methods are not available, the Paducah Site uses other nationally recognized methods such as those developed by DOE and the American Society for Testing and Materials. An analytical statement of work for laboratory services identifies the analytical methods to be used for a set of samples. Using guidance from US EPA, laboratories document the steps in handling and analyzing samples, reporting results, and following chain-of-custody procedures.

7.2.2 Laboratory Quality Control Samples

Laboratory QC samples are prepared and analyzed according to the requirements of the analytical methods used. Table 7.1 identifies the types of laboratory QC samples. If samples do not meet the QC acceptance criteria, then appropriate action is taken as specified by the analytical method, or the analytical data are qualified accordingly.

7.2.3 Independent Quality Control

The Paducah Site is required by DOE and US EPA to participate in independent QC programs. The Paducah Site also participates in voluntary independent programs to improve its analytical QC. These programs, which are conducted by US EPA, DOE, and commercial laboratories, generate data that are recognized as objective measures, enabling participating laboratories and government agencies to periodically review their performance. Data that do not meet acceptable criteria are investigated and documented according to formal procedures. Although participation in certain programs is mandatory, the degree of participation is voluntary so that each laboratory can select parameters of particular interest to that facility.

KDOW requires laboratories that analyze samples for KPDES permit compliance to hold a Kentucky Wastewater Laboratory Certification. Two laboratories and the FRNP sampling organization had this certification in 2022. Additional information about Kentucky Wastewater Laboratory certification can be found here.

7.2.4 Laboratory Audits and Accreditation

Laboratories used by FRNP participate in the DOECAP Accreditation Program, which certifies and accredits environmental laboratories through third-party organizations, including the American Association for Laboratory Accreditation, Perry Johnson Laboratory Accreditation, Inc., and the ANSI National Accreditation Board. This certification ensures that the laboratories comply with the appropriate regulations, methods, and procedures. Audit findings are documented and corrective action plans are developed by the laboratory and evaluated for acceptance by the accrediting body. Once corrective action plans are closed and accreditation is approved, the certificate of accreditation that includes the scope and period of accreditation will be provided to the laboratory. FRNP reviews the audit reports and certificates of accreditation with scope every two years for compliance with FRNP requirements. Laboratories that do not participate in the DOECAP Accreditation Program are audited by FRNP for compliance with DOECAP and the approved suppliers list requirements.

Analytical laboratories on the approved suppliers list that were used by the Paducah Site in 2022 include Advanced Terra Testing; GEL Laboratories, LLC; Eurofins TestAmerica in St. Louis, Missouri, Denver, Colorado, and Knoxville, Tennessee; ALS Global in Cincinnati, Ohio, Salt Lake City, Utah; Southwest Research Institute; Pace Analytical Services, LLC in Mt. Juliet, Tennessee, and Madisonville, Kentucky; Materials and Chemistry Laboratory, Inc.; EMSL Analytical, Inc.; and Summit Environmental.

Waste treatment, storage, and disposal facilities that were on the approved suppliers list and were used by the Paducah Site in 2022 include Veolia Environmental Services Technical Solutions in Port Arthur, Texas; Perma-Fix (Diversified Scientific Services, LLC, Florida and Northwest facilities); Waste Control Specialist, LLC; Clean Harbors, LLC in Deer Park, Texas, and El Dorado, Arkansas; and Energy*Solutions* in Clive, Utah, and Bear Creek, Tennessee.

7.3 Data Management

Data must be managed properly so users can retrieve it easily and rely on its integrity. The following sections identify the databases that the Paducah Site relies on to house critical data and describe the systems and methods used to screen, validate, verify, and assess data from environmental sampling.

7.3.1 Project Environmental Measurements System

The data generated from sampling events are stored in PEMS, a consolidated site data system for tracking and managing data. The system is used to manage field-generated data, import laboratory-generated data, input data qualifiers identified during the data review process, and transfer data to the Paducah OREIS database for reporting. PEMS uses references and code lists to ensure consistency and standardization of the data.

7.3.2 Paducah OREIS

The Paducah OREIS database consolidates data generated by the Environmental Monitoring Program. Data consolidation consists of activities necessary to prepare the evaluated data for the users. PEMS files containing the assessed data are transferred from PEMS to Paducah OREIS for future use. The Sample Management Office Manager is responsible for notifying the project team and other data users of the available data. Data used in reports that are distributed to external agencies, such as quarterly landfill reports and this Annual Site Environmental Report, are obtained from Paducah OREIS and have completed the data review process, which is documented in *Paducah Gaseous Diffusion Plant Data Management Plan* (DOE 2021c). Project-specific data sets are prepared during report writing and are included with reports, as appropriate. Environmental data loaded in Paducah OREIS have been assessed, verified, and validated, if applicable, as specified in CP3-ES-5003, *Quality Assured Data*.

7.3.3 PEGASIS

PEGASIS provides dynamic mapping and displays of environmental monitoring data. It allows members of the public to access environmental sampling data and site-specific geographic information system features through the Internet. It includes analytical sample results from environmental studies, restoration reports, supporting documents, and maps. Environmental data from Paducah OREIS is loaded in PEGASIS each quarter. PEGASIS does not contain data related to waste, deactivation, demolition, or facility characterization. Public access to PEGASIS is available here.

7.3.4 Electronic Data Deliverables

A results only electronic data deliverable is requested for all samples analyzed by each laboratory. The results and qualifier information from the electronic data deliverable are checked, as is the format of all fields provided. Discrepancies are reported immediately to the laboratory so they can make corrections or issue new electronic data deliverables. Approximately 10 percent of the electronic data deliverables are checked randomly to verify that the laboratory continues to provide adequate electronic data deliverables.

7.3.5 Data Packages

A Level IV data package is requested from the laboratory when data validation is to be performed on a specific sampling event or media. All data packages received from the laboratory are tracked, reviewed, and maintained in a secure environment. Tracked information includes the sample delivery group number, date received, receipt of any electronic data deliverable, and comments. The contents of the data package and the chain-of-custody forms are compared, and any discrepancies are identified. Discrepancies are reported immediately to the laboratory and to data validators. All data packages are submitted electronically to the Document Management Center for permanent storage.

7.3.6 Laboratory Contractual Screening

Laboratory contractual screening is the process of evaluating a set of data against the requirements specified in the analytical statement of work to ensure that all requested information is received. The contractual screening includes the chain-of-custody form, analytes requested, method used, units, holding times, and reporting limits achieved. The contractual screening is conducted electronically once data are received from the analytical laboratory. Any deviation from the analytical statement of work is identified and documented.

7.3.7 Data Verification, Validation, and Assessment

Data verification is the process for comparing a data set against a set standard or contractual requirement. Verification is performed electronically, manually, or both. Data verification includes contractual screening and other criteria specific to the data. Data are flagged as necessary. Verification qualifiers are stored in PEMS and transferred with the data to Paducah OREIS.

Data validation is performed for a data set by a qualified individual who is independent from sampling, laboratory, project management, or other decision-making personnel. Data validation evaluates how well the laboratory adheres to the requirements of the analytical method. Validation qualifiers are stored in PEMS and transferred with the data to Paducah OREIS. Five percent of the total data packages from routine sampling events are validated programmatically. All of the selected data packages are validated at a rate of 100 percent. A total of 94 packages of environmental monitoring data were validated in 2022.

Data assessment assures that the type, quality, and quantity of data are appropriate for its intended use based on the data quality objectives. It allows data users to determine that a decision (or estimate) can be made with the desired level of confidence, given the quality of the data set. Data assessment follows data verification and data validation (if applicable) and must be performed at a rate of 100 percent to ensure data are useable. The data assessment is conducted by trained technical personnel in conjunction with other project team members. Assessment qualifiers are stored in PEMS and transferred with the data to Paducah OREIS. Data are made available for reporting from Paducah OREIS once the data assessment is complete and associated documentation is stored in the project files. Rejected data that are identified in the data assessment and/or data validation process are noted as rejected in Paducah OREIS.

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Appendix A: Glossary

Appendix A Glossary

accuracy—The closeness of the result of a measurement to the true value of the quantity.

Air stripper—Equipment that bubbles air through water to remove volatile organic compounds from the water.

alkalinity—The capacity of an aqueous solution to neutralize an acid. Alkalinity measurements are important in determining the sensitivity of a body of water to acid inputs such as acidic pollution from rainfall or wastewater.

Alpha activity—The rate of emission of alpha particles from a given material.

Alpha particle—A positively charged particle emitted from the nucleus of an atom; it has the same charge and mass as that of a helium nucleus (two protons and two neutrons).

Ambient air—The surrounding atmosphere as it exists around people, plants, and structures.

Analyte—The specific component that is being measured in a chemical analysis.

Analytical detection limit—The lowest reasonably accurate concentration of an analyte that can be detected; this value varies depending on the method, instrument, and dilution used.

Anion—A negatively charged ion.

Aquifer—A permeable layer of sand, gravel, or rock below the ground surface that is capable of yielding quantities of groundwater to wells and springs.

atom—Smallest unit of an element capable of entering into a chemical reaction.

Average—A measure of the central tendency, or middle, of a group of numbers.

Background radiation—Naturally-occurring radiation that includes cosmic radiation, terrestrial radiation, and internal radiation.

Beta activity—The rate of emission of beta particles from a given material.

Beta particle—A negatively charged particle emitted from the nucleus of an atom during radioactive decay. It has a mass and charge equal to those of an electron.

Biota—Animal and plant life.

Blank—A control sample that is identical in principle to the sample of interest, except the substance being analyzed is absent. In such cases, the measured value for the substance being analyzed is believed to be a result of artifacts. Under certain circumstances, that value may be subtracted from the measured value to give a net result reflecting the amount of the substance in the sample. US EPA does not permit the subtraction of blank results in US EPA-regulated analyses.

Calibration—Determining the variance from a standard of accuracy of a measuring instrument to ascertain what correction factors are necessary.

Categorical exclusion—A class of actions that either individually or cumulatively do not have a significant effect on the human environment and therefore do not require preparation of an environmental assessment or environmental impact statement under the National Environmental Policy Act.

chain-of-custody—A process that documents custody and control of a sample through sample collection, transportation, and analysis.

Chemical oxygen demand—Indicates the quantity of oxidizable materials present in water, and varies with water composition, concentrations of reagent, temperature, period of contact, and other factors.

Closure—Formal shutdown of a hazardous waste management facility under the Resource Conservation and Recovery Act or Comprehensive Environmental Response, Compensation, and Liability Act.

Compliance—Fulfillment of the applicable requirements of a plan or schedule ordered or approved by a government authority.

Comprehensive Environmental Response, Compensation, and Liability Act—Legislation that provides for liability, compensation, cleanup, and emergency response for hazardous substances released to the environment and the cleanup of inactive hazardous waste disposal sites.

Concentration—The amount of a substance contained in a unit volume or mass of a sample.

Conductivity—A measure of water's capacity to convey an electric current. This property is related to the total concentration of the ionized substances in water and the temperature at which the measurement is made.

Confluence—The point at which two or more streams meet; the point where a tributary joins the main stream.

Contaminant—Any substance that enters a system, such as the environment, food, or the human body, where it is not normally found. Contaminants include substances that spoil food, pollute the environment, or cause other adverse effects.

Contamination—Deposition of unwanted material on the surfaces of structures, areas, objects, or personnel.

Cosmic radiation—Ionizing radiation with very high energies that originates outside the earth's atmosphere. Cosmic radiation contributes to natural background radiation.

Count—A measure of the radiation from an object or device; the signal that announces an ionization event within a counter.

curie—A unit of radioactivity, defined as the quantity of any radioactive nuclide that has 3.7×10^{10} (37 billion) disintegrations per second.

decay, radioactive—The spontaneous transformation of one radionuclide into a different radioactive or nonradioactive nuclide, or into a different energy state of the same radionuclide.

Decontamination and decommissioning—Removing equipment, demolishing buildings, disposing of waste, and investigating potential contamination in areas that are no longer part of current operations.

derived concentration standard—A derived concentration value for a radionuclide in a specified environmental medium (e.g., air or water) that would result in a dose in that medium of 100 mrem in a year to a gender- and age-weighted reference person using DOE approved dose coefficients and assuming continuous exposure. Derived concentration standard values represent concentrations at the point of discharge and do not account for attenuation along the pathway before reaching the receptor, therefore, if they are implemented to assist with determining dose to the public from a pathway, then an ALARA analysis is required. While the derived concentration standard values can be used in assessing the magnitude of the dose to the public, they are not recommended for use in public dose estimates as they are likely to produce doses that are overly conservative. For this reason, they are not used to demonstrate compliance with DOE radiation protection dose limits. A detailed pathway analysis is required for calculating public radiation doses resulting from DOE activities.

dose—In this document, dose is used exclusively to refer to a radiological dose, defined as the energy imparted to matter by ionizing radiation. Dose can also refer to chemical dose, but chemical dose is not discussed in this report.

> **effective dose**—A measure of the potential biological risk of health effects due to exposure to radiation measured in millirem (1 millirem = 0.01 millisievert). In this document, the term effective dose is often shortened to dose.
>
> **population dose**—The sum of the effective doses to all persons in a specified population measured in units of person-rem (or person-sievert).
>
> **absorbed dose**—The total amount of energy absorbed per unit mass (the amount of energy deposited in body tissue) as a result of exposure to radiation. The unit of absorbed dose is the rad, equal to 0.01 joule per kilogram in any medium (1 rad = 0.01 gray).

downgradient—The direction that groundwater flows; similar to downstream for surface water.

downgradient well—A well installed downgradient of a site that may be capable of detecting migration of contaminants from a site.

duplicate sample—A sample collected from the same location at the same time and using the same sampling device (if possible) as the regular sample.

effluent—A liquid or gaseous discharge to the environment.

effluent monitoring—The collection and analysis of samples or measurement of liquid and gaseous effluents to characterize and quantify the release of contaminants, assess radiation exposures to the public, and demonstrate compliance with applicable standards.

Environmental Restoration—A DOE program that directs the assessment and cleanup of its sites (remediation) and facilities (decontamination and decommissioning) contaminated as a result of nuclear-related activities.

exposure (radiation)—The incidence of radiation on living or inanimate material by accident or intent. Background exposure is the exposure to natural background ionizing radiation. Occupational exposure is exposure to ionizing radiation that takes place at a person’s workplace. Population exposure is the exposure to the total number of persons who inhabit an area.

external radiation—Exposure to ionizing radiation when the radiation source is located outside the body.

gamma ray—High-energy, short-wavelength electromagnetic radiation emitted from the nucleus of an excited atom. Gamma rays are identical to X-rays except for the source of the emission.

groundwater—Any water found below the land surface.

half-life, radiological—The time required for half of a given number of atoms of a specific radionuclide to decay. Each nuclide has a unique half-life; half-lives can range in duration from less than a second to many millions of years.

in situ—In its original place. Describes field measurements taken without removing the sample from its original location, or remediation performed while the contaminated media, such as groundwater or soil, remains below the surface or in place.

industrial solid waste landfill—A type of landfill that exclusively disposes of solid waste generated by manufacturing or industrial operations.

interim remedial measure—Cleanup activities initiated after it has been determined that contamination or waste disposal practices pose an immediate threat to human health or the environment. These measures are implemented until a more permanent solution can be made.

internal radiation—Occurs when radionuclides enter the body, for example, by ingestion of food or liquids, by inhalation, or through an open wound.

irradiation—Exposure to external radiation.

isotopes—Forms of an element having the same number of protons but differing numbers of neutrons in their nuclei.

maximally exposed individual—A hypothetical individual who—because of realistically assumed proximity, activities and habits—would receive the highest radiation dose, taking into account all pathways, from a given event, process, or facility. Defined by DOE Order 458.1.

maximum contaminant level—The maximum permissible level of a contaminant in drinking water provided by a public water system.

migration—The transfer or movement of a material through air, soil, or groundwater.

millirem—The dose that is one-thousandth of a rem.

monitoring—The process of periodically measuring the quantity and quality of factors that can affect the environment or human health to regulate and control potential impacts.

nuclide—An atom specified by atomic weight, atomic number, and energy state.

outfall—The point of conveyance, such as a drain or pipe, of wastewater or other effluents into a ditch, pond, or river.

part per billion—A unit measure of concentration equivalent to the weight to volume ratio expressed as microgram per liter (µg/L) or the weight to weight ratio of microgram per kilogram (µg/kg).

part per million—A unit measure of concentration equivalent to the weight-to-volume ratio expressed as milligrams per liter (mg/L), the weight to weight ratio expressed as milligrams per kilogram (mg/kg), or the weight to weight ratio expressed as micrograms per gram (µg/g).

perfluoroalkyl and polyfluoroalkyl substances—A group of manmade chemicals, collectively abbreviated as PFAS, used in nonstick products, such as Teflon, water- and stain-repellant fabrics, and firefighting foam, among others. PFAS are also used in the aerospace, automotive, construction, electronics, and military industries. Certain types of PFAS may have negative health effects for humans and the environment.

person-rem—A unit of measure for the collective dose to a population group. For example, a dose of 1 rem to 10 individuals results in a collective dose of 10 person-rem.

pH—A measure of the hydrogen ion concentration in an aqueous solution. Acidic solutions have a pH from 0 to 7, neutral solutions have a pH equal to 7, and basic solutions have a pH from 7 to 14.

polychlorinated biphenyls—Man-made chemicals that range from oily liquids to waxy solids. Polychlorinated biphenyls were used in hundreds of industrial and commercial applications due to their chemical properties until production in the United States ceased in 1977. Polychlorinated biphenyls have been demonstrated to cause a variety of adverse health effects in animals and may cause cancer and other adverse health effects in humans.

quality assurance—Any action in environmental monitoring to demonstrate the reliability of monitoring and measurement data.

quality control—The routine application of procedures to obtain the required standards of performance in monitoring and measurement processes.

rad—The unit of absorbed dose deposited in a volume of material.

radioactivity—The spontaneous emission of radiation, generally alpha or beta particles or gamma rays, from the nucleus of an unstable isotope.

radionuclide—A radioactive nuclide capable of spontaneously transforming into other nuclides by changing its nuclear configuration or energy level. This transformation is accomplished by emitting photons or particles.

rem—The unit used to measure dose (absorbed dose in rads multiplied by the radiation quality factor). Dose is frequently reported in millirem (mrem), which is one-thousandth of a rem.

remediation—The correction or cleanup of a site contaminated with waste. See Environmental Restoration.

reportable quantity—A release to the environment that exceeds the quantity that must be reported as defined by the Comprehensive Environmental Response, Compensation, and Liability Act.

Resource Conservation and Recovery Act—Federal legislation that regulates the transport, treatment, and disposal of solid and hazardous wastes.

riparian—Related to the banks of a river or wetlands adjacent to rivers and streams.

source—A point or object from which radiation or contamination emanates.

Superfund—The program operated under the legislative authority of the Comprehensive Environmental Response, Compensation, and Liability Act and Superfund Amendments and Reauthorization Act that funds and conducts US EPA emergency and long-term removal and remedial actions.

surface water—All water on the surface of the earth, as distinguished from groundwater.

suspended solids—Particles suspended in water, such as silt or clay, which can be trapped by a filter.

terrestrial radiation—Ionizing radiation emitted from radioactive materials in the earth's soils such as potassium-40, radon, thorium, and uranium. Terrestrial radiation contributes to natural background radiation.

transuranics—Elements, such as americium, plutonium, and neptunium, that have atomic numbers (the number of protons in the nucleus) greater than 92, which is the number of protons in uranium. All transuranics are radioactive.

trichloroethene—A colorless liquid used in many industrial applications as a cleaner or solvent; one of many chemicals that is classified as a volatile organic compound. High levels of trichloroethene may cause health effects such as liver and lung damage and abnormal heartbeat; moderate levels may cause dizziness or headache. The US EPA Integrated Risk Information System characterizes trichloroethene as carcinogenic to humans by all routes of exposure. This conclusion is based on convincing evidence of a causal association between trichloroethene exposure in humans and kidney cancer.

trip blank—A quality control sample of water that accompanies sample containers from the analytical laboratory to the field sampling location where environmental samples are collected, then back to the analytical laboratory to determine whether environmental samples have been contaminated during transport or shipment or by site conditions.

turbidity—A measure of the concentration of sediment or suspended particles in a liquid.

upgradient—In the opposite direction of groundwater flow; similar to upstream for surface water.

upgradient well—A well installed upgradient of a site to provide data to compare to a downgradient well to determine whether the site is affecting groundwater quality.

volatile organic compounds—Organic, or carbon-containing, compounds that evaporate readily at room temperature. These compounds are present in solvents, degreasers, paints, thinners, and fuels. Due to factors including widespread industrial use, they are commonly found as contaminants in soil and groundwater. Volatile organic compounds include trichloroethene, vinyl chloride, benzene, and dichloroethenes.

weighting factor for radiation—In radiation, the factor by which an absorbed dose (rad) is multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage to an exposed person. The weighting factor is used because some types of radiation, such as alpha particles, are more biologically damaging than others.

weighting factor for tissue—A tissue-specific number that represents the fraction of the total potential health risk resulting from uniform, whole body irradiation to the specific organ or tissue such as bone marrow, lungs, or thyroid.

wetland—An area that is inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and under normal circumstances does support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, floodplains, fens, and similar areas. A jurisdictional wetland is one that falls under state or federal regulatory authority; a non-jurisdictional wetland does not.

Appendix B:
Introduction to Radiation

Appendix B Introduction to Radiation

The information presented in this appendix summarizes concepts pertaining to radiation and radioactivity that the reader may find useful in understanding and interpreting the radiological information presented in this Annual Site Environmental Report (ASER).

B.1 What is Radiation?

Radiation is energy (Figure B.1). It can come from unstable atoms that undergo radioactive decay, or it can be produced by machines. Radiation travels from its source in the form of energy waves or particles. There are two kinds of radiation: non-ionizing radiation and ionizing radiation.

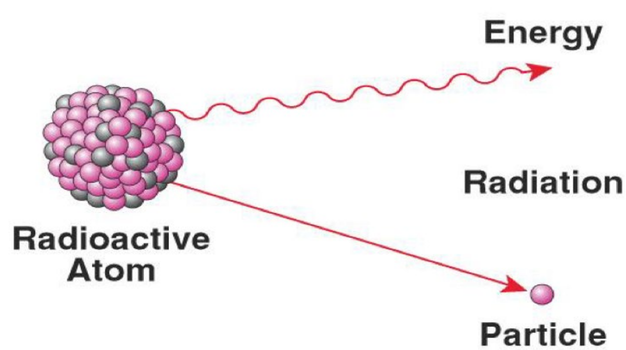


Figure B.1. Radioactive atom showing ionizing radiation

Non-Ionizing radiation

Non-ionizing radiation has enough energy to move atoms in a molecule around or cause them to vibrate but not enough to remove electrons from atoms. Examples of this kind of radiation are radio waves, visible light, and microwaves.

Ionizing radiation

Ionizing radiation has so much energy that it can knock electrons out of atoms, a process known as ionization. Examples of ionizing radiation include alpha and beta particles, gamma rays, and x-rays. Ionizing radiation can affect atoms in living things and cause biological damage that is potentially harmful to human health. Ionizing radiation comes from x-ray machines, cosmic particles from outer space, and radioactive elements. Radioactive elements emit ionizing radiation as their atoms undergo radioactive decay. As used in this ASER and the remainder of this appendix, the term radiation refers only to ionizing radiation.

Radioactive decay

Radioactive decay is the emission of energy in the form of ionizing radiation. The ionizing radiation that is emitted can include alpha particles, beta particles, and gamma rays.

Types of ionizing radiation

Alpha particles

Alpha particles are positively charged and are made up of two protons and two neutrons that are emitted from the atom's nucleus during radioactive decay. Alpha particles come from the heaviest radioactive elements such as uranium, radium, and polonium. Although alpha particles are very energetic, they are so heavy that they use up their energy over short distances and are unable to travel very far from the atom. Alpha particles can be stopped by thin layers of materials, such as the outer layer of your skin or a sheet of paper (see Figure B.2).

The health effect from exposure to alpha particles depends on how a person is exposed. Because alpha particles lack the energy to penetrate even the outer layer of skin, exposure to the outside of the body is not a major concern. Inside the body, however, they can be very harmful. If alpha particles are inhaled or swallowed, or get into the body through a cut, they can damage sensitive living tissue. Examples of alpha emitting-radionuclides include radioactive atoms of uranium, plutonium, and americium.

Beta particles

Beta particles are small, fast-moving particles with a negative electrical charge that are emitted from an atom's nucleus during radioactive decay. These particles are emitted by certain unstable atoms such as tritium, carbon-14, and strontium-90. Beta particles travel farther in air than alpha particles but can be stopped by a layer of clothing or by a thin layer of a substance such as aluminum foil, plastic, or wood (see Figure B.2).

The ability of beta particles to penetrate matter increases with energy. Some beta particles are capable of penetrating the skin and causing damage such as skin burns; however, as with alpha particles, beta particles are most hazardous when they are inhaled or swallowed. An example of a beta-emitting radionuclide is technetium.

Gamma rays

Gamma rays are weightless packets of energy called photons. Unlike alpha and beta particles, which have both energy and mass, gamma rays are pure energy. Gamma rays are similar to visible light but have much higher energy. Gamma rays are often emitted along with alpha or beta particles during radioactive decay.

Gamma rays are a radiation hazard for the entire body. They can easily penetrate barriers, such as skin and clothing, which can stop alpha and beta particles. Gamma rays have so much penetrating power that several inches of a dense material (like lead or even a few feet of concrete) may be required to stop them (see Figure B.2). Gamma rays can pass completely through the human body, and they can cause damage to tissue and cells as they pass through. An example of a gamma-emitting radionuclide is cesium.

X-rays

Because of their use in medicine, almost everyone has heard of X-rays. X-rays are similar to gamma rays in that they are photons of pure energy. X-rays and gamma rays have the same basic properties but come from different parts of the atom. X-rays are emitted from the processes outside the nucleus, and gamma rays originate inside the nucleus. X-rays are also generally lower in energy and, therefore, are less penetrating than gamma rays. X-rays can be produced naturally or by machines using electricity.

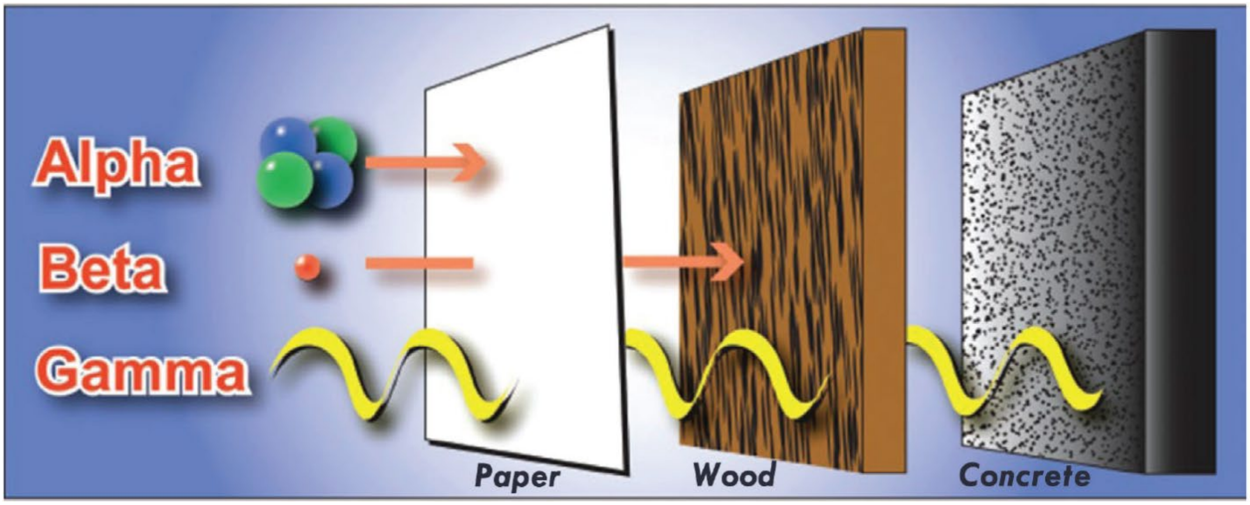


Figure B.2. Comparison of penetrating ability of alpha, beta, and gamma radiation

B.2 What is a Radionuclide?

Elements in the periodic table can take on several forms. Some of these forms are stable; other forms are unstable. The most stable form of an element is usually the most common in nature; however, all elements have an unstable form. Unstable forms emit ionizing radiation and are radioactive. Some elements have no stable form and are always radioactive such as uranium. Elements that emit ionizing radiation are called radionuclides.

When a radionuclide decays, it transforms into a different atom called a decay product. These atoms keep transforming into new decay products until they reach a stable state and are no longer radioactive. Radionuclides that decay in more than one step are called series radionuclides. The series of decay products created by these radionuclides is called a decay chain. Each series has its own unique decay chain.

Every radionuclide has a specific decay rate, which is measured in terms of half-life. Radioactive half-life is the time required for half of the radioactive atoms present to decay. Some radionuclides have half-lives of mere seconds, but others have half-lives of hundreds, millions, or billions of years.

Radionuclides in this report are expressed in different ways but each expression identifies the same radionuclide. For example, a common radionuclide of uranium may be expressed as uranium-238 or U-238.

B.3 What are Some Radionuclides of Concern?

Some radionuclides of concern include uranium-234, uranium-235, uranium-238, thorium-230, technetium-99, plutonium-238, plutonium-239, plutonium-240, neptunium-237, americium-241, and cesium-137. Appendix C lists these radionuclides along with their associated half-lives.

B.4 What is Radioactivity and How is it Measured?

As radionuclides decay, they emit one or more types of radiation at characteristic energies that can be measured and used to identify the radionuclide. Detection instruments measure the quantity of radiation emitted over a specified time. The number of decay events (nuclear transformations) over a fixed time can be calculated from this measurement.

Radioactivity is measured in curies (Ci) or becquerels (Bq). One Ci, based on the rate of decay of one gram of radium-226, is defined as the quantity of any radionuclide that undergoes an average transformation rate of 37 billion transformations per second. In the International System of Units, one Bq is equal to one transformation per second. In this ASER, radioactivity is usually expressed in Ci.

B.5 What is Dose and How is it Measured?

The possible effects of radiation must be measured to determine its potential to cause damage. The amount of energy absorbed by a material that receives radiation is measured in rads. A rad is 100 ergs of radiation energy absorbed per gram of material. Dose is a means of expressing the amount of energy absorbed, taking into account the effects of different kinds of radiation.

Alpha, beta, and gamma radiation affect the body to different degrees. Each type of radiation is given a quality factor that indicates the amount of human cell damage it can cause, compared with equal amounts of other ionizing radiation energy. Alpha particles cause 20 times as much damage to internal tissues as X-rays, so alpha radiation has a quality factor of 20 compared to gamma rays, X-rays, and beta particles, each of which has a quality factor of one.

The unit of dose measurement to humans is the roentgen equivalent man (rem). The number of rem is equal to the number of rads, multiplied by a quality factor for each type of radiation. For radiation protection purposes, 1 rem of any type of radiation has the same damaging effect.

Exposures to radiation from radionuclides outside the body are called external exposures; exposures to radiation from radionuclides inside the body are called internal exposures. This distinction is important because external exposure occurs only as long as a person is near the radionuclide; simply leaving the area of the source will stop the exposure. Internal exposure continues as long as the radionuclide remains inside the body. Radiation exposures to the human body, whether from external or internal sources, can involve all or a portion of the body. To enable radiation protection specialists to express exposures to portions of the body (and the accompanying doses) in terms of an equal dose to the whole body, the concept of effective dose was developed.

Unless otherwise noted, the generic term dose used in this report is the total effective dose to a person, which includes both the effective dose that can be attributed to sources outside the body and the committed effective dose from radionuclides deposited inside the body, which is based on a lifetime accumulated dose. For an adult, the lifetime accumulated dose is based on 50 years. Using the total effective dose allows doses from different types of radiation and to different parts of the body to be expressed on the same basis.

B.6 How are Radioactivity and Dose Reported?

Scientific notation

Concentrations of radionuclides detected in the environment are typically quite small. Scientific notation is used to express numbers that are very small or very large. A very small number may be expressed with a negative exponent, for example 1.5E-03 (or 1.5×10^{-3}). To convert this number to its decimal form, move the decimal point left by the number of places equal to the exponent. In this example, moving the decimal point 3 places to the left shows that the number 1.5E-03 may also be expressed as 0.0015. For large numbers with a positive exponent, such as 1.5E+06 (or 1.5×10^{6}), move the decimal point to the right by the number of places equal to the exponent. In this case, 1.5E+06 may also be written as 1,500,000, or 1.5 million. Units for very small and very large numbers are often expressed with a prefix. For example, the prefix kilo (abbreviated as k) means 1,000 of a given unit. One kilometer, therefore, equals 1,000 meters. Table B.1 defines the values of radiation-related prefixes used in this ASER.

Table B.1. Commonly used numerical prefixes

Multiple	Decimal equivalent	Prefix	Symbol
10^{-3}	0.001	milli	m
10^{-6}	0.000001	micro	µ
10^{-12}	0.000000000001	pico	p

Concentrations of radioactivity in environmental sample media

Radiological environmental samples identify the concentration of radioactivity using the following units of measure:

- Air samples use the term microcuries per milliliter (µCi/mL).
- Liquid samples use the term picocuries per liter (pCi/L).
- Sediment samples use the term picocuries per gram (pCi/g).
- Radiation exposure measured by environmental dosimeters uses the term millirem (mrem).

Dose

This ASER expresses dose in standard units, followed by the equivalent International System of Units, or SI units, in parentheses when applicable. SI is the official system of measurement used internationally to express units of radioactivity and radiation dose. The basic SI unit of radioactivity is the becquerel (Bq), which is equivalent to one nuclear disintegration per second. Multiply the number of curies by 3.7×10^{10} to obtain the equivalent number of becquerels. The concept of dose may also be expressed using the SI units: gray (Gy) for absorbed dose (1 Gy = 100 rad) and sievert (Sv) for effective dose (1 Sv = 100 rem). Table B.2 shows the names and symbols for measurements used to describe radioactivity and dose.

Table B.2. Names and symbols for units of radioactivity and radiological dose

Symbol	Name
Ci	curie (1 Ci = 3.7×10^{10} disintegrations per second)
pCi	picocurie (1 pCi = 1×10^{-12} Ci)
rad	radiation absorbed dose (100 rad = 1 Gy)
mrem	millirem (1 mrem = 1×10^{-3} rem)
Bq	Becquerel (1 Bq = 1 disintegration per second)
Sv	Sievert (1 Sv = 100 rem)
mSv	milliSievert (1×10^{-3} Sv)
Gy	Gray (1 Gray = 100 rad)
mGy	milliGray (1 mGy = 1×10^{-3} Gy)

B.7 What is an Exposure Pathway?

An exposure pathway is how a radioactive material is released to the environment, transported to a receptor (a person, animal, or plant), and comes into contact with a receptor. Figure B.3 illustrates common exposure pathways. Most people come into contact with released radioactive material via one of the following routes:

- Inhaling gases and particulates

- Ingesting vegetables, crops, wild game, milk, and fish
- Ingesting surface water and groundwater
- Absorbing the material through the skin (also called dermal absorption)
- External exposure to ionizing radiation

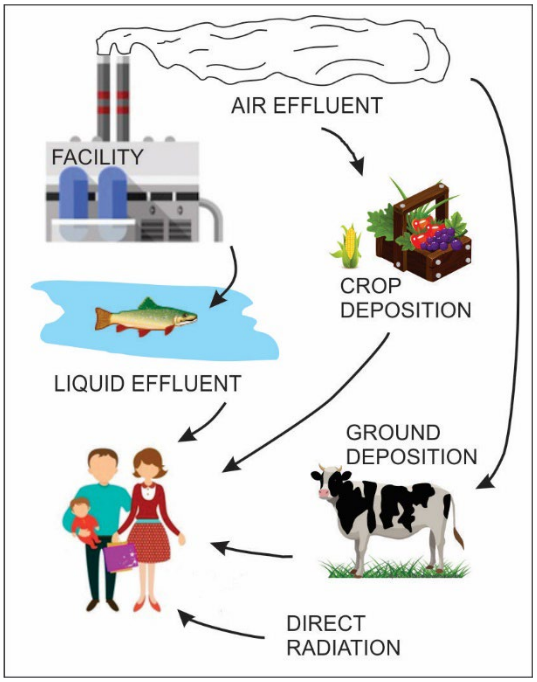
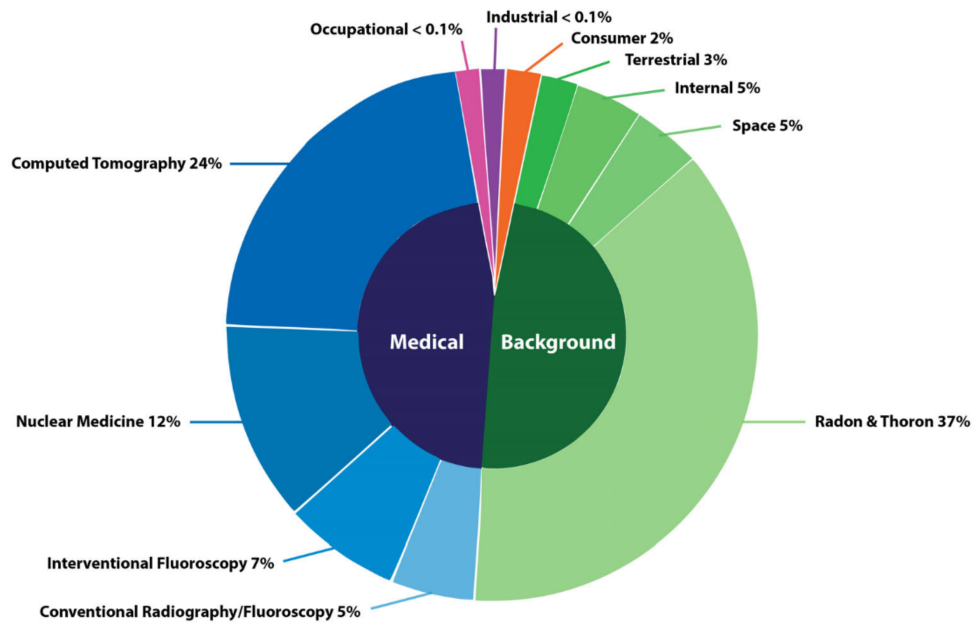


Figure B.3. Potential exposure pathways

B.8 What Radiation Sources and Doses are we Exposed to?

Sources of radiation are around us at all times. Everyone is routinely exposed to radiation from natural sources, such as minerals in the ground, and man-made sources such as medical X-rays. Radiation has the same effect on people, whether it is natural or man-made. According to the National Council on Radiation Protection and Measurements Report No. 160, *Ionizing Radiation Exposure of the Population of the United States*, the average annual radiation dose per person in the US is about 620 mrem (6.2 mSv). Figure B.4 shows the various sources of exposure and the contributions of these sources to the total collective dose for the US population in 2006. Actual doses vary depending on such factors as geographic location, building ventilation, and personal habits.

To estimate your average annual yearly dose from the most significant sources of ionizing radiation, use the online calculator on the US EPA website, which can be found here.



Average Annual Radiation Dose

Sources	Radon & Thoron	Computed Tomography	Nuclear Medicine	Interventional Fluoroscopy	Space	Conventional Radiography/ Fluoroscopy	Internal	Terrestrial	Consumer	Occupational	Industrial
Units mrem (United States) mSv (International)	228 mrem 2.28 mSv	147 mrem 1.47 mSv	77 mrem 0.77 mSv	43 mrem 0.43 mSv	33 mrem 0.33 mSv	33 mrem 0.33mSv	29 mrem 0.29 mSv	21 mrem 0.21 mSv	13 mrem 0.13 mSv	0.5 mrem 0.005 mSv	0.3 mrem 0.003 mSv

(Source: National Council on Radiation Protection & Measurements, Report No. 160)

Figure B.4. Sources of radiation exposure

Natural sources of radiation

Naturally occurring radioactive minerals in the ground, soil, and water produce background radiation, which accounts for 50 percent of the radiation received by the US population. The human body even contains some of these naturally occurring radioactive minerals. Cosmic radiation from space also contributes to the background radiation around us. Natural background radiation levels can vary significantly from place to place and in the same location over time. The paragraphs below provide more detail on natural sources of background radiation.

External exposure from space (cosmic radiation)

The earth's atmosphere and magnetic shield protect us from cosmic radiation. Earth's magnetic shield is strongest at the equator and weakest near the poles. The magnetic shield diverts most of the cosmic radiation around the earth. Earth's atmosphere shields us from most of the remaining cosmic radiation that travels to earth. People who live at a higher altitude, like Denver, Colorado, are exposed to slightly more cosmic radiation than people who live at a lower altitude.

Cosmic radiation also produces cosmogenic radionuclides by the interaction of cosmic radiation within the atmosphere or in the earth. The energy from this cosmic radiation blasts apart atoms in the earth's atmosphere and continuously produces radionuclides such as tritium, beryllium-7, sodium-22, and carbon-14. Cosmogenic radionuclides, particularly tritium and carbon-14, have been measured in humans, animals, plants, soil, polar ice, surface rocks, sediments, the ocean floor, and the atmosphere. The average annual radiation exposure from cosmic radiation is about 33 mrem.

External exposure from terrestrial radiation (primordial radionuclides)

The primordial radionuclides detected today are billions of years old. The external radiation dose to a person from primordial radionuclides comes from radiation emitted from radioactive materials in the earth's rocks, soils, and minerals. Uranium and thorium, which are naturally found in the earth, are the main source of terrestrial radiation. Trace amounts of uranium, thorium, and their decay products can be found everywhere. Terrestrial radiation dose levels vary by location, but areas with higher concentrations of uranium and thorium in surface soils generally have higher dose levels. The average annual radiation exposure from terrestrial radiation is about 21 mrem.

Internal exposure from inhalation of radon, thoron, and their decay products

Radon is an inert gas that comes from the natural breakdown of uranium in soil, rock, and water. Radon can accumulate in buildings and can get into the air we breathe through cracks, crevices, openings in the foundation or from bricks, and other building materials. Radon gas is not visible and has no odor or taste. It is the second leading cause of lung cancer in the United States after smoking. As shown in Figure B.3, radon, thoron, and their decay products are responsible for most of the annual effective dose (about 228 mrem) from background radiation produced by naturally occurring radionuclides. Radon levels vary widely across the United States. State programs work in partnership with US EPA to provide education and awareness of the health hazards caused by radon.

Internal exposures from radionuclides in the body

Traces of radioactive materials can be found in our bodies; they include potassium-40, the thorium-232 series, and the uranium-238 series. The primary source is potassium-40, which is found in food we ingest—primarily fruits and vegetables. Radionuclides from the thorium-232 and uranium-238 series are found in food and water we ingest. Our bodies contain small amounts of radiation because the body metabolizes the nonradioactive and radioactive forms of potassium and other elements in the same way.

Man-made sources of radiation

In addition to natural sources of radiation, most people are exposed to man-made sources of radiation through medical procedures and consumer products.

Medical

Medical sources are the main source of exposure to the average American from man-made radiation, making up 48 percent of the total dose. This total does not include dose from radiation therapy used in the treatment of cancer, which is typically many times larger. The average annual effective dose from medical sources is roughly 300 mrem and includes medical imaging and nuclear medicine.

Medical imaging

Radiation is used in many medical imaging procedures, which deliver X-ray beams to a specific part of the body, creating a digital image or film that shows the structures inside—like bones, tissues, and organs. Healthcare providers can use these images to find out what is causing the health problem (diagnostics) or to guide treatment. Medical imaging does not distribute radionuclides uniformly throughout the body, so the concept of effective dose, which relates the significance of exposure of organs and body parts to the effect on the entire body, is useful in making comparisons. Medical imaging tests which use ionizing radiation are as follows:

- Computed tomography (CT): This medical imaging test uses X-rays to create cross-sectional pictures, like slices, inside selected areas of the body from different angles. The images can show internal organs, blood vessels, soft tissues, and bones. CT scans combine a series of X-ray images into a three-dimensional picture. Common uses of CT scans include checking for tumors, infections, blood clots, and internal bleeding. These tests provide an average annual effective dose of 147 mrem.

- Interventional fluoroscopy: This uses x-rays to create a real-time image to guide small instruments, such as catheters through blood vessels, or other pathways in the body. This process provides an average annual effective dose of 43 mrem.
- Conventional radiography and fluoroscopy: Radiography is the use of X-ray machines by health care providers and dentists to pass X-ray beams through a part of the body to produce images of the tissues, organs, bones, or teeth inside. Fluoroscopy is a medical technique that takes real-time moving images of internal structures in the body by placing a patient between a fluorescent screen and an X-ray source. These processes provide an average annual effective dose of 33 mrem.

Nuclear medicine

Nuclear medicine uses radioactive material inside the body to see how organs or tissue are functioning (diagnostic) or to target and destroy damaged or diseased organs or tissues (treatment). Nuclear medicine does not distribute radionuclides uniformly throughout the body, so the concept of effective dose, which relates the significance of exposure of organs and body parts to the effect on the entire body, is useful in making comparisons. The average annual dose from nuclear medicine is 77 mrem.

For most diagnostic procedures, a tracer containing the radioactive material is injected, swallowed, or inhaled. Then the healthcare provider or radiologist uses a radiation detector to see how much of the tracer is absorbed or how it reacts in the organ or tissue. This gives the healthcare provider information on how well the organ or tissue is functioning. Common uses of nuclear medicine for diagnosis include scans of the heart, lung, kidneys, gallbladder, and thyroid.

When nuclear medicine is used in treatment, the tracer targets a harmful organ or tissue and radioactivity damages or stops growth of its cells. Two common uses of nuclear medicine for treatment include radioactive iodine therapy and brachytherapy, a form of radiation treatment where a sealed radiation source is placed inside or next to the area requiring treatment.

Consumer products and activities

The average annual effective dose to an individual from consumer products and activities is about 13 mrem. Cigarette smoke accounts for 35 percent of the dose from consumer products and activities. Building materials account for 27 percent of this dose. Commercial air travel accounts for 26 percent, mining and agriculture account for 6 percent, miscellaneous consumer-oriented products account for 3 percent, combustion of fossil fuels accounts for 2 percent, and highway and road construction materials account for 0.6 percent.

Industrial and occupational

Other sources of radiation include emissions of radioactive materials from nuclear facilities such as uranium mines, fuel processing plants, and nuclear power plants; transportation of radioactive materials; and mineral extraction facilities. The average annual radiation exposure to the general public from these sources has been estimated at less than 1 mrem per year.

B.9 What are the Potential Health Effects of Radiation Exposure?

The three primary pathways by which people may be exposed to radiation are direct exposure, inhalation, and ingestion. Exposure from radiation may be from a source outside the body (external exposure) or from radioactive particles that have been taken in by breathing or eating and have become lodged inside the body (internal exposure). Radionuclides that are taken in are not distributed the same way throughout the body. Radionuclides of strontium, plutonium, and americium concentrate in the skeleton, while iodine concentrates in the thyroid. Some radionuclides, such as tritium, carbon-14, or cesium-137, however, are distributed throughout the body.

The human body has mechanisms that repair damage from exposure to radiation, but these repair processes are not always successful. Living tissue in the human body can be damaged by ionizing radiation. The severity of the damage depends upon several factors such as the following:

- The amount of exposure (low or high)
- The duration of the exposure (long-term—known as chronic, or short-term—known as acute)
- The type of radiation (alpha, beta, or gamma radiations of various energies)
- The sensitivity of the human (or organ) receiving the radiation

The greatest risk from exposure to ionizing radiation is cancer. Much of our knowledge about the risk is based on studies of more than 100,000 survivors of the atomic bombs in Hiroshima and Nagasaki, Japan, at the end of World War II. Studies of radiation industry workers and people receiving large doses of medical radiation are also important sources of information. Scientists have gained the following important information from these studies:

- The chance of developing cancer (not the seriousness or severity of the cancer) increases as the radiation dose increases.
- Cancers caused by radiation do not appear until years after the radiation exposure.
- Some people are more likely to develop cancer from radiation exposure than others.
- For people who receive low doses of radiation, the risk of cancer from radiation exposure is so small that it is not distinguishable from cancer caused by exposure to chemicals, genetics, smoking, or diet.

Appendix C:
Radionuclide and Chemical Names

Appendix C Radionuclide and Chemical Names

Table C.1. Names and abbreviations for elements and chemical constituents

Constituent	Symbol
Aluminum	Al
Ammonia	NH_3
Antimony	Sb
Arsenic	As
Barium	Ba
Beryllium	Be
Cadmium	Cd
Calcium	Ca
Chromium	Cr
Cobalt	Co
Copper	Cu
Iron	Fe
Lead	Pb
Magnesium	Mg
Manganese	Mn

Constituent	Symbol
Mercury	Hg
Nickel	Ni
Nitrogen	N
Nitrate ion	NO_{3-}
Nitrite ion	NO_{2-}
Phosphate ion	PO_4^{2-}
Potassium	K
Selenium	Se
Silver	Ag
Sodium	Na
Sulfate ion	SO_{4-}
Thallium	Tl
Uranium	U
Vanadium	V
Zinc	Zn

Table C.2. Selected names, abbreviations, and half-life for radionuclides

Radionuclide	Symbol	Half-life (years)
Americium-241	Am-241	432.2
Cesium-137	Cs-137	30.1671
Neptunium-237	Np-237	2,144,000
Plutonium-238	Pu-238	87.7
Plutonium-239	Pu-239	24,110
Plutonium-240	Pu-240	6,564
Technetium-99	Tc-99	211,100
Thorium-228	Th-228	1.9116
Thorium-230	Th-230	75,380
Thorium-232	Th-232	14,050,000,000
Uranium-233	U-233	159,200
Uranium-234	U-234	245,500
Uranium-235	U-235	704,000,000
Uranium-236	U-236	23,420,000
Uranium-238	U-238	4,468,000,000

Source: DOE-STD-1196-2022, *Derived Concentration Technical Standard*, Table 9.

Note:
Not all of the radionuclides listed above are found at the Paducah Site.

Appendix D:
Units of Measure

Appendix D Units of Measure

Due to differing permit reporting requirements and instrument capabilities, various units of measurement are used in this report. This list of units of measure and conversion factors is intended to help readers make approximate conversions to other units, as needed, for specific calculations and comparisons.

Table D.1. Units of measure and their abbreviations

becquerel	Bq	micrometer	µm
British thermal unit	Btu	millicurie	mCi
centimeter	cm	milligram	mg
curie	Ci	milliliter	mL
day	d	millimeter	mm
degrees Celsius	°C	million	M
degrees Fahrenheit	°F	million gallons per day	MGD
disintegrations per minute	dpm	millirad	mrad
foot	ft	millirem	mrem
gallon	gal	milliroentgen	mR
gallons per minute	gal/min	millisievert	mSv
gram	g	minute	min
gray	Gy	nanogram	ng
gross square feet	gsf	parts per billion	ppb
hectare	ha	parts per million	ppm
hour	h	parts per trillion	ppt
inch	in.	picocurie	pCi
joule	J	pound	lb
kilocurie	kCi	pound mass	lbm
kilogram	kg	pounds per square inch	psi
kilometer	km	pounds per square inch gauge	psig
kilowatt	kW	quart	qt
linear feet	LF	radiation absorbed dose	rad
liter	L	roentgen	R
megajoule	MJ	roentgen equivalent man	rem
megawatt	MW	second	S
megawatt-hour	MWh	sievert	Sv
meter	m	standard unit (pH)	SU
metric tons	MT	ton (2,000 lb)	ton
microcurie	µCi	yard	yd
microgram	µg	year	yr

Table D.2. Quantitative prefixes

exa	$\times 10^{18}$	atto	$\times 10^{-18}$
peta	$\times 10^{15}$	femto	$\times 10^{-15}$
tera	$\times 10^{12}$	pico	$\times 10^{-12}$
giga	$\times 10^{9}$	nano	$\times 10^{-9}$
mega	$\times 10^{6}$	micro	$\times 10^{-6}$
kilo	$\times 10^{3}$	milli	$\times 10^{-3}$
hecto	$\times 10^{2}$	center	$\times 10^{-2}$
deka	$\times 10^{1}$	decic	$\times 10^{-1}$

Table D.3. Unit conversions

Unit	Conversion	Equivalent	Unit	Conversion	Equivalent
		Length			
in.	× 2.54	cm	cm	× 0.394	in.
ft	× 0.305	m	m	× 3.28	ft
mile	× 1.61	km	km	× 0.621	mile
		Area			
acre	× 0.405	ha	ha	× 2.47	acre
ft^2	× 0.093	m^2	m^2	× 10.764	ft^2
$mile^2$	× 2.59	km^2	km^2	× 0.386	$mile^2$
		Volume			
ft^3	× 0.028	m^3	m^3	× 35.31	ft^3
qt (US liquid)	× 0.946	L	L	× 1.057	qt (US liquid)
gal	× 3.7854118	L	L	× 0.264172051	gal
		Concentration			
ppb	× 1	µg/kg	µg/kg	× 1	ppb
ppm	× 1	mg/kg	mg/kg	× 1	ppm
ppb	× 1	µg/L	µg/L	× 1	ppb
ppm	× 1	mg/L	mg/L	× 1	ppm
		Weight			
lb	× 0.4536	kg	kg	× 2.205	lb
lbm	× 0.45356	kg	kg	× 2.2046226	lbm
ton, short	× 907.1847	kg	kg	× 0.00110231131	ton, short
		Temperature			
°C	°F = (9/5)°C + 32	°F	°F	°C = (5/9) (F–32)	°C
		Activity			
Bq	$\times 2.7 \times 10^{-11}$	Ci	Ci	$\times 3.7 \times 10^{10}$	Bq
Bq	× 27	pCi	pCi	× 0.037	Bq
mSv	× 100	mrem	mrem	× 0.01	mSv
Sv	× 100	rem	rem	× 0.01	Sv
nCi	× 1,000	pCi	pCi	× 0.001	nCi
mCi/km^2	× 1	nCi/m^2	nCi/m^2	× 1	mCi/km^2
dpm/L	$\times 0.45 \times 10^{9}$	$\mu Ci/cm^3$	$\mu Ci/cm^3$	$\times 2.22 \times 10^{9}$	dpm/L
pCi/L	$\times 10^{-9}$	µCi/mL	µCi/mL	$\times 10^{9}$	pCi/L
pCi/m^3	$\times 10^{12}$	$\mu Ci/cm^3$	$\mu Ci/cm^3$	$\times 10^{12}$	pCi/m^3