CALENDAR YEAR 2017 PADUCAH GASEOUS DIFFUSION PLANT ANNUAL SITE ENVIRONMENTAL REPORT (ASER): STUDENT SUMMARY

ABSTRACT

Student Summary of the DOE Paducah Gaseous Diffusion Plant Annual Site Environmental Report (ASER) document for 2017.

MARSHALL COUNTY HIGH SCHOOL

2019 - 2020 MCHS Ecology Classes

Calendar Year 2017

PADUCAH GASEOUS DIFFUSION PLANT ANNUAL SITE ENVIRONMENTAL REPORT (ASER): Student Summary

December 2020

Marshall County High School Ecology and Physics Students

Based on U.S. Department of Energy Paducah Gaseous Diffusion Plant Calendar Year 2017 Annual Site Environmental Report (ASER), September 2018 (FRNP-RPT-0022)

Prepared by

Kentucky Research Consortium for Energy and Environment

for

United States Department of Energy Portsmouth/Paducah Project Office

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Cover Photo: Tupelo Swamp located in the West Kentucky Wildlife Management Area in the vicinity of the Department of Energy's Paducah Gaseous Diffusion Plant Reservation.

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Message from the Department of Energy

Every calendar year the U.S. Department of Energy (DOE) conducts comprehensive environmental monitoring at the Paducah Gaseous Diffusion Plant (PGDP) site and nearby areas to ensure protection of human health and the environment. Each year the PGDP site publishes a summary of its environmental monitoring activities in a comprehensive Annual Site Environmental Report (ASER).

During the 2019-20 school year, Marshall County (Kentucky) High School Ecology and Advanced Placement (AP) Science students participated in classroom and field activities related to the DOE's *Paducah Site Environmental Report for Calendar Year 2017 (2017 ASER)*. Students compiled the results of their ASER review in the document *CALENDAR YEAR 2017 ANNUAL SITE ENVIRONMENTAL REPORT (ASER): Student Summary Report*.

Environmental work at DOE's facilities is technically complex and challenging. The scale of the PGDP industrial complex, its infrastructure and impacts on the surface and subsurface environment magnify the technical complexities faced by the DOE in its management and cleanup efforts. Beginning in 2014 DOE's challenges increased with the shutdown of PGDP's enrichment operations and the preparation for the dismantling of enrichment process facilities.

The annual ASER Student Summary Report is an important tool DOE uses to explain the comprehensive PGDP environmental monitoring and remediation programs to stakeholders and the public. PGDP environmental data collected from soil, surface water, sediment, air, and groundwater during 2017 indicated that the site was in compliance with regulatory and human health standards and was also actively pursuing the remediation of on-site sources of environmental contamination and the deactivation and dismantlement of the site's industrial facilities and infrastructure.

The PGDP site sincerely appreciates the work of the students and staff at Marshall County High School in the production of the *CALENDAR YEAR 2017 ANNUAL SITE ENVIRONMENTAL REPORT (ASER): Student Summary Report.* On behalf of the entire Department of Energy, we congratulate each of you for your effort, enthusiasm, and willingness to support DOE with this project.

We hope that you enjoy the *CALENDAR YEAR 2017 ANNUAL SITE ENVIRONMENTAL REPORT (ASER): Student Summary Report.*

Sincerely,

Jennifer Woodard, DOE Paducah Site Lead

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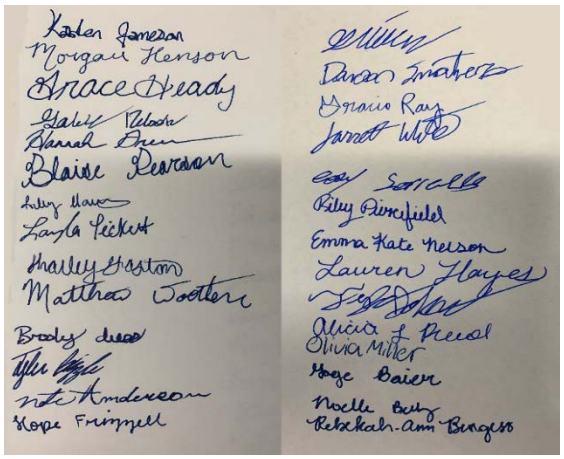
Credits

Letter from Class

Dear Reader,

The students of Mrs. Marshall's Ecology and AP Physics classes at Marshall County High School collaborated to create this Student Summary of the U.S Department of Energy Paducah Gaseous Diffusion Plant (PGDP) Calendar Year 2017 Annual Site Environmental Report (ASER). We hope this report helps you understand the history and importance of the PGDP, what industrial operations related to uranium enrichment occurred at the PGDP and what activities the DOE conducted in 2017 to ensure compliance with environmental laws and regulations.

We are thankful for the opportunity to explore the PGDP and learn about uranium enrichment. The nearly 80 students that participated in the preparation of this ASER Summary report are listed below.



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Acronyms

AEC	Atomic Energy Commission
ASER	Annual Site Environmental Report
CAB	Paducah Citizens Advisory Board
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CY	Calendar Year
D&D	Decontamination and Decommissioning
DOE	United States Department of Energy
EIS	Environmental Impact Statement
EPA	U.S. Environmental Protection Agency
FFA	Federal Facility Agreement
FY	Fiscal Year
GW	Groundwater
KAR	Kentucky Administrative Regulations
KDAQ	Kentucky Division of Air Quality
KDEP	Kentucky Department for Environmental Protection
KDWM	Kentucky Division of Waste Management
KOW	Kentucky Ordinance Works
KPDES	Kentucky Pollutant Discharge Elimination System
LLW	low-level (radioactive) waste
MCL	maximum contaminant level
MEI	maximally exposed individual
MW	monitoring well
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NOV	Notice of Violation
NPL	National Priorities List
OREIS	Oak Ridge Environmental Information System
PGDP	Paducah Gaseous Diffusion Plant
PEGASIS	PPPO Environmental Geographic and Spatial Information System
PPPO	Portsmouth/Paducah Project Office
QA	quality assurance
QC	quality control
RCRA	Resource Conservation and Recovery Act
RGA	Regional Gravel Aquifer
SMP	Site Management Plan
SWMU	solid waste management unit
TCE	trichloroethene
TLD	thermoluminescent dosimeter
UCRS	Upper Continental Recharge System
VOC	volatile organic compound
WKWMA	West Kentucky Wildlife Management Area

1. History & Background

1.1. The Need for Uranium

In the 1930s, tensions were rising in Europe as Nazi Germany came to power. In 1938, German physicists in Berlin successfully split a uranium atom.

The physicists observed that the splitting of a uranium atom created a lighter atom. Using Albert Einstein's famous equation relating mass to energy, $E=mc^2$, they concluded that the mass lost in the split was converted to energy and released. In 1939 they termed the process "fission" and noted its ability to release vast amounts of energy.

The scientific world noted the possibility of harnessing nuclear fission's energy to power manufacturing, produce electricity and atomic weapons.

Albert Einstein (Figure 1) recognized the power of atomic weapons and wrote a letter to President Roosevelt explaining the dangers if Nazi Germany were to harness fission for weapons prior to the rest of the world.

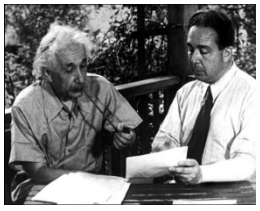

Figure 1. Einstein's Letter to the President

In 1939, President Roosevelt gathered the world's brightest scientific minds and created the "Secret Uranium Committee" which included German scientists who had fled Europe.

In 1942, the Committee became the Manhattan Project, and its mission was to harness the energy from fission and develop an atomic weapon.

Large amounts of uranium ore had to be refined to produce the quantity of uranium that could be processed for use in weapons (Inset).

To accomplish uranium enrichment, three isotope separation processes were conducted in large Manhattan Project facilities at Clinton Works (map: Clinton Works Map) (Figure 2) in Oak Ridge, Tennessee: electromagnetic separation, liquid thermal diffusion, and gaseous diffusion.

The element uranium occurs in several different forms called isotopes.

Isotope, one of two or more species of atoms of a chemical element with the same atomic number and position in the periodic table and nearly identical chemical behavior but with different atomic masses and physical properties. Every chemical element has one or more **isotopes**. (https://www.britannica.com/science/isotope)

An atom of each form, or each isotope, of uranium contains the same number of protons but different numbers of neutrons in its nucleus. The three principal uranium isotopes in naturally occurring uranium are uranium-238 (U-238) which comprises 99.27% of naturally occurring uranium, uranium-235 (U-235) which comprises 0.72% of naturally occurring uranium and uranium-234 (U234) which comprises 0.005% of naturally occurring uranium.

U235 is a 'fissile' isotope of uranium and that means it can sustain a nuclear chain reaction that continuously releases energy. To obtain the quantities of U-235 necessary for weapons or fuel manufacture, the amount of U-235 found in naturally occurring uranium had to be increased or "enriched".

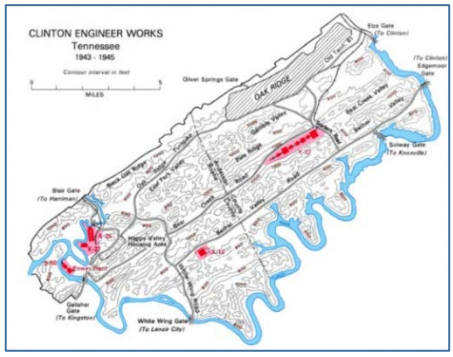

Figure 2. Clinton Works facilities in Oak Ridge, Tennessee

Enrichment is the process of increasing the percentage of U-235 isotope to levels higher than what is found in naturally occurring uranium. Enrichment was the key to producing the material needed for weapons or fuel.

The gaseous diffusion process was one of three enrichment processes developed and conducted on an industrial scale for the Manhattan Project. Gaseous diffusion required uranium to be mixed with fluorine to produce gaseous uranium hexafluoride. Gaseous uranium hexafluoride was propelled through membranes in a very large piece of equipment known as a "converter" (Figure 3). A barrier in the converter contained holes, less than one one-millionth of an inch in diameter (Figure 4), which allowed the separation of atoms of the lighter uranium-235 isotope from atoms of the uranium-238 isotope.

Gaseous diffusion required uranium hexafluoride gas to be passed through converters many times to reach the desired level of U-235 enrichment. So PGDP utilized many converters in sequence, called a 'cascade', to accomplish enrichment. Converters were coupled with a compressor, a heat exchanger to remove the heat of compression and an aircraft engine motor for propulsion which together comprised a 'Stage' (Figure 5). The gaseous diffusion process at PGDP contained more than 1800 stages.

From 1942 – 1945 the three uranium enrichment facilities were able to produce 50 kg (110 pounds) of uranium highly enriched in the isotope U-235. A uranium and a plutonium path achieved the goal of producing bombs by 1945.

The *Atomic Age* began on July 16th, 1945 with a successful test of the "Gadget" carried out near Los Alamos, New Mexico, followed by the bombings which prompted the end of World War II: the bombings of the Japanese cities of Hiroshima and Nagasaki.

The *Cold War* began soon after the end of WWII. The Soviet Union tested their first atomic weapon in 1949 marking the beginning of a worldwide *Nuclear Arms Race*. A year later the *Korean War* began when North Korea, supported by China and the Soviet Union, invaded South Korea. Early in the war, North Korea nearly drove U.S. and South Korean troops off the Korean peninsula.

Knowing that the Soviet Union was beginning to produce nuclear weapons, fearing expanding world conflicts and with growing concern about the spread of communism, the United States determined it would need to expand its nuclear arsenal.

Figure 3. PGDP 8th Stage Converter & Its Crew

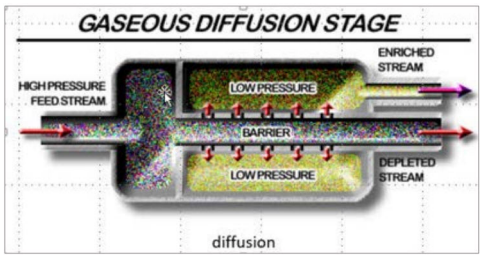

Figure 4. Gaseous Diffusion Converter details

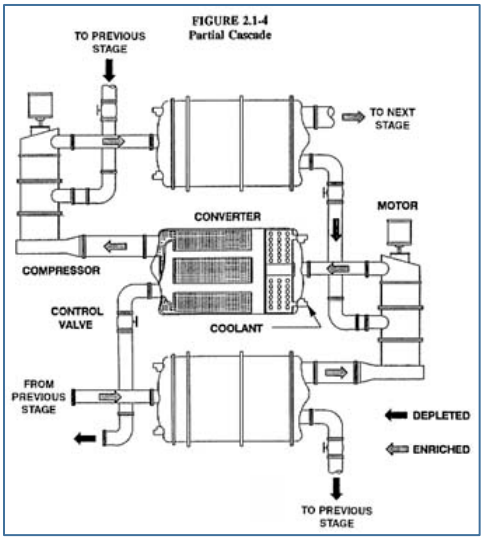

Figure 5. Flow of UF_6 in a Gaseous Diffusion Cascade

1.2. Why Paducah

In July 1950, the Atomic Energy Commission (AEC) and Department of Defense secretly identified

military needs for more atomic weapons and began planning to build more enrichment facilities to supplement the enriched uranium produced in Oak Ridge, Tennessee. They developed several criteria to guide their site selection including: workforce readiness; proximity to rail & river transportation; proximity to industrial targets; need to buy land; and availability of coal and water resources.

In October 1950, the Department of Defense secretly chose the Paducah Site (Figure 6) for the construction of a new gaseous diffusion enrichment plant. In early December 1950, President Truman approved the construction of new enrichment plants.

Figure 6. AEC & DOD Choose Paducah Site

The federal government remained silent about months-long rumors of an atomic plant being built near Paducah. On December 15, 1950, the Paducah Sun-Democrat made rumors official with the headline "AEC to Build A-Plant at KOW Site" (Figure 7).

The Paducah Sun-Democrat

Add Your Own Comment

AEC To Build A-Plant At KOW Site

Chinese Reds Drive Into UN Beachhead

Building Force Of 10,000 May Be Required

Cost Set At $500,000,000; 1,600 Permanent Jobs Expected

Many See Business Boom, Others Fearful City To Become Prime Military Target As Atomic Plant Story Brings Mixed Reaction

Plant's Power To Come From TVA, New Firm

Figure 7. Paducah Sun Headline, Friday, December 15, 1950

Kentucky Ordinance Works (KOW)

Among the sites that met criteria for the siting of a new enrichment plant was the former KOW plant near Paducah, Kentucky. The KOW was built during WWII to supply explosive Trinitrotoluene (TnT) for the war effort.

The KOW was the nation's largest ordnance works and supplied more TnT for WWII than any other U.S. ordnance works (Figure 8). The KOW was closed after World War II, but the government retained ownership of the 4,000 acres of land after it closed.

Figure 8. 1940s KOW Guard Shack (Read the Signs)

1.3. PGDP Construction

The construction of the PGDP began on January 2, 1951 and employed some 23,000 workers (Figure 9). An additional 6,000 workers constructed two new nearby steam power plants to feed electricity to the Plant.

Figure 9. Workers in Line at PGDP Portal

In early 1951 site preparation began with the upgrade of KOW's water supply and treatment

facilities for PGDP use along with road and rail upgrades.

Construction focused on the C-331 and C-333 "Process" buildings where the industrial gaseous diffusion process of enrichment would take place (Figure 10). The C-331 footprint covered 517,153 square feet (11.9 acres) and the C-333 building footprint covered more than 1,065,060 square feet (24.5 acres). When completed in 1953, the C-333 Process Building was one of the largest buildings in the world with an immense volume of more than 9.6 million cubic feet. At the time of its completion in 1955 the Shawnee Steam Plant, which was built to supply electrical power to the PGDP, was the largest and highest-capacity steam electric plant in the world.

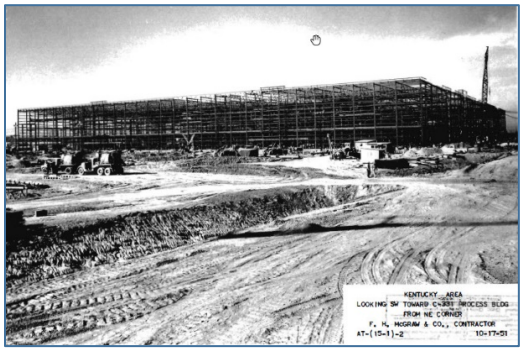

Figure 10. C-331 Early Construction

Figure 11. C-331 Process Building Completed

As work progressed on the construction of the process buildings, construction of support facilities began, including: The C-300 Central Control Building which housed state-of-the-art instrumentation to run and monitor the entire enrichment process; the C-410 and C-420 Feed Plant complex where refined uranium was mixed with fluorine gas to provide gaseous uranium hexafluoride "feed" (UF_6) for the enrichment process; the C-400 Cleaning Facility where process equipment was routinely cleaned; the C-600 Steam Plant which provided steam for the enrichment process in order to keep uranium hexafluoride in gaseous form.

By late-fall 1951, the AEC announced that PGDP's enrichment capacity would be doubled with the construction of two additional Process Buildings, C-335 and C-337.

The C-410 Fluorine Plant was the largest fluorine plant in the world. The C-410 and C-420 Complex operated from 1952 until 1977, after which all feed was produced off-site.

The official ceremony opening the PGDP was held in September 1952 as construction continued. Construction of the PGDP was completed in 1956 at a cost of $800 million dollars.

Figure 12. PGDP Opening Ceremony, September. 1952

1.4. PGDP Operations

In October 1952, the first enrichment stages in the C-331 building went online. In November 1952, the first enriched uranium product was withdrawn and shipped to Oak Ridge.

From March 1951 until the shutdown of enrichment operations in 2013, the PGDP operated seven days a week to satisfy the Nation's demand for uranium. To operate the PGDP it took:

- 1,200 to 1,800 employees
- 3 shifts per day 7 days a week to continuously run the gaseous diffusion process
- 15 billion annual kWh of electricity

- More annual electricity than the annual electrical demand of New York City,
- 4% of all the electrical power produced in the U.S
- 80,000 instruments to control process equipment
- 7.5 million tons of coal to generate electricity and steam
- 20,000 pounds of steam per day to keep UF_6 in a gaseous state for processing.
- 340 million gallons of water circulated through the system every day to remove excess heat generated by the diffusion process.
- Up to 32 million gallons of water per day extracted from the Ohio River
- 10,000 miles of control cables ran through the plant.
- The electrical system contained 25,000 tons of steel and 10,000 tons of copper.
- 100 miles of underground cables to transfer electricity to plant buildings

1.4.1. Uranium Enrichment

The primary mission of the PGDP was uranium enrichment. Initially, that mission required PGDP to produce enough enriched uranium to satisfy the Nation's defense needs. In the 1960s, the primary mission shifted to the production of enriched uranium for domestic and international nuclear reactors, as well as military needs, such as nuclear fuel to power naval vessels.

During its 61 years of operation, the PGDP processed more than 1 million tons of refined uranium to produce low-enriched uranium (LEU). originally 2-3% U-235, and later up to 5.5% U-235.

Over 200,000 tons of LEU was shipped to other facilities, primarily the K-25 Site in Oak Ridge, TN and the Portsmouth Gaseous Diffusion Plant near Piketon, Ohio. The LEU was further enriched at those facilities for use in weapons and fuel in commercial and military reactors, including naval fuel.

Depleted uranium hexafluoride (DUF_6) is stored in 12 foot long x 4 foot diameter cylinders in 'cylinder yards' at the PGDP which occupy nearly 100 acres (76 football fields) of the industrial site (Figure 13). More than 46,000 cylinders of DUF_6 now occupy the cylinder yards and comprise the largest stockpile of mined uranium in the world.

Unlike the secondary products of many industrial processes, the DU in the DUF_6 is not a waste product. DUF_6 was kept on-site to be used as process feed material because it contained sufficient U-235 for "re"-enrichment.

Figure 13. PGDP Cylinder Yard

1.4.2. Other Industrial & Technical Activities

Other industrial and technical activities have been conducted at the PGDP. The C-340 Metals Complex produced various forms of uranium metal for industrial and government customers.

The unique nature of the site's process components and machinery required that on-site solutions be designed, built, and tested. Those activities took place in the C-720 Maintenance Facility.

The C-720 was a 'state of the art' engineering design, fabrication, and testing facility. Development, crafting, and utilization of on-site solutions resulted in research patents and many projects outsourced to government and industry in a program known as "Work for Others".

Figure 14. Uranium metal button

Some of the ongoing work at the PGDP was the recovery of metal and precious metals from the site and Work for Others projects (Inset).

Metals Recovery

Aluminum Recovery – From 1962 to the early 1980s.

Nickel Recovery –Operated from 1976 until the late 1980s. Uncontaminated "clean" nickel was processed through the smelter before contaminated nickel. About 17 million pounds of nickel were smelted, cast into ingots, and sold. Approximately 19.6 million lbs. of contaminated nickel were cast into ingots and remain stored at the PGDP.

Gold Recovery – Approximately 60,000 troy ounces was returned to the U.S. Treasury via recovery of gold from dismantled weapons and equipment at the C-736A smelter.

Silver Recovery – Recovery of 102 bars of silver from classified government and industry x-ray film was conducted at the C-736A smelter. Approximately 7,650 pounds of silver were reclaimed from the reprocessing of classified x-ray film from 1966 to 1974 and returned to the U.S. Treasury.

Worldwide, as nuclear weapons were dismantled and reactors were decommissioned, a glut of uranium feedstock became available. With the large stockpile of DUF_6, DOE began to focus on converting DUF_6 into an oxide for long term storage or disposal.

Deactivation involves reducing/removing radioactive and hazardous materials from process equipment, shutting down facility systems and de-energizing equipment in preparation for future decontamination and decommissioning (D&D).

In 2011, PGDP's DUF_6 conversion facility (Figure 15) began processing the site's DUF_6 inventory into uranium oxide and hydrofluoric acid (HF). The oxide is a stable chemical form of depleted uranium that can be disposed of, re-used, or stored (Figure 16). HF from the conversion process is sold to industry for re-use. The PGDP's DUF_6 inventory is expected to be processed in approximately 30 years.

Figure 15. The PGDP DUF_6 Conversion Facility

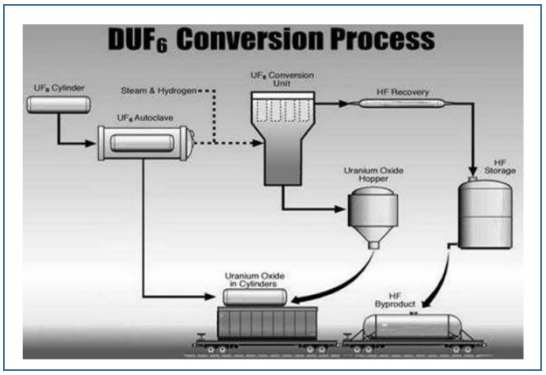

Figure 16. The DUF_6 Conversion Process

1.5. Legacy Operations

1.5.1. Deactivation, Decontamination & Decommissioning & Demolition

Thirty-two unused structures have been demolished at the PGDP following deactivation, decontamination and decommissioning (D & D) of

facilities and equipment, as of publication of the 2017 ASER.

Two of the demolished facilities, the C-340 Metals Plant Complex and the C-410/C-420 Feed Plant Complex, played key roles in PGDP operations.

The C-340 Metals Plant complex (Figure 17) operated from 1956 into the 1980s to produce uranium tetrafluoride (UF_4), uranium metal, and hydrofluoric acid (HF). The refining of uranium metal and processing of UF_4 and HF resulted in radiation contamination inside the C-340 building. The deactivation and decontamination (Figure 18) of the building was followed by demolition (Figure 19) of the structure which was completed in 2013 (Figure 20).

Figure 17. C-340 Metals Complex with transite siding that is sealed to stabilize hazardous and radioactive materials during demolition

Figure 18. Workers deactivate C-340 Instrument Systems

Figure 19. Demolition of C-340 Structures

Figure 20. The C-340 Site following Demolition

The C-410 Fluorine Plant was the largest fluorine plant in the world and operated from 1952 until 1977, after which all feed for PGDP's enrichment process was produced off-site. The Feed Plant converted solid uranium trioxide (UO_3) to uranium oxide (UO_2) and then produced gaseous uranium hexafluoride, UF_6, which was used as the 'feedstock' for the diffusion process. The conversions utilized reactions involving hazardous and radioactive materials including uranium, hydrofluoric acid, hydrogen, and fluorine gas.

The demolition of the C-410 and C-420 Complex required deactivation of complex internal process system piping and machinery (Figure 21, Figure 22 & Figure 23) and removal of residual radioactive and hazardous materials including asbestos.

Figure 21. C-410 & C-420 Complex

Figure 22. Deactivation radiation screening

Figure 23. Steel girder removal during C-410/C-420 demolition

1.5.2. Environmental

PGDP's industrial facilities operated around the clock for 61 years to fulfill the Site's primary mission producing enriched uranium. Site industrial processes used resources and generated by-products and wastes like many industrial sites in the U.S and across the world.

Beginning in the 1940s and 50s, the understanding of industrial impacts on worker health, the environment and the public began to increase significantly. In response, Congress began to pass legislation to control releases and disposition of hazardous and radioactive materials.

In 1976 the Resource Conservation and Recovery Act (RCRA) requiring 'cradle to grave' (production to disposal) management of hazardous materials was passed.

In 1980 the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and its 'Superfund' Program were implemented.

In 1988, the McCracken County Health Department and the Kentucky Radiation Control Program found Trichloroethene (TCE) and technetium-99 (Tc^{99}) in residential drinking water wells north of the PGDP. Public drinking water was immediately supplied to potentially impacted citizens through DOE's Water Policy.

The US Environmental Protection Agency (EPA) and the DOE entered an Administrative Order by Consent (AOC) to address known and suspected environmental contamination.

As a result of the AOC, extensive environmental impact characterization began at the PGDP.

Routine environmental monitoring, surveillance and remedial activities followed, including:

1975 – PGDP tests biodegradation of waste oils containing uranium, polychlorinated biphenyls (PCBs) and solvents at on-site oil landfarm (SWMU 001) as a treatment option

1983 – 1300 drums of PCB-contaminated soil removed from site ditches

1986 – TCE contamination found in groundwater at on-site burial ground

1988 –TCE and Tc^{99} detected in residential drinking water wells north of the PGDP

1988 – DOE 'Water Policy' implemented which provided municipal drinking water to potentially impacted properties in vicinity of the PGDP

1989 – 1993 Phase I and II environmental investigations were undertaken and completed. Addressed nature and extent of impacts to all media (surface water, soil, sediment, groundwater, air, and ecological).

1991 – Signs posted at local waterways to warn of potential presence of harmful contamination

1993 – The PGDP was placed on the National Priorities List (NPL) and became a "Superfund" site.

1994 – The PGDP re-routed contaminated surface water discharges for treatment before its off-site release

1994 – Phased GW Investigations determined that leaking and leaching of disposed materials contaminated both soil and groundwater at the site, resulting in the largest documented TCE and technetium-99 groundwater plumes in the DOE complex.

1994 – PGDP implemented the Northwest Plume Pump and Treat action to mitigate off-site releases of Trichloroethene and Tc^{99} groundwater contamination.

1996 – DOE, Monsanto, and General Electric test LASAGNA™ technology to remove TCE from shallow soils in-situ. Technology removes more than 200 gallons (or 98%) of TCE from test plot soils

1997 – PGDP constructs C-Landfill to allow on-site disposal of certain types of solid wastes

1997 – Northeast Plume groundwater treatment system begins operation to contain highest concentrations of groundwater leaving the eastern perimeter of PGDP

2000 –66 million pounds of contaminated scrap metal removed from "Drum Mountain" (NW corner of industrial area) containing trace amounts of uranium and transuranic radionuclides.

2002 – Contaminated sediments found in central industrial site ditches removed.

2003 – Waste materials in on and off-site storage areas shipped off-site for disposal

2004 – PGDP begins removal of facilities with no planned future use

2005 – DOE Nitrogen Facility undergoes D&D

2006 – Site completes deactivation, decontamination, and decommissioning of Lime House facility

2006 – Site completes removal of 30,000 tons of scrap metal from NW corner of industrial area

2007 – Depleted Uranium Hexafluoride (DUF_6) Conversion facility construction completed

2008 – Construction begins on Phase I system to remove TCE from soil and groundwater near the C-400 Cleaning Facility.

2008 –Accelerated D&D work begins with demolition of KOW concrete water towers

2009 – Legacy Low-Level Waste (LLW) shipped from PGDP to facilities for treatment and disposal

2010 – Phase 1 Electrical Resistance Heating operations begin at C-400 Building TCE groundwater contamination source areas

2010 – On-site metal reduction facilities and smelter undergo D&D.

2010 – HF Lagoon removed

2010 - Additional site ditch soil removed.

2011 – DUF_6 Conversion Facility in operation to convert PGDP's on-site stockpile of DUF_6 into uranium oxide for disposal and fluorine gas for industrial use

2013 – C-340 Metals Facility deactivation, decontamination and demolition completed

2015 – C-410 & 420 Feed Complex deactivation, decontamination and demolition completed

2016 – SWMU 001 Oil Landfarm in- situ deep soil mixing utilized to remediate contaminated soils above PGDP's aquifer.

Summary of Environmental Actions

7,500 gallons of TCE have been removed by Groundwater Pump and Treat operations,

Application of Electrical Resistance Heating and Injection of Steam into the groundwater aquifer and overlying soils to vaporize and vacuum extract TCE from soil and groundwater.

6 million cubic feet of waste including old waste from environmental cleanup and site operations and waste from material storage areas has been characterized and shipped off site for disposal.

1 million cubic feet of contaminated soils and sediment has been removed from on-site ditches and waterways.

Groundwater Pump and Treat operations have removed and treated more than 4 billion gallons of contaminated groundwater.

2. Site Setting & Environmental Setting

The Paducah Gaseous Diffusion Plant (PGDP) is a retired uranium enrichment facility located west of Paducah, Kentucky (Figure 25). The PGDP is owned by the United States Department of Energy (DOE), operated and managed by DOE contractors. Uranium enrichment operations were carried out on an industrial site of more than one square mile.

2.1. Site Location

The PGDP industrial site occupies one square mile (640 acres) of a 3,556-acre DOE reservation located 10 miles west of Paducah and 3 miles south of the Ohio River (Figure 24). The reservation can be broken down as follows: 628 acres of security-fenced industrial site, 809 industrial acres outside of the security fence, 133 acres in acquired easements (Figure 24). The remaining 1,986 acres of the reservation are licensed to the Commonwealth of Kentucky as the West Kentucky Wildlife Management Area (WKWMA).

The WKWMA and non-industrial portions of the DOE Reservation consist of woodlands, meadows, wetlands, and cultivated fields.

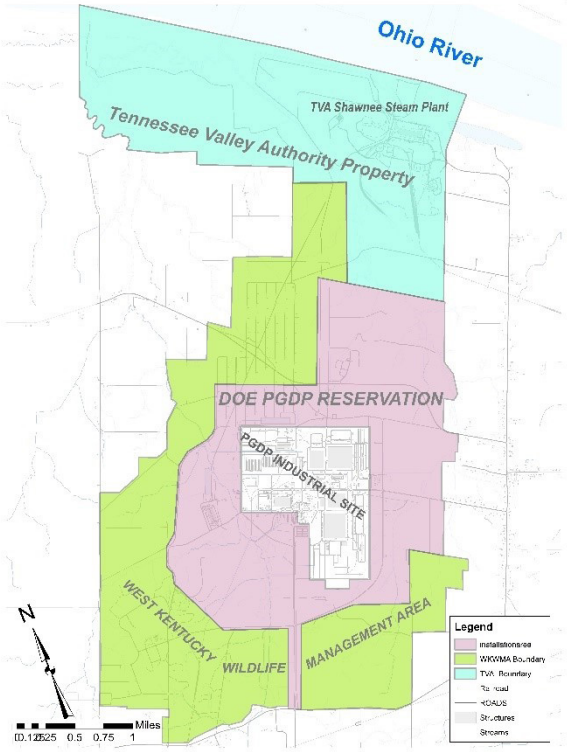

Figure 24. PGDP Reservation and Surrounding Tracts

WKWMA is popular for deer and waterfowl hunting, trapping, hunting-dog training, hunting-dog competitions, horseback riding, fishing, and general outdoor recreation.

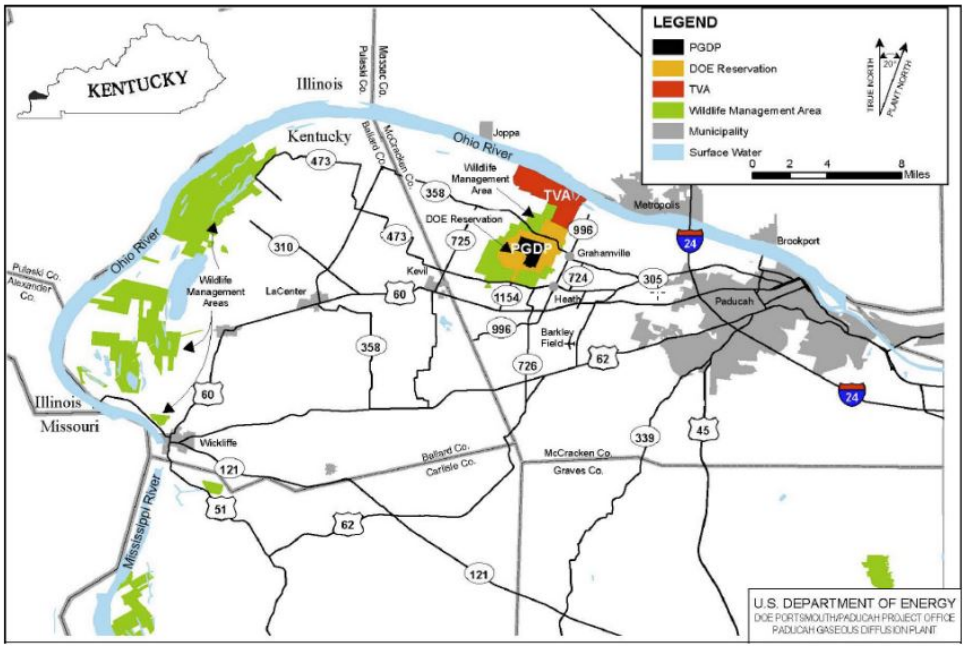

Figure 25. PGDP & Vicinity Map

2.2. Climate

The Paducah Plant and surrounding DOE Reservation are in the eastern United States humid continental zone characterized by warm summers and moderately cold winters. Precipitation averages at 49 inches per year.

2.3. Hydrology/Hydrogeology

The Paducah Plant is located approximately 3 miles south of the Ohio River in the lower Ohio River Basin. The Cumberland and Tennessee Rivers join the Ohio River approximately 15 miles upstream of the PGDP. The confluence of the Ohio and Mississippi Rivers is about 35 miles downstream of the PGDP.

The PGDP DOE Reservation occupies portions of the Bayou Creek and Little Bayou Creek watersheds (Figure 26). PGDP industrial area runoff and surface water enters drainage ditches that discharge to Bayou and Little Bayou Creeks. Surface water from the east side of the PGDP industrial site discharges into intermittent upstream portions of Little Bayou Creek. Surface water from the west side of the PGDP industrial site discharges into perennial portions of Bayou Creek. The confluence of Bayou and Little Bayou Creeks is 3 miles north of the PGDP industrial site and it immediately discharges into the Ohio River.

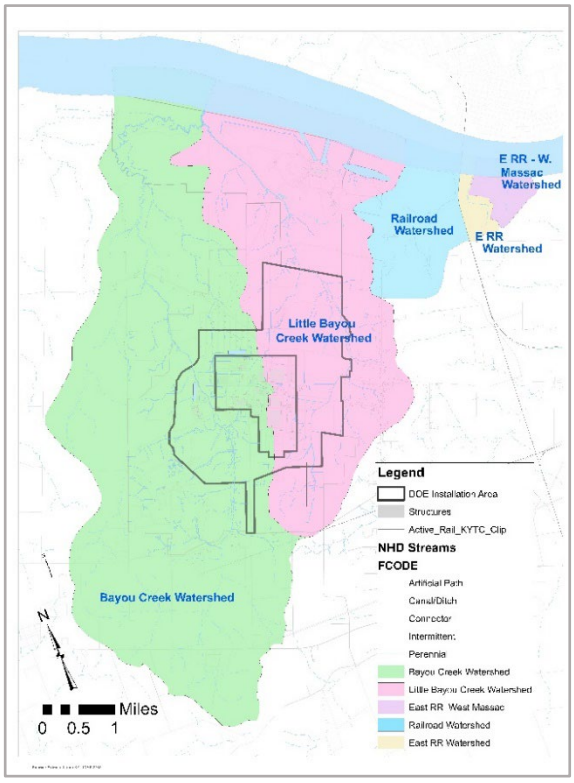

Figure 26. PGDP Watersheds (KRCEE, 2019) based on KY 2013 LIDAR for McCracken County.

Soils around the Paducah Plant are predominantly silt loam soils. They are poorly drained, acidic, and have little organic content. Groundwater in the vicinity of the PGDP is utilized extensively for agriculture and domestic purposes.

More than 1,100 separate wetlands, totaling over 1,600 acres, are found in 12,000 acres around the PGDP. More than 60% of the total wetland area is forested.

As part of activities associated with the annual PGDP ASER Student Summary project, MCHS students have provided hands-on assistance to the University of Kentucky and the WKWMA with the assessment of natural and man-made amphibian-wetland habitats in 16 tracts surrounding the PGDP (Figure 27).

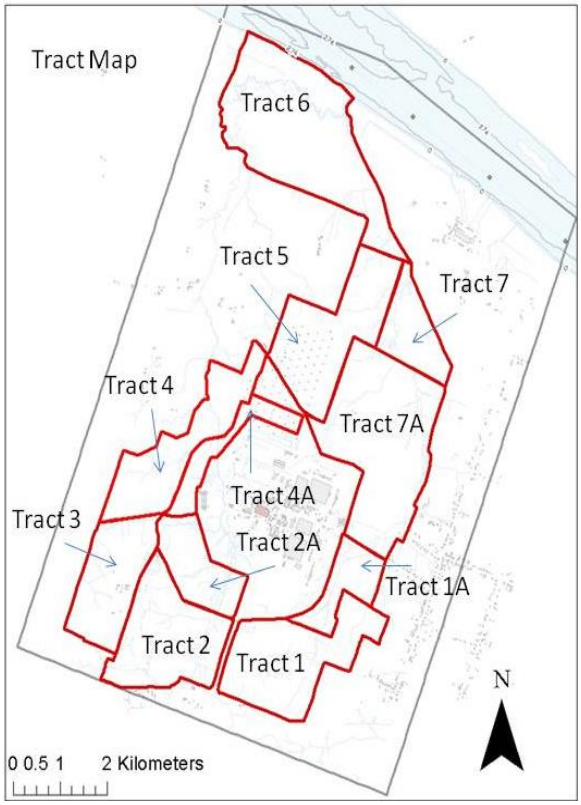

Figure 27. Amphibian Study Wetland Tracts surrounding PGDP

3. PGDP Environmental Compliance Summary

3.1. Background

During calendar year 2017, DOE and its site contractors conducted extensive environmental monitoring as part of Environmental Management Program (Inset) activities at the PGDP. Monitoring and environmental management are conducted to ensure that PGDP is protective of public health and complies with Federal and State environmental laws and regulations as well as DOE Orders.

PGDP Environmental Management Goals

1. Keep visitors, workers, public, wildlife and the environment safe from harmful chemicals and radiation related to the site;
2. Follow current environmental regulations.

The primary regulations the PGDP must comply with in its environmental activities are the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the Resource Conservation and Recovery Act (RCRA), DOE Orders for radiation protection, and DOE Orders for the management, handling and disposal of radioactive materials.

On May 31, 1994, the PGDP was placed on the EPA National Priorities List (NPL) which identifies the nation's sites with the highest need for site cleanup based on potential impacts to human health and the environment. Section 120 of CERCLA requires federal agencies responsible for an NPL site to enter into a Federal Facility Agreement (FFA) with EPA.

The FFA ensures requirements under CERCLA and its amendments are coordinated with requirements under the Resource Conservation and Recovery Act (RCRA) and its amendments. The PGDP entered its FFA with EPA and the Kentucky Department for Environmental Protection (KDEP) in 1998. The PGDP FFA also addresses coordination of site activities with other environmental regulations.

EPA Region 4 and KDEP are the main regulatory agencies that oversee the DOE's PGDP environmental activities.

EPA develops environmental standards and enforces environmental regulations to follow laws passed by Congress. EPA's authority is delegated to KDEP when Kentucky's regulatory program criteria meet or exceed EPA requirements.

RCRA regulatory requirements are the responsibility of the State of Kentucky and administered through KDEP.

EPA and KDEP issue permits, review compliance reports, provide input on remediation strategies, participate in joint monitoring programs, inspect facilities and operations, and oversee compliance with applicable laws and regulations.

3.2. Calendar Year 2017 Environmental Compliance Summary

Tables on the following pages outline the laws and regulations that DOE complies with annually in its environmental management of the PGDP. The tables are organized as: 1) Primary Environmental Laws/Regulation; 2) Radiation Protection Regulations; 3) Additional Major Regulations; 4) Other Environmental Statutes; and 5) Sustainability Activities. The first column of each table identifies the law, regulation, or DOE Order and the second column identifies the action taken in calendar year 2017.

3.2.1. Primary Environmental Laws/Regulations

Applicable Law or Regulation	Site Status (Achievements) 2017
Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). CERCLA is the framework of regulations that address the remediation of hazardous substances and sites where hazardous substances have been handled or disposed. CERCLA commonly referred to as 'Superfund' and PGDP is on National Priorities List as a Superfund Site. Under Superfund PGDP is managed by under a Federal Facilities Agreement (FFA) between DOE, EPA and KDEP. The FFA coordinates compliance activities conducted for CERCLA, RCRA and other regulatory programs.	During 2017, the DOE completed the activities below relative to CERCLA requirements and management under the FFA: **1)** Field work for the optimization of the Northeast Plume groundwater pump and treat system; **2)** Draft Feasibility Study for Burial Grounds Operable Unit, Solid Waste Management Unit (SWMU) 4. SWMU 4 is also known as the 'Uranium Burial Grounds'; **3)** Draft Feasibility Study for Burial Grounds Operable Unit, Solid Waste Management Units SWMU's 2, 3, 7, and 30; **4)** A Site Management Plan (SMP) for federal fiscal year 2018.
Resource Conservation and Recovery Act (RCRA). RCRA regulates the generation, storage, handling, and disposal of hazardous wastes. Program is a 'cradle to grave' approach for managing hazardous substances and hazardous waste. KDEP is responsible for administration of RCRA treatment, storage, and disposal of hazardous waste including Hazardous Waste Facility Permitting. PGDP's current Hazardous Waste Facility Permit went into effect in August 2015. EPA administers air emission standards relative to PGDP's current Hazardous Waste Amendments Permit that went into effect in March 2016.	There were no Notices of Violation (NOVs) issued for the RCRA Hazardous Waste Facility or Hazardous Waste Amendments Permits in 2017.
Superfund Amendments and Reauthorization Act. Amended & updated CERCLA based on EPA's 10 years of CERCLA administration. Put a focus on human health problems posed by sites and increased public participation in CERCLA decision making.	Part of CERCLA above
Federal Facilities Compliance Act - Site Treatment Plan. Waived immunity for Federal Facilities for violations of RCRA hazardous waste management. Requires sites to develop approvable Site Treatment Plans (STPs) for the management of DOE mixed (hazardous & radioactive) waste and implementation of a waste minimization and prevention program. DOE and KDEP entered an Agreed Order/STP in September 1997.	No mixed low-level waste was added during 2017.
National Environmental Policy Act (NEPA). Requires review of Federal activities for environmental impacts and determination of the need for an environmental assessment, environmental impact statement (EIS), or categorical exclusion. CERCLA activities do not require preparation of NEPA documentation.	In 2015, transfer of real property to third parties was evaluated and a Finding of No Significant Impact was issued.
Toxic Substances Control Act (TSCA). Requires that information about production and use as well as environmental and health effects of chemical substances be obtained by EPA and that EPA has the means to regulate chemicals and chemical mixtures. Examples of regulated chemical substances are lead, polychlorinated biphenyls (PCBs), asbestos and chlorofluorocarbons.	Paducah produced an Annual PCB report and a Compliance Agreement Report for 2017.

3.2.2. Radiation Protection Regulations

Regulation/Purpose	Site Status (Achievements) 2017
DOE Order 458.1 'Radiation Protection of the Public and Environment'. DOE establishes requirements for protection of the public and environment from radiation and activities at DOE sites. The order ensures that risk from radioactive waste is protective of worker and public health, safety, and the environment. The order establishes the application of 'ALARA' (As Low As Reasonably Achievable) to decisions regarding protection of public health, the environment and waste management.	The PGDP implemented and complied with a site-specific Environmental Radiation Protection Program (ERPP) to ensure compliance with Order 458.1 requirements.
DOE Order 435.1 'Radioactive Waste Management'. DOE to ensure that risk from radioactive waste is managed to be protective of worker and public health, safety and the environment.	DOE operated storage and disposal units in compliance with Order 435.1 during 2017.

3.2.3. Additional Major Regulations

Regulation/Purpose	Site Status (Achievements) 2017
Clean Air Act at PGDP. Administered by EPA Region IV and/or the KY Division of Air Quality. Authority for PGDP air emissions falls under several permits: 1) DUF_6 Conversion Facility Conditional Major Air Permit; 2) the Four Rivers Nuclear Partnership Title V Air Permit; or 3) CERCLA.	DOE did not receive any Notices of Violation relative to the Clean Air Act in 2017.
National Emission Standards for Hazardous Air Pollutants (NESHAPS). Radionuclide air emissions at PGDP are regulated under NESHAPS and an EPA approved NESHAP Management Plan for Emission of Radionuclides. Potential PGDP sources under NESHAPS are uranium transfer, demolition of facilities, environmental remediation activities.	DOE conducted ambient air monitoring at nine off-site locations to measure fugitive and diffuse sources from the PGDP and PGDP activities. DOE prepared an annual NESHAPS report that was submitted to EPA.
Pollutants and Sources Subject to Regulation. The PGDP Deactivation Project potentially releases carbon monoxide, nitrogen & sulfur oxides from coal burning boilers and hydrogen fluoride from the site's Depleted Uranium Hexafluoride (DUF_6) Conversion facility.	DUF_6 releases are permitted by the Kentucky Division of Air Quality (KDAQ).
Stratospheric Ozone Protection. Ozone depleting substances are regulated at the PGDP under the Clean Air Act Title V Permit. PGDP utilized industrial quantities of refrigerant containing chlorofluorocarbons to cool enrichment process equipment. The idled enrichment process cooling system holds more than 6.3 million pounds of R-114 refrigerant and another 2.2 million pounds of R-114 is stored in railcars at the PGDP.	In 2017 the PDGP tracked and repaired R-114 releases. The site also removed some R-114 from the idle enrichment process system and transferred it to railcars. Disposition of the site's R-114 was under evaluation in 2017 along with procurement of additional storage containers.

Clean Water Act. Non-radiological (non-radiation-containing) discharges to waters of the United States are regulated under the four major components of the Clean Water Act: 1) Non-point source and stormwater discharges 2) Oil and hazardous substance spill control and prevention; 3) Dredge and fill discharges; 4) Financial assistance for public sewage treatment construction.	
Kentucky Pollutant Discharge Elimination System. The Commonwealth of Kentucky Division of Water issues Kentucky Pollutant Discharge Elimination System (KPDES) permits for Clean Water Act non-radiological discharges to Bayou and Little Bayou Creeks at PGDP.	Three KPDES Notices of Violation (NOVs) were received in 2017. 1 & 2) Two for chronic toxicity test failures at KPDES Outfall 017, indicating that discharged water could be harmful to aquatic organisms; and 3) one for an exceedance of carbonaceous biochemical oxygen demand (CBOD) from a water treatment plant at KPDES Outfall 004.
Storm Water Management & the Energy Independence and Security Act of 2007. The Energy Independence Act of 2007 requires DOE to conduct energy and water audits.	
Safe Drinking Water Act (SDWA). PGDP provides on-site drinking water (treated) from Ohio River.	Three NOV's issued during 2017: 1) failure to meet Total Organic Carbon for 1 month; 2) Failure to meet operational reporting requirements for 3 months (rescinded); 3) Failure to meet trihalomethane treatment requirements for 3 months.

3.2.4. Other environmental Statutes

Regulation/Purpose	Site Status (Achievements) 2017
ENDANGERED SPECIES ACT. Addresses protection of species listed as endangered at site.	No 2017 Projects or activities impacted listed Endangered Species at site. None of 14 potential endangered species at site have been found at site.
National Historic Preservation Act. - There are 101 potential historic properties at PGDP based on role in developing commercial nuclear power development.	PGDP has conducted architectural & historic properties survey and follow Cultural Resources Management Plan for Site.
Migratory Bird Treaty Act. The Migratory Bird Treaty Act of 1918 is applicable to the PGDP. DOE has MOU with federal Fish and Wildlife service and abides by Executive Order to minimize impacts to migratory birds.	DOE documents that guide site work identify the need to minimize impacts to avoid disturbing nesting sites of migratory birds.

Asbestos Program. Asbestos was widely used in construction and maintenance of PGDP facilities.	
Floodplain Wetlands Environmental Review Requirements. PGDP must follow procedures under two Executive Orders and Title 10 CFR Part 1022 to evaluate impacts to wetlands.	DOE activities during 2017 did not impact or pose impacts to wetlands.
Underground Storage Tanks. Regulated under RCRA and Kentucky Underground Storage Tank Regulations by KDEP.	There were no in-service underground storage tanks at PGDP in 2017.

4. Environmental Monitoring

4.1. Why

In 1988, the McCracken County Health Department and the Kentucky Radiation Control Program found TCE and technetium-99 in residential drinking water wells north of the PGDP. DOE implemented its Water Policy program and supplied public drinking water to potentially impacted properties. The EPA and the DOE worked together to address known and suspected environmental contamination. Rigorous and routine environmental monitoring and surveillance began at the PGDP.

Trichloroethene (TCE) is a volatile industrial solvent that was used at the PGDP for degreasing metal components of enrichment process equipment. At the C-400 Cleaning Facility, TCE was utilized in hot baths to immerse process equipment for degreasing. Through the early 1990's, cleaning liquids containing TCE were discharged to the site sewer system for treatment. TCE vapors were vented to the atmosphere through the C-400 stack system.

Technetium-99 (^{99}Tc/Tc-99) is primarily a man-made radionuclide that is a fission product of uranium fission in a nuclear reactor or weapon. Only trace amounts of ^{99}Tc are found in the earth's crust. Tc-99 is unique because one of the compounds it forms (the pertechnetate ion) is very mobile in the environment.

4.2. How

Samples are collected using media-specific procedures according to EPA guidelines. Sample media consists of air, surface water, groundwater, and sediment. Soils are sampled as part of specific site environmental investigations.

Sample 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 is documented in a logbook or data form, on a chain-of-custody form, and on the sample container label, then is input directly into the Paducah Environmental Management System (PEMS) database.

For all environmental samples, chain-of-custody forms are maintained from the point of sampling, and the handling of samples is recorded until they are placed in the custody of an analytical laboratory.

4.3. Site Monitoring

4.3.1. Air

Coal-fired steam plant emissions were the largest permitted non-radiological source at the Site until 2015 when coal was replaced by natural gas fired boilers which do not require monitoring. Air monitoring (Figure 28) continues to be conducted for radioactive constituents released by Site activities including remediation (Chapter 5)

4.3.2. Surface Water

Clean Water Act regulations were complied with through the KPDES permit for PGDP surface water outfall discharges to the Bayou and Little Bayou Creeks. Effluent discharges from permitted landfills were monitored under separate landfill permits.

Surface water sample locations (Figure 29) and the monitoring programs that sampling is conducted under at the Paducah site are listed in Table 1. Calendar Year (CY) 2017 non-radiological surface water sample results are summarized in Table 2. Trends of TCE at select surface water sampling locations are provided on Figure 30.

4.3.3. Sediment

Radiological and non-radiological sediment sampling at the Paducah Site was conducted during June 2017. The sampling was conducted at locations chosen to assess areas of public access, introduction of plant effluents to the environment, unplanned releases, and to check the PGDP's effluent controls (Figure 31) and contaminated sediment removal.

The sediment concentration results for CY 2017 are similar to those measured during previous years. Uranium isotope activity was above background activity in Bayou and Little Bayou Creeks in the immediate vicinity and downstream of the PGDP industrial site. Other radionuclides were detectable in trace concentrations that were not significantly above background values presented in Methods for Conducting Risk Assessments and Risk Evaluations (DOE 2016a).

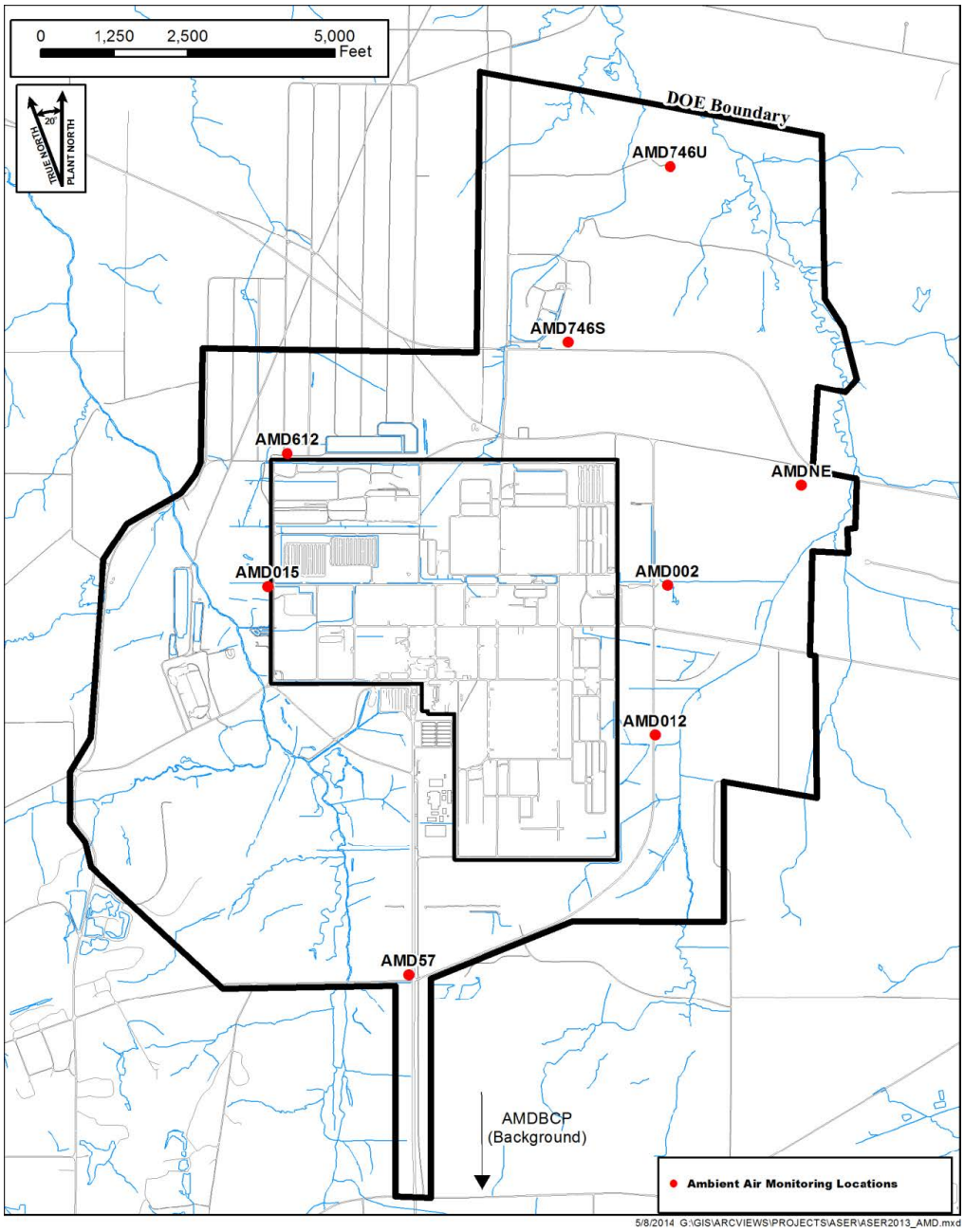

Figure 28. PGDP Air Monitor Locations

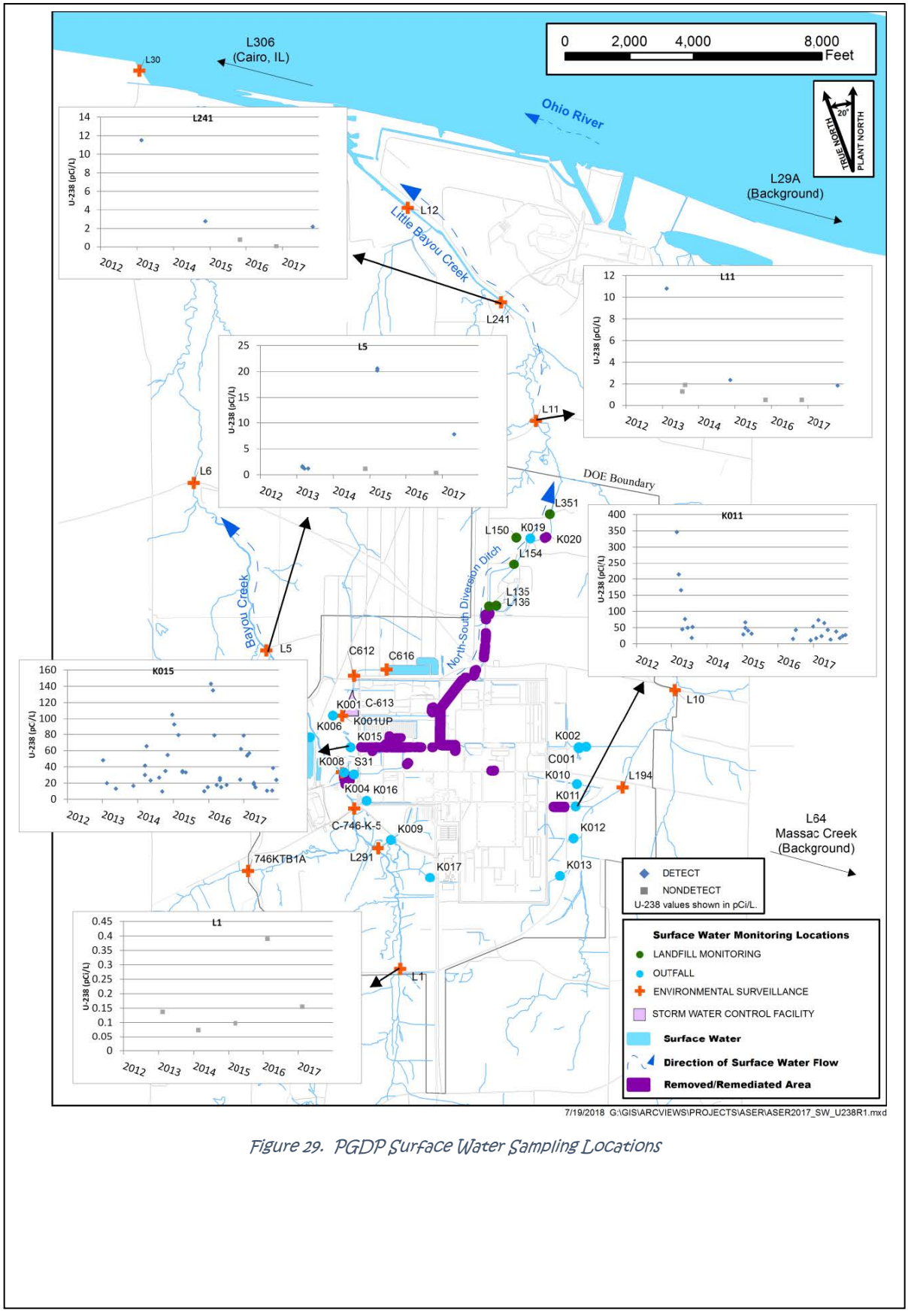

Figure 29. PGDP Surface Water Sampling Locations

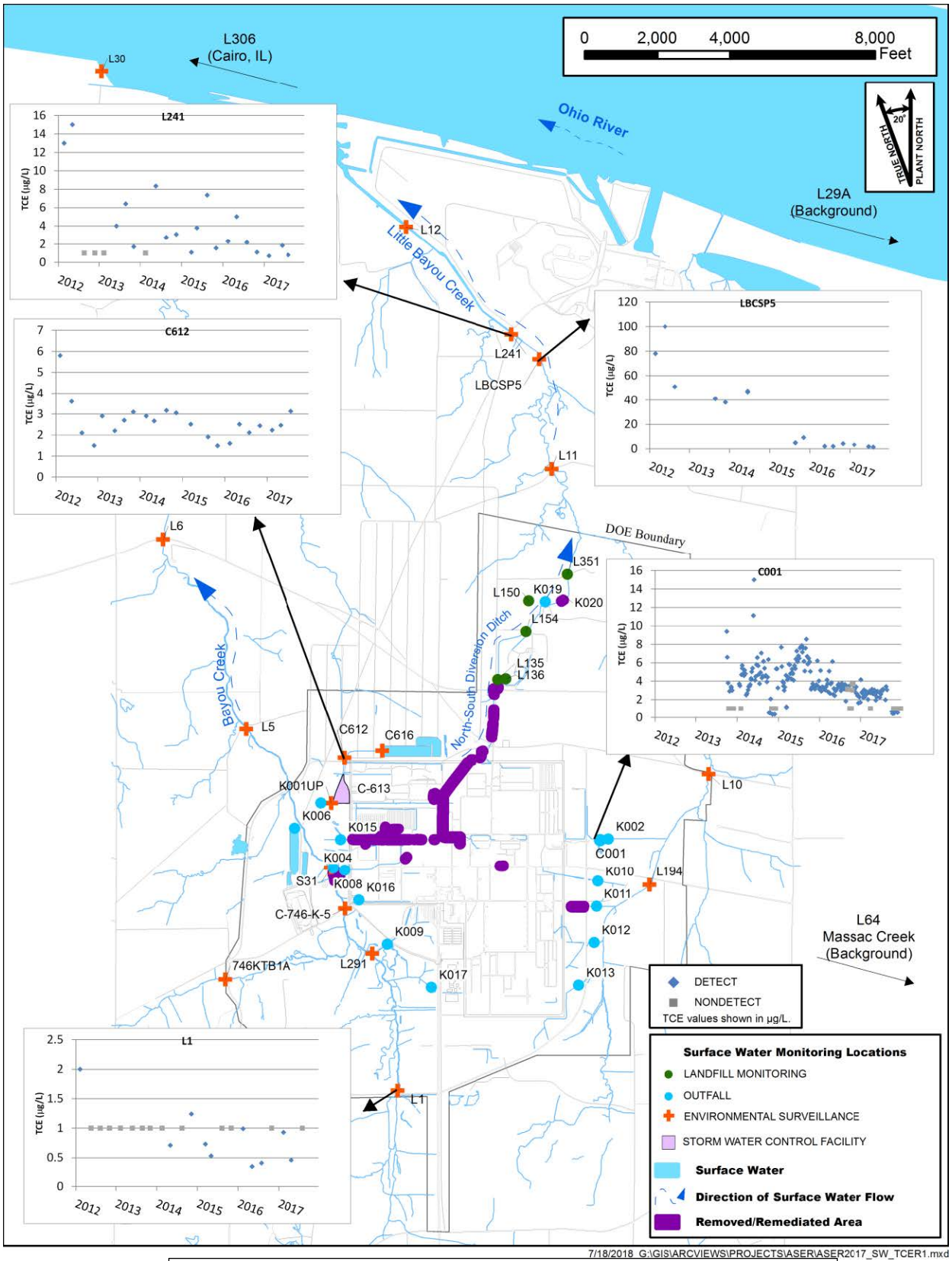

Figure 30. Surface Water and Seep Monitoring with TCE Trends

Table 1. Surface Water Monitoring Locations 2017

Program and Reporting Location	Locations
Effluent Watershed Monitoring Program	
C-746-S and C-746-T Landfill Surface Water *Quarterly Compliance Monitoring Reports*: First Quarter 2017 (January–March) Second Quarter 2017 (April–June) Third Quarter 2017 (July–September) Fourth Quarter 2017 (October–December)	L135, L136, L154*
C-746-U Landfill Surface Water *Quarterly Compliance Monitoring Reports*: First Quarter 2017 (January–March) Second Quarter 2017 (April–June) Third Quarter 2017 (July–September) Fourth Quarter 2017 (October–December)	L150, L154*, L351
KPDES** Monthly 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, C612, C616, C746K-5, K001UP, L1, L10, L11, L12, L194, L241, L291, L29A, L30, L306, L5, L6, L64, S31
Seep	LBCSP5
Northeast Plume Effluent *Semiannual FFA Progress Reports:* Second Half of FY 2017 (Data reported January–June 2017) First Half of FY 2018 (Data reported July–December 2017)	C001

*Location is listed for both C-746-S and C-746-T and for C-746-U.

**During 2017, sampling was performed as part of a Toxicity Reduction Evaluation (TRE) under the KPDES permit. Data from the TRE are included in this section.

Table 2. Range of Analytes Detected in Surface Water

Analyte	**Range (ug/L)**
Total Organic Carbon	2,780–26,800
Total Solids	60,000–420,000
Volatile Organic Compounds	
1,1,1-Trichloroethane	0.57-0.57
Acetone	1.95–4.98
Bromodichloromethane	0.340–3.13
Chloroform	0.530–6.19
cis-1,2-Dichloroethene	0.340–4.83
Dibromochloromethane	0.340–1.30
Toluene	5.50–5.70
Trichloroethene	0.340–5.82
Herbicides/Pesticides/PCBs	
2,4-D	0.0847–14.1
4,4'-DDD	0.00582–0.00582
4,4'-DDE	0.00235–0.00235
alpha-BHC	0.00549–0.00549
gamma-Chlordane	0.00192–0.00192
Dieldrin	0.00368–0.00368
Endosulfan I	0.00620–0.00620
Endosulfan sulfate	0.00289–0.00289
Endrin	0.00294–0.0034
Endrin aldehyde	0.00335–0.0770
Heptachlor	0.0378–0.0378
Methoxychlor	0.0112–0.0112
PCB-1242	0.0399-0.0506
PCB-1248	0.0425–0.0513
PCB-1254	0.0475–0.0475
PCB-1260	0.0369–0.171
Total PCBs	0.0369–0.171
Other Organics	
Oil and Grease	1,130–4,370
Metals	
Aluminum	34.1–447
Aluminum, Dissolved	29.3–30.6
Antimony	1.04–1.04
Arsenic	2.00–5.00
Arsenic, Dissolved	2.01–2.82
Barium	10.5–127
Barium, Dissolved	13.5–204
Boron	7.52–252
Boron, Dissolved	8.50–45.2
Calcium	9,760–152,000
Calcium, Dissolved	10,100–53,400
Chromium	3.19–3.19
Chromium, hexavalent	5.01–14.7
Cobalt	0.302–1.05
Copper	0.360–7.10
Copper, Dissolved	0.617–5.59
Iron	81.4–2,460
Iron, Dissolved	35.2–231
Lead	0.500–1.05
Lithium	3.15–6.23
Lithium, Dissolved	3.07–3.26
Magnesium	1,630–41,400
Magnesium, Dissolved	1,690–12,600
Manganese	13.2–209
Manganese, Dissolved	1.24–119
Mercury	0.0690–0.110
Mercury, Dissolved	0.108–2.71
Molybdenum	0.218–41.4
Molybdenum, Dissolved	0.547–40.0
Nickel	0.569–66.3
Nickel, Dissolved	0.614–2.28
Phosphorous	23.2–4,160
Phosphorous, Dissolved	20.2–236
Potassium	703–5,650
Potassium, Dissolved	711–2,960
Selenium	2.07–5.00
Selenium, Dissolved	2.04–2.99
Silver	0.317–0.397
Sodium	624–65,200
Sodium, Dissolved	5,840–43,000
Strontium	69.5–2,290
Strontium, Dissolved	73.7–2,290
Thallium	0.944–1.04
Thorium	0.889–0.94
Thorium, Dissolved	1.15–1.15
Tin	1.40–1.40
Tin, Dissolved	2.88–2.88
Titanium	2.00–7.56
Uranium	0.075–393
Uranium, Dissolved	0.0850–53.8
Vanadium	3.46–4.27
Vanadium, Dissolved	3.55–3.66
Zinc	3.38–115
Zinc, Dissolved	4.45–49.1

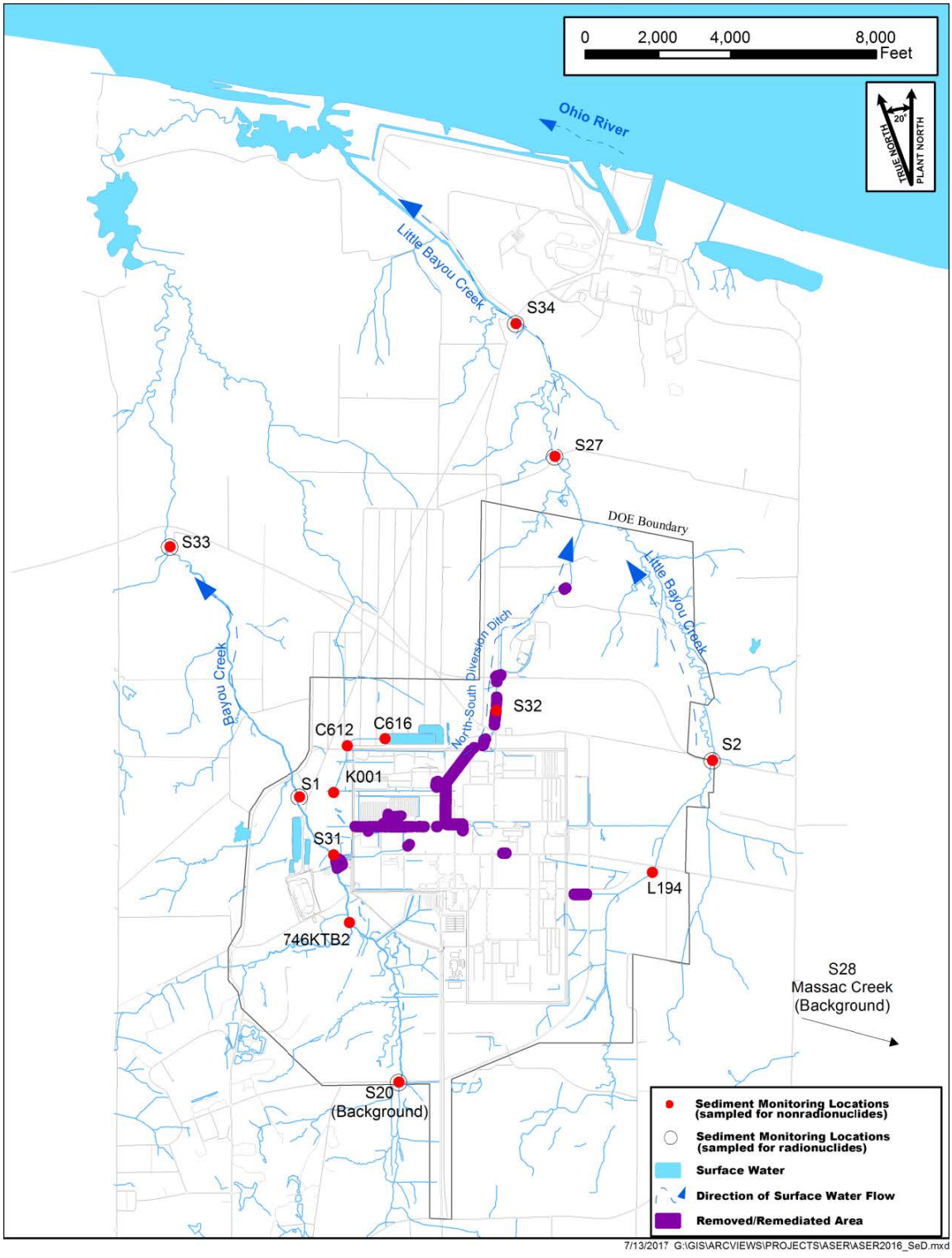

Figure 31. Surface Water and Sediment Monitoring Locations 2017

4.3.4. Biota/Food

Biological monitoring was not required by regulatory programs that were in place during 2017.

4.3.5. Groundwater

Monitoring wells are used at the PGDP to assess the impacts of plant operations on groundwater quality. Figure 33 identifies the surveillance and compliance monitoring wells sampled in 2017 and shows the 2016 TCE plumes associated with the Paducah Site.

The groundwater flow system at the Paducah Site includes the following components (from shallowest to deepest): (1) the Terrace Gravel flow system, (2) Upper Continental Recharge System (UCRS), (3) The Regional Gravel Aquifer (RGA), and (4) the McNairy flow system. Additional water-bearing zones monitored at the Paducah Site are the Eocene Sands and the Rubble Zone (i.e., the weathered upper portion of the Mississippian bedrock). These components are illustrated on Figure 32.

Groundwater compliance monitoring is conducted to ensure that the site is in compliance with environmental and health regulations. Groundwater surveillance monitoring is conducted for the early detection of contamination from past and present PGDP activities, to detect the nature and extent of groundwater contamination including the types and concentrations of groundwater contaminants and the movement of groundwater

The PGDP approach for site-wide groundwater surveillance, monitoring, and compliance is outlined in the PGDP Groundwater Protection Plan and the *Paducah Site Environmental Monitoring Plan (DOE, 2016).*

Data obtained from PGDP groundwater monitoring supports decision-making about the treatment of groundwater contamination and the management and treatment of contamination sources (Figure 34). Groundwater monitoring is conducted at the PGDP to ensure that the site is in compliance with environmental and health regulations.

During 2017 over 200 monitoring wells and residential water supply wells were sampled. in accordance with DOE Orders, Federal, State, and local requirements. Table 3 identifies the groundwater monitoring and surveillance programs, number of wells and flow system components for 2017.

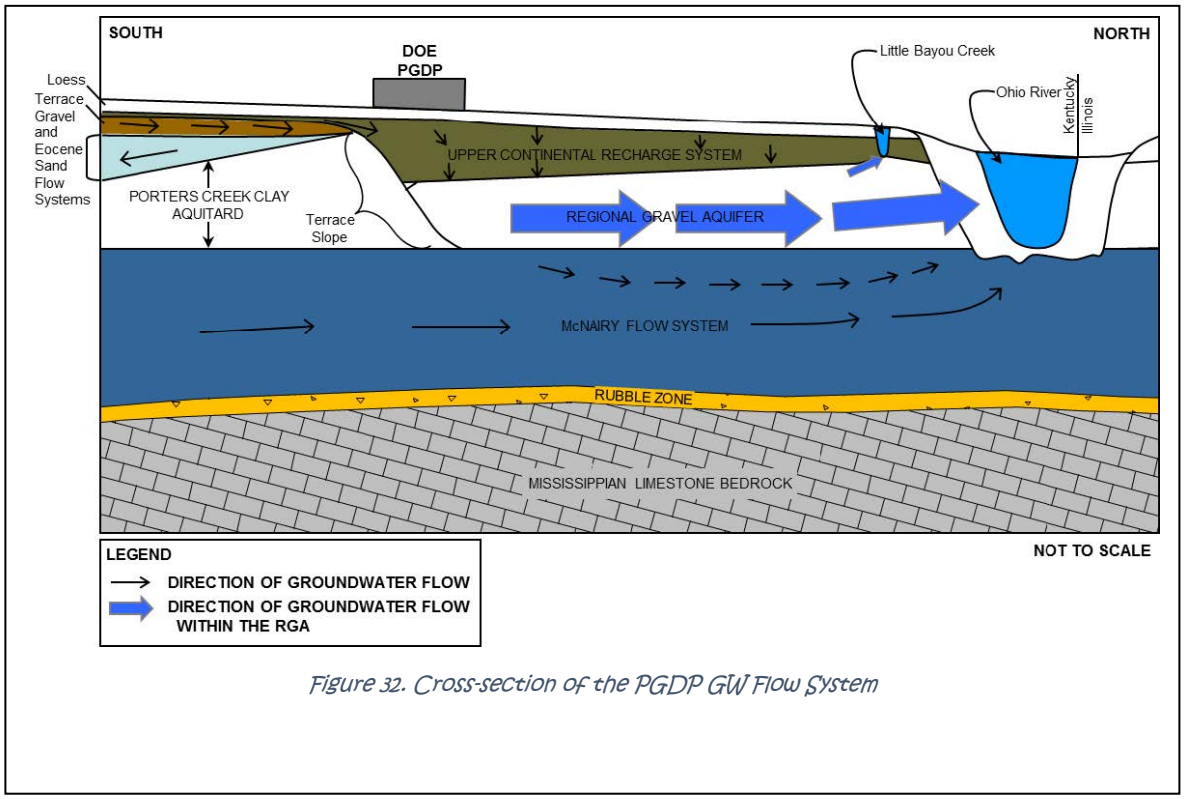

Figure 32. Cross-section of the PGDP GW Flow System

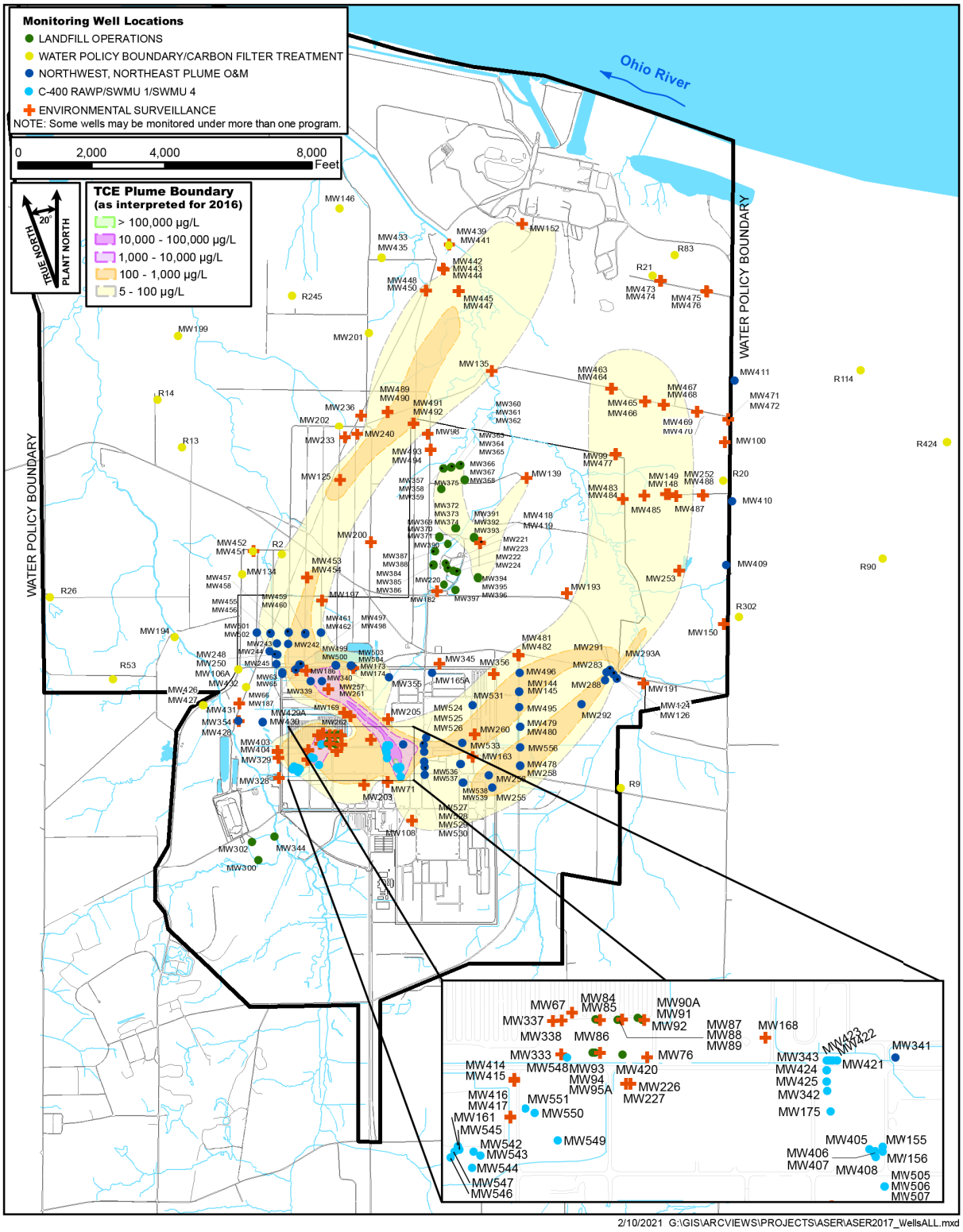

Figure 33. PGDP Groundwater Surveillance and Compliance Monitoring Wells

Table 3. Groundwater Monitoring 2017

Program / Reporting Location	Number of Wells[a]					
	Terrace Gravel/Eocene Sands	UCRS	RGA	McNairy Flow System	Rubble Zone	Total
Groundwater Monitoring Program for Landfill Operations						
C-746-S and C-746-T Landfill Wells *Quarterly Compliance Monitoring Reports*:	0	5b	18	0	0	23[c]
C-746-U Landfill Wells *Quarterly Compliance Monitoring Reports*:	0	9b	12	0	0	21
C-404 Landfill Wells (required by permit) *Semiannual C-404 Groundwater Monitoring Reports:*	0	4	5	0	0	9
C-404 Landfill Wells (Not Committed)	0	0	12	0	0	12
C-746-K Landfill Wells *Semiannual FFA Progress Reports:*	3	0	0	0	0	3
Northeast Plume Operations and Maintenance Program (*Semiannual FFA Progress Reports:* (see links above))						
Semiannual Wells	0	0	14	0	0	14
Quarterly Wells	0	0	2	0	0	2
Quarterly Optimization Wells	0	0	32	0	0	32
Northwest Plume Operations and Maintenance Program (*Semiannual FFA Progress Reports:* (see links above))						
Semiannual Wells	0	0	32	0	0	32
Quarterly Wells	0	0	1	0	0	1
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	9	0	0	9
SWMU 1 Monitoring Wells *Five-Year Review* (to be reported in 2018)						
Quarterly Wells	0	0	7	0	0	7
Water Policy Boundary Monitoring Program (*Annual Site Environmental Report)*						
Northwestern Wells (quarterly)	0	0	20	0	0	20
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	1	29	0	1	24
Biennial	0	4	80	1	0	85
Semiannual Wells	0	0	3	0	0	3
Quarterly Wells	0	0	3	0	0	3

[a] Some wells are sampled under more than one program.
[b] Not all wells had a sufficient amount of water to obtain samples.
[c] The total number of wells where sampling is required by the permit associated with the C-746-S&T Landfills is 25; however, 2 of these wells are required by the permit only for water level measurement. The total number of analytically measured wells, therefore, is 23.

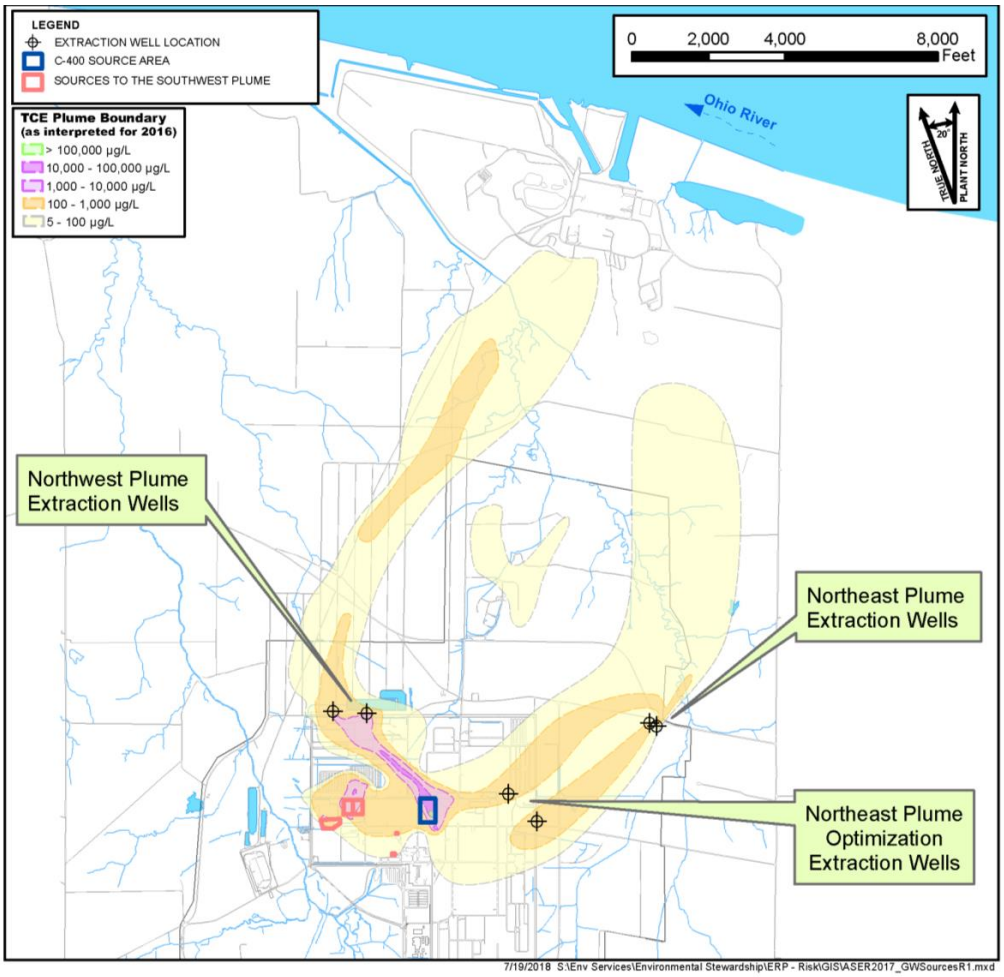

Figure 34. PGDP Groundwater Contaminant Source Areas

Table 4. TCE Removal at Groundwater Source Areas

Source Area	Cumulative TCE Removed (gal) [a,b]
Northwest Plume Groundwater Treatment System	3,564
Northeast Plume Containment System	318
C-400 Cleaning Building Interim Remedial Action (including treatability study)	3,572
Southwest Plume Sources Remedial Action	24
LASAGNA™ treatment at Cylinder Drop Test Site	246

[a] TCE values include liquid VOCs and recovered VOCs on carbon.
[b] Cumulative through December 31, 2017. Value taken from DOE 2018d.

CY 2017 groundwater monitoring at the PGDP was conducted at current and inactive landfills (compliance monitoring), groundwater plume pump-and-treat operations (performance monitoring), C-400 Cleaning Building Interim Remedial Action (performance monitoring) and area residential wells (surveillance monitoring). Results are compiled in the Paducah Oak Ridge Environmental Information System (OREIS) database. A summary of detected materials in 2017 are shown in Table 6.

PGDP groundwater plume maps are revised every two years to include routine groundwater monitoring and characterization data, demonstrate the progress of groundwater cleanup, and facilitate planning for ongoing groundwater cleanup. Plume maps depict the general footprint of the TCE and Tc-99 contamination in the regional gravel aquifer (RGA) and convey the general magnitude and distribution of contamination within the plumes.

Records of decision are in place at the PGDP to clean up the Northwest Plume, the Northeast Plume, the C-400 Cleaning Building source area, and sources to the Southwest Plume. Table 4 lists the total TCE removed through all of the plume and plume source area remedial projects. Graphs in Figures 35 and 36 illustrate the total TCE removed by the Northeast Plume Containment System and the Northwest Plume Groundwater Treatment System.

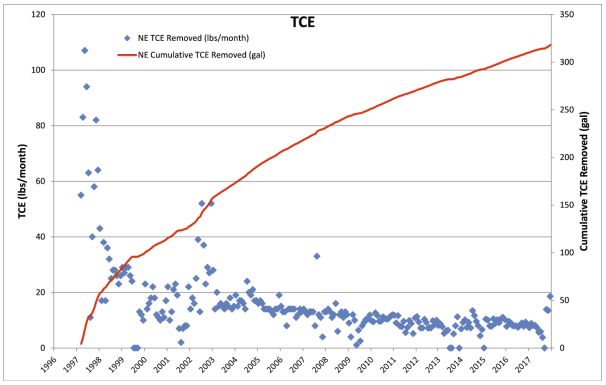

Figure 35. TCE Removed through Northeast Plume Containment System

The groundwater maximum contaminant level (MCL) for TCE is 5 ug/L and exceedances of that MCL at the PGDP C-746 landfill complex are listed in Table 5. A Groundwater Assessment Report documented that there was no evidence of release from the C-746-U Landfill. The report

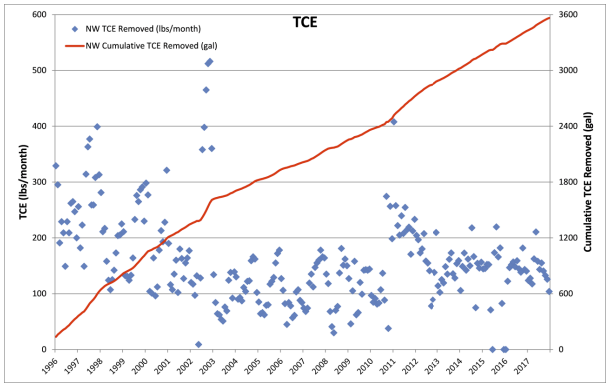

Figure 36. TCE Removed Through Northwest Plume Groundwater Treatment System

found that the beta activity (associated with Tc-99) and TCE in the wells were sourced from upgradient of the C-746-U Landfill and associated with migration of historical plumes. Statistical analyses are also used to evaluate compliance monitoring wells (MWs) at the landfills. Each report lists any statistical exceedance that is found.

Table 5. MCL Exceedances at the C-746 Landfill Complex

Upper Continental Recharge System	Upper RGA	Lower RGA
C-746-S and C-746-T Landfills		
No exceedances	MW369: trichloroethene MW372: beta activity, trichloroethene MW384: beta activity MW387: beta activity MW391: trichloroethene MW394: trichloroethene	MW370: beta activity MW373: trichloroethene MW385: beta activity MW388: beta activity MW392: trichloroethene
C-746-U Landfill		
No exceedances	MW357: trichloroethene MW366: trichloroethene MW369: trichloroethene MW372: beta activity, trichloroethene	MW361: trichloroethene MW364: trichloroethene MW370: beta activity MW373: trichloroethene

Shading indicates a background monitoring well.

Table 6. Groundwater Monitoring Analytes & Range of Results

Analyte	Range
Anions	
Bromide (µg/L)	68.6–1,240
Chloride (µg/L)	1,090–118,000*
Fluoride (µg/L)	49.0–640
Nitrate as Nitrogen (µg/L)	34.2–4,770
Sulfate (µg/L)	4,830–1,010,000
Wet Chemistry Parameters	
Alkalinity (µg/L)	53,900–186,000
Chemical Oxygen Demand (µg/L)	9,170–65,300
Cyanide (µg/L)	1.76–6.40
Dissolved Solids (µg/L)	21,400–533,000
Iodide (µg/L)	169–758
Total Organic Carbon (µg/L)	674–7,290
Total Organic Halides (µg/L)	3.38–174
Volatile Organic Compounds	
1,1,1-Trichloroethane (µg/L)	0.600–0.600
1,1,2-Trichloroethane (µg/L)	0.390–1.49
1,1-Dichloroethane (µg/L)	0.420–19.5
1,1-Dichloroethene (µg/L)	0.350–116*
Acetone (µg/L)	1.80–1.80
Benzene (µg/L)	5.21–5.21
Bromodichloromethane (µg/L)	0.870–0.870
Carbon disulfide (µg/L)	15.2–15.2
Carbon tetrachloride (µg/L)	0.370–142
Chloroform (µg/L)	0.350–374
cis-1,2-Dichloroethene (µg/L)	0.360–36,300*
Tetrachloroethene (µg/L)	0.540–2.40
Toluene (µg/L)	0.370–0.410
trans-1,2-Dichloroethene (µg/L)	0.470–9.11*
Trichloroethene (µg/L)	0.340–49,600*
Vinyl chloride (µg/L)	0.780–468
PCBs	
PCB-1242 (µg/L)	0.0432–0.0914
PCB-1248 (µg/L)	0.0540–0.131
Total PCBs (µg/L)	0.0432–0.131

Analyte	Range
Metals	
Aluminum (µg/L)	19.1–14,800
Arsenic (µg/L)	1.95–19.1
Barium (µg/L)	20.5–503
Beryllium (µg/L)	0.342–0.551
Boron (µg/L)	5.27–1,590
Cadmium (µg/L)	0.304–0.619
Calcium (µg/L)	6,390–272,000
Chromium (µg/L)	3.02–985
Cobalt (µg/L)	0.100–60.9
Copper (µg/L)	0.311–11.3
Iron (µg/L)	34.9–129,000
Iron (2+) (ug/L)	50.0-3300.0
Lead (µg/L)	0.504–8.35
Magnesium (µg/L)	3,390–58,200
Manganese (µg/L)	1.02–14,600
Mercury (µg/L)	0.067–0.292
Molybdenum (µg/L)	0.202–8.09
Nickel (µg/L)	0.502–282
Potassium (µg/L)	169–24,700
Selenium (µg/L)	2.02–4.14
Silver (µg/L)	0.313–1.11
Sodium (µg/L)	16,000–166,000
Uranium (µg/L)	0.071–8.22
Vanadium (µg/L)	3.38–22.1
Zinc (µg/L)	3.37–51.5
Arsenic, Dissolved (µg/L)	2.54–11.0
Barium, Dissolved (µg/L)	18.6–456
Chromium, Dissolved (µg/L)	3.06–39.0
Selenium, Dissolved (µg/L)	2.64–2.80
Uranium, Dissolved (µg/L)	0.068–395
Radionuclides	
Alpha activity (pCi/L)	3.22–18.5
Beta activity (pCi/L)	2.22–484
Radium-226 (pCi/L)	0.235–1.76
Radium-228 (pCi/L)	3.81–5.78
Technetium-99 (pCi/L)	14.5–15,000*
Thorium-230 (pCi/L)	0.661–1.69
Thorium-232 (pCi/L)	0.801–0.999
Uranium-234 (pCi/L)	1.32–2.24
Uranium-238 (pCi/L)	0.6561.41–1.9541

*Maximum results are from C-400 Cleaning Building Interim Remedial Action monitoring wells.

5. Environmental Radiation Monitoring

5.1. Background: The Atom & Radioactivity

Atoms are the basic building block of everything that surrounds us. They are very small; the size of the largest atom is less than 1/100,00th the width of a human hair. Each atom is composed of subatomic particles: protons, neutrons, and electrons. The center or "nucleus" of an atom contains protons and neutrons which make up most of every atom's mass. Orbiting the nucleus of every atom is an electron cloud that contains the rest of the atom's mass (Figure 37; Figure 38).

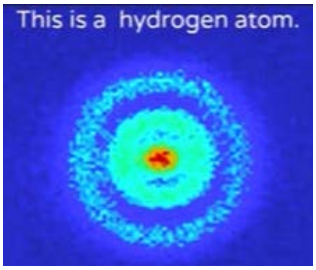

Figure 37. Scanning Transmission Electron Microscope Photo of a Hydrogen Atom

(Above: photo of the structure of a hydrogen atom – the nucleus containing a single proton is red/yellow with surrounding electron obit.)

Elements are composed of atoms that contain the same number of protons in their nucleus. Elements are identified on the periodic table by their atomic number which is the number of protons in an element's nucleus. The lightest element, hydrogen, is assigned atomic number 1 because it contains only 1 proton in its nucleus and a single orbiting electron (Figure 38).

Atoms of an element may exist in several different forms, known as isotopes. Each isotope of an element contains a different number of neutrons in its nucleus. For example, hydrogen has three naturally occurring isotopes: protium with no neutrons and one proton in its nucleus, deuterium with 1 neutron and 1 proton in its nucleus, and tritium with 1 proton and 2 neutrons in its nucleus (Figure 39).

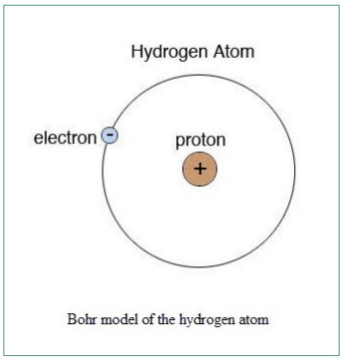

Figure 38. Bohr Model of the Hydrogen Atom

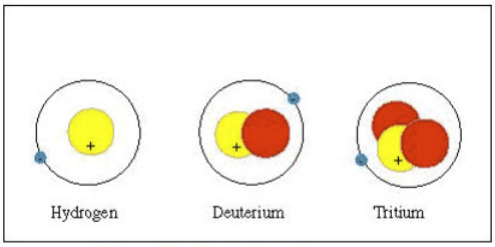

Figure 39. Bohr Model of Hydrogen Isotope Atoms

Uranium (U) is a primordial element and the heaviest naturally-occurring abundant element found on earth with atomic number 92. Uranium contains 92 protons in its nucleus, a varying number of neutrons and 92 orbiting electrons.

Isotopes are identified by their mass number which is equal to the number of protons + neutrons in the nucleus. The most common isotope of naturally occurring uranium has 92 protons + 146 neutrons in its nucleus (92 + 146 = 238) and is identified as the isotope uranium-238, U-238 or ^{238}U.

Other naturally occurring isotopes of uranium are uranium-235 (^{235}U) and uranium-234 (^{234}U).

Some atoms have an unstable nucleus (Figure 40). Unstable atoms, including large atoms like uranium, can naturally split and instantaneously release a portion of their nuclear mass as particles and pure energy in the nuclear reaction process known as radioactive decay.

The energy and particles given off in radioactive decay event are called radiation. Three general types of radiation (Table 7) can be emitted during

radioactive decay: alpha particles, beta particles, and gamma rays (energy).

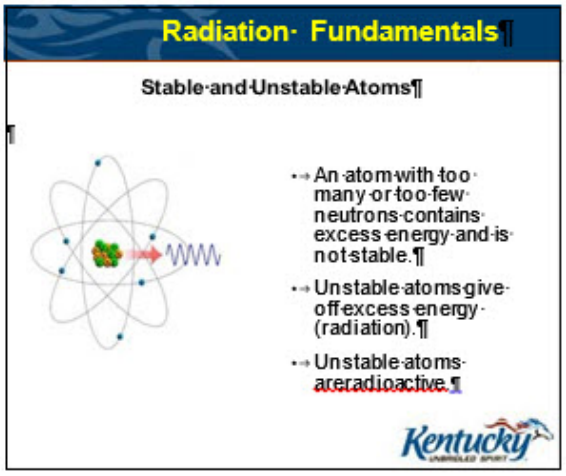

Figure 40. Stable and Unstable Atoms

Table 7. Types of radiation

Type	Radiation Emitted
Alpha decay	alpha particle (2 protons and 2 neutrons) + energy
Beta decay	beta particle (1 electron) + energy
Gamma decay	energy (gamma ray)

Radioactive decay results in the formation of a new isotope of the parent element or the formation of lighter elements that may either undergo further radioactive decay or be stable and not undergo further radioactive decay.

Atoms can also be split by nuclear reactions which involve the collision of atomic nuclei or the bombardment of an atom's nucleus by a proton, neutron, or energetic particle. Material that contains atoms which undergo the radioactive decay process is called radioactive material (Inset).

Nuclear fission is a radioactive decay process or nuclear reaction where atoms split into smaller parts and release vast amounts of energy. Energy is released according to Einstein's famous formula $E = mc^2$, where E = energy, m is the small amount of mass and c is the speed of light, which is a very, very large number.

Under certain circumstances, isotopes of some elements are "**fissile**", meaning that they are capable of supporting a self-sustained, or chain, nuclear reaction. Non-fissile isotopes, like U-238, are not capable of supporting a chain nuclear reaction. The isotope uranium-235 is fissile and

Radiation a. the process in which energy is emitted as particles or waves. b. the complete process in which energy is emitted by one body, transmitted through an intervening medium or space, and absorbed by another body. c. the energy transferred by these processes.

Radioactive decay (also known as **nuclear decay**, **radioactivity**, **radioactive** disintegration, or **nuclear** disintegration) is the process by which an unstable atomic nucleus loses energy by radiation.

Source:
https://en.wikipedia.org/wiki/Radioactive_decay

because of its fissile property it is the desired uranium isotope to utilize as a source of energy.

In the 1930s and '40s, prior to the onset of World War II, scientists discovered the energy released during nuclear fission. They quickly recognized its potential as a weapon and as an efficient heat source for driving turbines and generating electricity.

Radioactive Materials are substances that contain unstable, radioactive atoms that give off radiation as they decay.

5.2. Environmental Radiation Background

Members of the public are routinely exposed to radiation from natural and man-made sources (Figure 41). Routine operations at the PGDP may release *radioactive materials* into the environment. The releases may result in a radiation *exposure* (Inset) to the public and/or the environment. An exposure may result in a *dose* (Inset) to an individual.

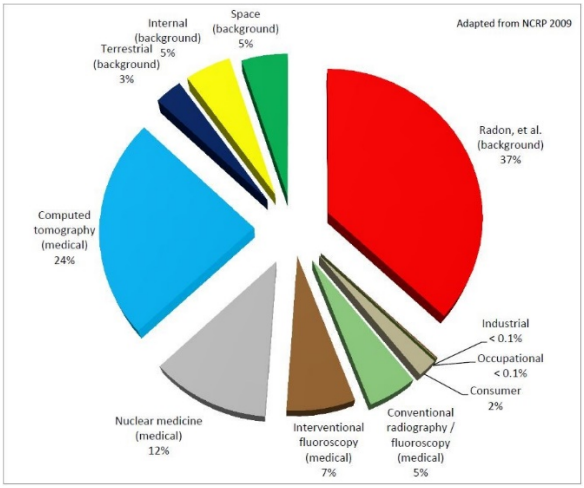

Figure 41. Average Annual Radiation Dose

> **Exposure** to radiation is a transfer of energy from a radioactive substance to an individual. This transfer of energy can result in tissue damage. Exposures may be external from radionuclides outside the body or internal from inside the body.

DOE Order 458.1, *Radiation Protection of the Public and the Environment* requires an environmental surveillance program at DOE sites and requires that the program include any pathway

> **Dose** is the amount of energy absorbed by the human body resulting from exposure to a source of radiation. Dose is measured in rems or millirems (mrem).

that could result in public exposure and a dose to a member of the public. The environmental surveillance and monitoring conducted at the PGDP specific to radioactive materials is commonly referred to as *radiological monitoring*.

PGDP radiological monitoring includes the following media and pathways: surface water, groundwater, sediment, direct radiation, and air.

DOE has established dose limits to the public so that DOE operations will not contribute significantly to an individual's dose from an average annual exposure. Each year, PGDP operations may contribute to the public's or individuals' dose through releases of and resulting exposure to radioactive material. The PGDP monitors releases of its radioactive materials and calculates an annual dose amount through:

- The use of effluent release data
- Direct radiation monitoring data
- Environmental monitoring data (along with relevant site-specific data)

DOE Order 458.1 establishes an acceptable *dose* limit for the public of 100 mrem per year above background dose. The PGDP monitors the presence and releases of radiation as well as the amount of radiation that the public receives. The PGDP uses radiation monitoring data to confirm that doses are below the public and individual dose limits established in DOE Order 458.1.

5.2.1. Radioactive Materials

Radioactive materials at the PGDP are the result of processing uranium into nuclear materials. Technetium-99 is a man-made element created as a product of the fission process in nuclear reactors.

> **Radioactive Elements/Isotopes** that can be or have been found at the PGDP
>
> Uranium-234 (245,000 year half-life)
>
> Uranium-235 (704,000,000 year half-life)
>
> Uranium-238 (4,470,000,000 year half-life)
>
> Thorium-230 (75,400 year half-life)
>
> Technetium-99 (211,000 year half-life)
>
> Plutonium-238 (87.7 year half-life)
>
> Plutonium-239 (24,100 year half-life)
>
> Neptunium-237 (2,140,000 year half-life)
>
> Americium-241 (432 year half-life)
>
> Cesium-137 (30.2 year half-life)

Tc^{99} was introduced at the PGDP during the reprocessing (recycling) of spent nuclear fuel.

5.2.2. Sources/Pathways

An exposure pathway is the route a released radioactive material takes from a source to a receptor (a plant, person, or animal). Routine operations at the PGDP and DUF_6 facilities release incidental radioactive materials into the environment through atmospheric and liquid discharges.

The principal pathways (Figure 42) by which people are potentially exposed are:

- Inhalation of gases and particulates
- Ingestion of vegetables, crops, milk, and wildlife
- Ingestion of surface water and groundwater
- Skin absorption (also called dermal absorption)
- External exposure to ionizing radiation.

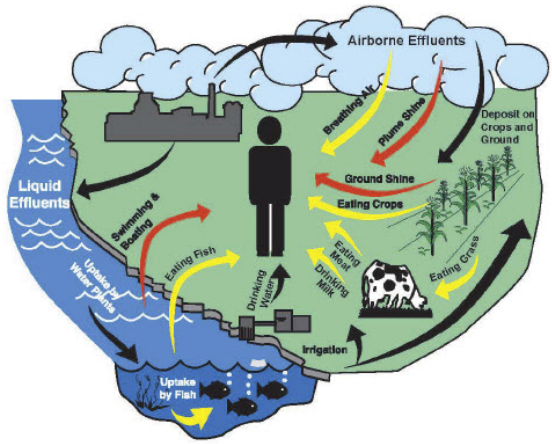

Figure 42. Radiation Exposure Pathways

5.2.3. Radiation Protection

Under DOE orders 458.1 (Radiation Protection of the Public and the Environment) and 435.1 (*Radioactive Waste Management*), the DOE establishes the requirements for protection of the public and the environment against any undue risk from radiation from the Site. It also makes sure radioactive waste is managed in a safe way, limiting exposure to workers, the public, and the environment.

The DOE utilizes authorized limits (Inset) to ensure that doses to the public meet DOE standards and are As Low As Reasonably Achievable or 'ALARA' (Inset), that groundwater is protected, that future remediation would not be needed, and that no radiological protection requirements are violated. The Site complies with DOE Order 435.1 and DOE Order 458.1. The ways the Site complies with these DOE Orders are as follows:

- Conduct radiological activities so that exposure to members of the public is maintained within the dose limits;
- To control the removal of radiological property;
- To ensure that potential radiation exposures to members of the public are ALARA (Inset);
- To monitor routine and nonroutine radiological releases and to assess the radiation dose to members of the public; and
- To protect the environment from the effects of radiation and radioactive material.

ALARA means "**as low as reasonably achievable**," which is an approach to radiation protection to manage and control releases of radioactive material to the environment, the workforce, and members of the public so that levels are as low as reasonably achievable, taking into account societal, environmental, technical, economic, and public policy considerations. ALARA is not a specific release or dose limit, but a process that has the goal of optimizing control and managing release of radioactive material to the environment and doses so they are as far below the applicable limits as reasonably achievable. ALARA optimizes radiation protection.

5.2.4. Dose Assessment

The assessment of dose at the PGDP is conducted using methods consistent with DOE Order 458.1, other guidance documents, and Methods for Conducting Risk Assessments and Risk Evaluations *(DOE 2017. Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant Paducah, Kentucky Volume 1. Human Health, DOE/LX/07-01074D2/R8, July 2017).*

Measurements of radionuclide concentrations in liquids and air released from the PGDP are modeled to estimate the maximum exposure to an individual in a year.

The population living within a 50-mile radius of Paducah Site is evaluated in the Site's assessment of compliance with public off-site dose limits. In the assessment, the "Maximally Exposed Individual" (MEI) is a hypothetical resident who could be affected the most by any radiological release.

The exposure pathways evaluated for calculating a dose for the MEI are:

- The MEI is exposed to air releases at the highest concentration of radionuclides that were measured in air during a year.
- The MEI consumes milk, meat, and vegetables produced at that location.
- The MEI spends time on or near Bayou or Little Bayou Creek.
- The MEI hunts on the wildlife reservation and consumes hunted wildlife.
- The MEI ingests surface water from the nearest public water withdrawal in Cairo, Illinois.
- The MEI ingests sediment with surface water as a recreational user of Bayou and Little Bayou Creeks on the DOE Reservation.
- The MEI is evaluated as the nearest plant neighbor for calculation of the MEI's dose associated with airborne releases of radionuclides.
- The MEI does not consume Groundwater because all persons downgradient of the Paducah Site are provided water from the local public water supply system under DOE's Water Policy.

Additional assumptions related to the Paducah Site MEI are that surface water is not used for irrigation of crops. Little Bayou Creek is not a permanent stream and does not support aquatic life for consumption. Fish are not caught and consumed from Bayou Creek, so fish ingestion is not considered.

Authorized Limits have been approved for:

Disposal of residual radioactive materials at the C-746-U Landfill and Release of residual radioactive materials from DOE-owned property outside the Limited Area.

Burning lube oil and transformer oil at Clean Harbors in Deer Park, Texas, and Veolia in Port Arthur, Texas;

Unrestricted release of aqueous hydrofluoric acid generated during DUF_6 conversion;

Shipping low-level waste to Waste Control Specialists, LLC, RCRA Landfill;

Disposal of waste containing residual radioactive materials at the Energy Solutions Carter Valley Landfill, Tennessee.

6. Site Radiation Monitoring & Dose Assessment

6.1. Air

DOE operations that may result in airborne radionuclide releases include CERCLA remedial actions and incidental emissions. Several potential sources were evaluated at the PGDP in 2017 including groundwater treatment facilities and the DUF_6 Conversion facilities, including:

- Northwest Plume Groundwater Pump and Treat System (Surface Water & Air Releases)
- Northeast Plume Groundwater Alternate Pump and Treat System (Surface Water & Air Releases)
- DUF_6 Conversion Facility (Air Releases)
- C-709/C-710 Laboratory Hoods (Air Releases)
- Seal and wet air exhaust systems in PGDP process and support buildings (Air Releases)

Specific activities that could generate fugitive emissions include transport and disposal of waste, decontamination of contaminated equipment, and environmental cleanup activities.

Ambient air monitoring is conducted of Paducah Site operations using eight continuous air monitors surrounding the Paducah Site, portions of the Paducah DOE reservation and one background air monitor. Monitored radioactive substances are identified in the FY 2016 and FY 2017 Environmental Monitoring Plans (FPDP 2016; FPDP 2017a).

Table 8. Radioactive Air Releases

Emission Sources	Dose to the Maximally Exposed Individual for the Plant (mrem)
Group D—C-709/C-710 Laboratory Hoods	3.2E-04
Group F—Seal Exhaust/Wet Air Group	5.3E-05
Northwest Plume Treatment System	6.5E-05
Northeast Plume Treatment Unit SP234	1.6E-06
Northeast Plume Treatment Unit SP235	5.0E-07
DUF_6 Conversion Facility	9.4E-07
Total from All Sources	**4.4E-04**

Table 9. Air Release Dose Estimates

Radionuclide	Northwest Plume Groundwater Treatment System	Northeast Plume Containment System Alternate Treatment Unit SP234	Northeast Plume Containment System Alternate Treatment Unit SP235	DUF_6 Conversion Facility	C-709 & C-710	Seal Exhaust/ Wet Air Group	Total Site Emissions
Tc-99	9.53E-05	8.62E-06	2.92E-06	0.00E+00	0.00E+00	6.80E-07	1.08E-04
U-234	0.00E+00	0.00E+00	0.00E+00	9.90E-07	9.98E-04	4.18E-06	1.00E-03
U-235	0.00E+00	0.00E+00	0.00E+00	4.53E-08	3.81E-05	2.27E-07	3.84E-05
U-238	0.00E+00	0.00E+00	0.00E+00	2.43E-06	1.02E-04	1.68E-06	1.06E-04
Np-237	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Pu-239	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Th-230	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.37E-06	5.37E-06
Th-231	0.00E+00	0.00E+00	0.00E+00	3.53E-07	0.00E+00	0.00E+00	3.53E-07
Total Curies/Year	**9.53E-05**	**8.62E-06**	**2.92E-06**	**6.82E-05**	**1.14E-03**	**1.21E-05**	**1.33E-03**

*Values are taken from *National Emissions Standard for Hazardous Air Pollutants Annual Report for 2017* (FRNP 2018c).

Table 10. Collective Dose from PGDP Airborne Releases

Effective Dose to Maximally Exposed Individual (mrem)	Percent of Standard (%)	Collective Effective Dose (person-rem)
4.4E-04	0.0044	3.8E-03

Radioactive releases from stacks and diffuse PGDP sources were modeled using the EPA-approved computer code CAP-88. The CAP-88 air dispersion models use meteorological data and calculate dose based on ingestion, inhalation, air immersion and ground pathways. Table 8 provides site estimates of atmospheric releases in curies and Table 9 provides the modeled dose to the MEI from individual PGDP point sources.

The hypothetical maximally exposed individual was calculated potentially to receive an effective dose equivalent of 0.00044 mrem, which is well below the National Emission Standards for Hazardous Air Pollutants standard of 10 mrem. The calculated CAP-88 collective effective dose for the entire population within 50 miles of the PGDP is in Table 10.

6.2. Surface Water

During 2017, surface water environmental surveillance monitoring was conducted quarterly at four locations (Figure 29), one background location, and a downstream Ohio River location near the Cairo, Illinois public water supply. Locations were prioritized for areas of public access, introduction of plant material to the environment, and places where the plant's discharge controls could be checked.

Isotope analysis for multiple possible radionuclides is performed on samples collected at environmental, quarterly, and permitted sampling locations. If a sample contains alpha and beta activity at levels below established screening thresholds, no further analysis is conducted. The screening threshold is 14 pCi/L for alpha activity and 300 pCi/L for beta activity. During 2017 no surface water environmental surveillance monitoring location samples exceeded the alpha or beta screening thresholds.

In addition, samples were taken throughout the year near twenty KPDES-permitted outfalls. Threshold values were exceeded during CY 2017 at KPDES Outfalls 004 and 017.

Effluent surface water sampling is conducted at five (5) locations associated with the C-746-S&T and C-746-U Landfills and one location associated with Northeast Plume effluent. CY 2017 isotopic analyses of surface water and KPDES outfall samples is summarized in Table 11.

Table 11. Radiation Effluent Monitoring

Isotope	Range
Technetium-99 (pCi/L)	2.68E+01–5.94E+01
Uranium-234 (pCi/L)	1.07E+00–2.04E+01
Uranium-235 (pCi/L)	1.02E+00–2.71E+00
Uranium-238 (pCi/L)	1.18E+00–7.84E+01

Surface water from the Paducah Site is not used as a drinking water source, but it is eventually discharged into the Ohio River, which is used as a public drinking water source at Cairo, Illinois, located downstream at the confluence of the Ohio and Mississippi Rivers. The concentrations of radionuclides detected near the surface water collection inlet at Cairo during CY 2017 were used to calculate the dose to the MEI resulting from consumption of surface water. The maximum alpha and beta activities detected in Cairo samples was 1.34 and 6.01 pCi/L, respectively. Maximum contaminant level (MCL) for alpha and beta activities are 15 pCi/L and 4 mrem/year, respectively.

6.3. Drinking Water

The drinking water pathway dose was calculated for the MEI consuming water from the Cairo drinking water location. The maximum annual MEI dose was calculated to be 0.09 mrem/yr in 2017 as a default value since the Cairo location samples did not exceed alpha and beta screening thresholds and no isotopic analyses were conducted on the samples.

Dose to the hypothetical MEI is calculated based on incidental ingestion of surface water due to wading or swimming in Bayou and Little Bayou Creeks and their tributaries. The assumptions on incidental ingestion of surface water are that someone may swim or wade 45 days/year, 2.6 hours/day, and incidentally ingest 0.05 liters per

hour while swimming. The highest monthly surface water results from the various sampling locations are utilized to calculate the top concentration and resulting dose. The annual dose due to the incidental ingestion of surface water is 0.19 mrem/year.

6.4. Landfill Leachate

C-746-U Landfill leachate is sampled routinely and screened against DOE Order 458.1 limits. Treated leachate is released through permitted outfalls to ensure compliance with permit standards.

6.5. Sediment

The sediment dose to the MEI assumes potential exposure to contaminated sediment in the Bayou and Little Bayou Creeks during hunting, fishing, and other recreational activities. Exposure is assumed to occur through incidental ingestion of 100 mg/day contaminated sediment at one creek location every other day during the hunting season (104 days/year). Exposure calculations for sediment include ingestion, inhalation, and external gamma pathways. The downstream location with the maximum dose is assumed to represent the dose received from this pathway. The highest annual sediment exposure pathway dose was calculated at location S27 (0.05 mrem/yr) downstream of the PGDP (Table 12) at the Bayou Creek and Outfall 001 confluence. The sediment exposure pathway is a major contributor to the dose received by the MEI (Table 13).

6.6. Wildlife and Food Consumption

As part of PGDP environmental surveillance the ingestion of contaminated wildlife and farm-raised animal meat, eggs, and milk is evaluated as a pathway for exposure through the animals' ingestion of contaminated water, sediment, other animals, or direct contact with contaminated areas.

Irrigation and deposition of waterborne radionuclides on food crops is an incomplete pathway because municipal water is supplied to nearby residents for household and agricultural use. Irrigation and deposition of radionuclides does not contribute to dose.

6.7. External Radiation Exposure

Due to Paducah Site security protocols in CY 2017, no members of the public were routinely allowed near the security fence. The external radiation doses measured by thermoluminescent dosimeter (TLDs) in areas accessible to the public were not statistically above background and the possible contribution to public dose is negligible (Figure 43).

6.8. Total Dose to the MEI

The combined (internal and external) dose to the MEI was calculated to be 4.1 mrem/yr, well below the DOE annual dose limit of 100 mrem/year to members of the public. The airborne releases to the MEI were calculated to be 0.00044 mrem/year which is well below the EPA airborne dose limit of *10 mrem/year to the public (Table 13).*

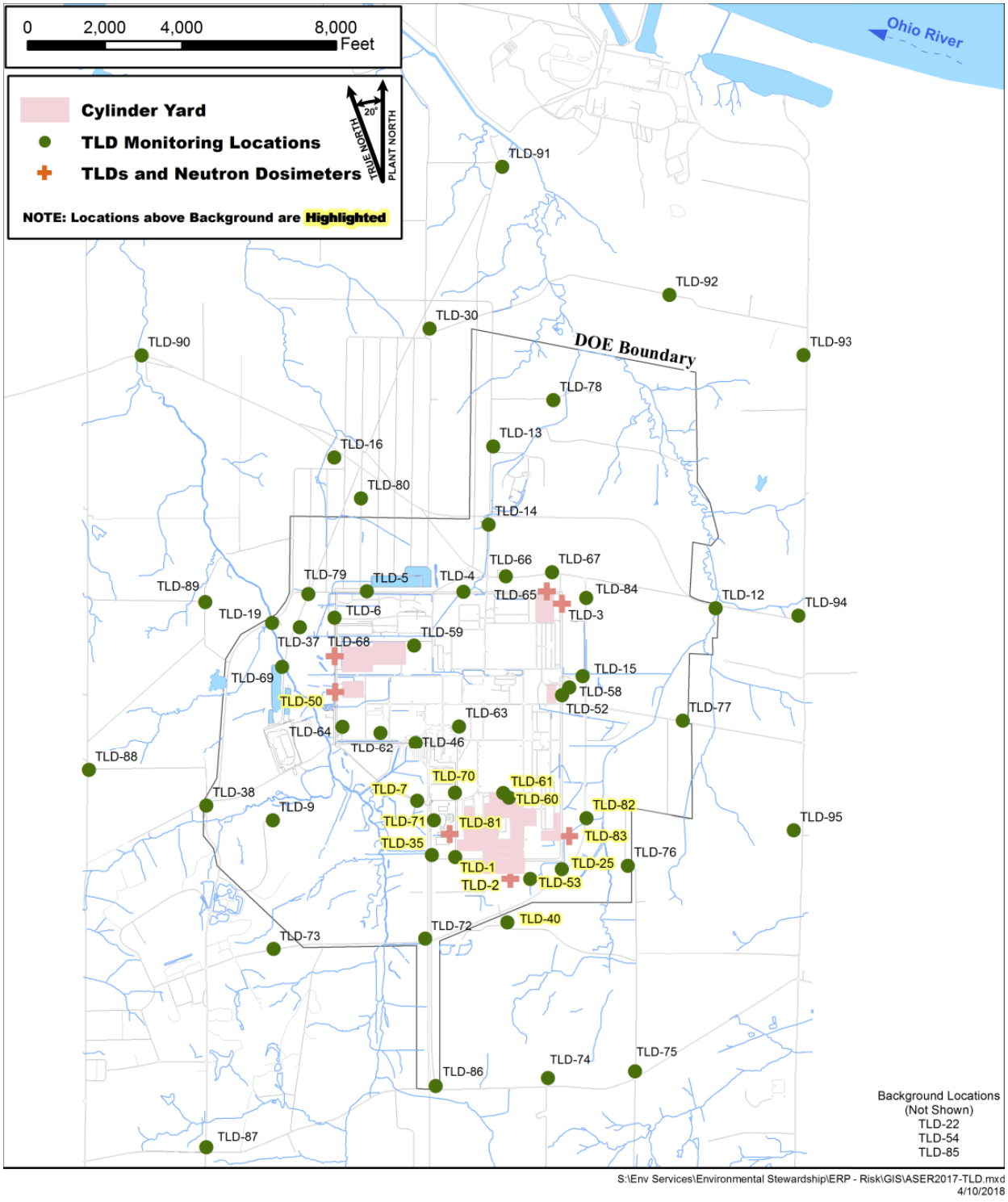

Figure 43. Dosimeter Direct Dose Monitoring Locations

Table 12. Sediment Ingestion Dose

Location	Committed Effective Dose Equivalent (mrem/year)—Sediment Ingestion										
	Am-241	Cs-137	Np-237	Pu-238	Pu-239/ Pu-240	Tc-99	Th-230	U-234	U-235	U-238	Total (mrem)
S20 (background)[b]	1.57E-03	0.00E+00	3.27E-03	7.09E-04	0.00E+00	2.65E-05	6.69E-03	2.01E-03	1.32E-02	6.32E-03	3.38E-02
S1[b]	0.00E+00	1.36E-02	0.00E+00	0.00E+00	0.00E+00	2.12E-04	1.51E-03	3.88E-03	0.00E+00	2.56E-02	4.48E-02
S2[b]	0.00E+00	0.00E+00	0.00E+00	4.01E-04	1.02E-03	1.70E-06	1.06E-03	0.00E+00	0.00E+00	1.66E-02	1.91E-02
S27[b]	0.00E+00	7.44E-04	0.00E+00	0.00E+00	0.00E+00	1.20E-03	1.20E-02	1.91E-03	0.00E+00	3.41E-02	***5.00E-02***
S33[b]	0.00E+00	2.64E-03	0.00E+00	0.00E+00	9.68E-04	9.30E-06	1.49E-03	0.00E+00	0.00E+00	4.60E-04	5.57E-03
S34[b]	0.00E+00	1.38E-03	0.00E+00	0.00E+00	6.83E-04	0.00E+00	1.13E-02	8.00E-04	0.00E+00	0.00E+00	1.42E-02
	Net Exposure from Paducah Site to the Maximally Exposed Individual[a,b,c,d] (Downstream Little Bayou) =										**5.0E-02**

[a] Maximum allowable exposure is 100 mrem/year for all contributing pathways and 25 mrem/year from one source (DOE Order 458.1).
[b] Radionuclide dose from S20 is considered background and has been subtracted from Paducah Site-related doses. If location dose is less than background dose or less than zero, the dose is specified as 0.00E+00 mrem/year.
[c] Dose calculated as ratio of listed dose for Adult Recreator in Table A.8 in *Methods for Conducting Risk Assessments and Risk Evaluations at the Paducah Gaseous Diffusion Plant* (DOE 2017a), which includes the ingestion, inhalation, and external gamma pathways.
[d] When more than one sample is present at the listed location, the doses of each sample are averaged.

Table 13. Summary of Potential Radiological Dose to the MEI from the Paducah Site for CY 2017

Pathway[a]	Dose to Maximally Exposed Individual (mrem/year)	Percent of DOE 100 mrem/year Limit	Estimated Collective (Population Dose) (person-rem/year)	Population within 50 miles
Air[c]	4.4E-04	0.00044%	3.8E-03	~534,116
Water[d]				
Ingestion of drinking water[e]	9.0E-02	0.09%	2.5E-01[f]	2,830
Incidental ingestion of surface water	1.1E-01	0.11%	[g]	[g]
Sediments (incidental ingestion)	5.0E-02	0.050%	[g]	[g]
Direct radiation	3.8E+00	3.8%	5.6E-01[h]	150
All Relevant Pathways[a]	**4.1E+00[b]**	**4.1%**	**8.1E-01**	

[a] Pathways defined in previous sections.
[b] Maximum allowable exposure from all sources is 100 mrem/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 AirDose EPA food chain modeling routines. DOE source emissions were from Northwest Plume Groundwater Treatment System, Northeast Plume Containment System Alternate Treatment Unit, DUF_6 conversion activities, and C-709 and C-710 Seal Exhaust/Wet Air Group.
[d] Groundwater is not a viable pathway for the maximally exposed individual due to DOE's providing public water to downgradient residents.
[e] Ingestion of drinking water is assessed from the nearest surface water intake, 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.
[g] Incidental ingestion of surface water and sediment within plant creeks and ditches is not applicable for calculation of collective dose to residents who reside within 50 miles of the Paducah Site. Collective dose is not calculated for the incidental ingestion pathway due to the lack of a plausible exposure scenario. This pathway is more likely to involve individuals; therefore, it is more suited for the maximally exposed individual dose calculation.
[h] Population dose for direct radiation is based on a representative assumption using the estimated visitors hiking in WKWMA only.

7. Public involvement

The DOE and Site contractors are committed to enhancing public awareness of PGDP activities through community and educational outreach programs.

7.1. PGDP CAB

The Paducah Citizens Advisory Board (CAB) is a site-specific advisory board chartered by DOE under the Federal Advisory Committees Act. The CAB is composed of up to 18 members chosen to reflect the diversity of the PGDP area. The CAB reflects the community's concerns regarding the environmental management of the PGDP site and conveys those concerns to the DOE. The CAB meets bimonthly to focus on early citizen participation in environmental cleanup priorities and related issues at the DOE facility.

The PGDP CAB subcommittees addressed issues related to the following PGDP subjects:

- Decontamination and Decommissioning
- Environmental Restoration
- Community Engagement
- Integrated Priority List

PGDP CAB meetings were open to the public and all regular board meetings were publicly advertised. In addition to its voting members, the CAB also has non-voting members representing EPA Region 4, Kentucky Division of Waste Management (KDWM), Kentucky Cabinet for Health and Family Services, and WKWMA.

7.2. Site Visits

A comprehensive DOE Community Relations and Public Participation Program (DOE 2016b) was updated in CY 2016. The Program provides the public with opportunities to become involved in decisions relating to environmental issues at the PGDP site.

During CY 2017 DOE's PGDP Environmental Management Program conducted ten guided public tours of the PGDP site.

7.3. Education

In a joint project between DOE and the Kentucky Research Consortium for Energy and Environment (KRCEE) at the University of Kentucky, students from Marshall County High School participated in a program that: produced a summarized version of a previous year's PGDP Annual Site Environmental Report; received briefings from subject matter experts about PGDP history & operations, nuclear science, environmental impacts, and ecology; and also participated in field ecological data collection activities in the WKWMA around the PGDP site. The KRCEE continued development of a PGDP Virtual Museum during 2017 to document the history and accomplishments of the PGDP as an interactive web resource.

7.4. Outreach

DOE supported several educational and community outreach activities during 2017. Site employees participated in a "Feds Feed Families" program in which employees brought nonperishable food items to donate to local food pantries.

DOE and its contractors engaged students through educational outreach programs such as the annual DOE National Science Bowl, for which regional competitions were held in February for Western Kentucky and Southern Illinois middle and high schools. DOE and its contractors also supported the Western Kentucky Regional Science Fair, local school career fairs, and a middle school Science, Technology, Engineering, and Math program. In 2017, DOE contractors sponsored a 10-week Internship Program for college students to work and be mentored by engineers, project managers, and leaders in the business, safety, and regulatory departments to get a first-hand perspective of what they would like to do after graduation.

Glossary

absorption—The process by which the number and energy of particles or photons entering a body of matter are reduced by interaction with the matter.

activity—See radioactivity.

adsorption—The accumulation of gases, liquids, or solutes on the surface of a solid.

air stripping—The process of bubbling air through water to remove volatile organic compounds (VOCs) from the water.

alpha activity—A measure of the emission of alpha particles during radioactive decay. Alpha particles are positively charged particles emitted from the nucleus of an atom having the same charge and mass as that of a helium nucleus (two protons and two neutrons).

ambient air—The atmosphere around people, plants, and structures.

analyte—A constituent or parameter being analyzed.

aquifer—A geologic formation, group of formations, or part of a formation capable of yielding a significant amount of groundwater to wells or springs.

assimilate—To take up or absorb.

authorized limit—A limit on the concentration or quantity of residual radioactive material on the surfaces or within property that has been derived consistent with DOE directives including the as low as reasonably achievable (ALARA) process requirements. An authorized limit also may include conditions or measures that limit or control the disposition of property.

beta activity—A measure of the emission of beta particles during radioactive decay. Beta particles are negatively charged particles emitted from the nucleus of an atom. It has a mass and charge equal to those of an electron

biota—The animal and plant life of a particular region considered as a total ecological entity.

biota concentration guide (BCG)—The limiting concentration of a radionuclide in soil, sediment, or water that would not cause dose limits for protection of populations of aquatic and terrestrial biota (as used in DOE technical standard, DOE-STD-1153-2002) to be exceeded.

chain-of-custody form—A form that documents sample collection, transport, analysis, and disposal.

clearance of property—The removal of property that contains residual radioactive material from DOE radiological control under 10 *CFR* Part 835 and DOE Order 458.1.

closure—Formal shutdown of a hazardous waste management facility under Resource Conservation and Recovery Act requirements.

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

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

conductivity—A measure of a material's capacity to convey an electric current. For water, 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.

contained landfill—A solid waste site or facility that accepts disposal of solid waste. The technical requirements for contained landfills are found in 401 *KAR* 47:080, 48:050, and 48:070 to 48:090.

contamination—Deposition of radioactive material on the surfaces of structures, areas, objects, or personnel; or introduction of microorganisms, chemicals, toxic substances, wastes, or wastewater into water, air, and soil in a concentration greater than that found naturally.

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

curie (Ci)—A unit of radioactivity. One curie is defined as 3.7×10^{10} (37 billion) disintegrations per second. Several fractions and multiples of the curie are used commonly
- **kilocurie (kCi)**—10^{3} Ci, one thousand curies; 3.7×10^{13} disintegrations per second.
- **millicurie (mCi)**—10^{-3} Ci, one-thousandth of a curie; 3.7×10^{7} disintegrations per second.
- **microcurie (μCi)**—10^{-6} Ci, one-millionth of a curie; 3.7×10^{4} disintegrations per second.
- **picocurie (pCi)**—10^{-12} Ci, one-trillionth of a curie; 3.7×10^{-2} 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.

dense nonaqueous-phase liquid (DNAPL)—The liquid phase of chlorinated organic solvents. These liquids are denser than water and include commonly used industrial compounds such as tetrachloroethene and trichloroethene.

detected value—The value reported by the laboratory for an analysis that the laboratory or a third-party data validator does not qualify with a "U" or "<."

disintegration, nuclear—A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus of an atom.

dose—The energy imparted to matter by ionizing radiation. The unit of absorbed dose is the rad, equal to 0.01 joules per kilogram in any medium.

absorbed dose—The quantity of radiation energy absorbed by an organ divided by the organ's mass. Absorbed dose is expressed in units of rad (or gray) (1 rad = 0.01 Gy).

dose equivalent—The product of the absorbed dose (rad) in tissue and a quality factor. Dose equivalent is expressed in units of rem (or sievert) (1 rem = 0.01 Sv

committed dose equivalent—The calculated total dose equivalent to a tissue or organ over a 50-year period after known intake of a radionuclide into the body. Contributions from external dose are not included. Committed dose equivalent is expressed in units of rem (or sievert).

committed effective dose equivalent/committed effective dose—The sum of total absorbed dose (measured in mrem) to a tissue or organ received over a 50-year period resulting from the intake of radionuclides, multiplied by the appropriate weighting factor. The committed effective dose equivalent is the product of the annual intake (pCi) and the dose conversion factor for each radionuclide (mrem/pCi). Committed effective dose equivalent is expressed in units of rem (or sievert).

effective dose equivalent/effective dose—The sum of the dose equivalents received by all organs or tissues of the body after each one has been multiplied by an appropriate weighting factor. The effective dose equivalent includes the committed effective dose equivalent from internal deposition of radionuclides and the effective dose equivalent attributable to sources external to the body.

collective effective dose equivalent/collective dose equivalent—The sums of the dose equivalents or effective dose equivalents of all individuals in an exposed population within a 50-mile radius expressed in units of person-rem (or person-sievert). When the collective dose equivalent of interest is for a specific organ, the units would be organ-rem (or organ-sievert). The 50-mile distance is measured from a point located centrally with respect to major facilities or DOE program activities.

downgradient—In the direction of decreasing hydrostatic head.

effluent—A liquid or gaseous waste discharge to the environment.

effluent monitoring—The collection and analysis of samples or measurements of liquid and gaseous effluents for purposes of characterizing and quantifying the release of contaminants, assessing radiation exposures to members of the public, and demonstrating 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 with waste 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 that exposure to ionizing radiation received 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.

formation—A mappable unit of consolidated or unconsolidated geologic material of a characteristic lithology or assemblage of lithologies.

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, unconfined—Water that is in direct contact with the atmosphere through open spaces in permeable material.

half-life, radiological—The time required for half of a given number of atoms of a specific radionuclide to decay. Each radionuclide has a unique half-life.

hardness—The amount of calcium carbonate dissolved in water, usually expressed as part of calcium carbonate per million parts of water.

high-level waste—High-level radioactive waste means: (1) irradiated reactor fuel; (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel; and (3) solids into which such liquid wastes have been converted.

hydrogeology—Hydraulic aspects of site geology.

hydrology—The science dealing with the properties, distribution, and circulation of natural water systems.

internal exposure—Occurs when natural radionuclides enter the body by ingestion of foods or liquids or by inhalation. Radon is the major contributor to the annual dose equivalent for internal radionuclides.

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

long-lived isotope—A radionuclide that decays at such a slow rate that a quantity of it will exist for an extended period (half-life is greater than three years).

short-lived isotope—A radionuclide that decays so rapidly that a given quantity is transformed almost completely into decay products within a short period (half-life is two days or less).

laboratory 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.

limited area—The industrial area at PGDP, comprising approximately 644 acres.

low-level waste—Low-level waste is radioactive waste that is not high-level waste; spent nuclear fuel; transuranic waste; byproduct material (as defined in Section 11e.(2) of the *Atomic Energy Act of 1954*, as amended); or naturally occurring radioactive material.

maximally exposed individual—A hypothetical individual who remains in an uncontrolled area and would, when all potential routes of exposure from a facility's operations are considered, receive the greatest possible dose equivalent.

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

monitoring—Process whereby the quantity and quality of factors that can affect the environment or human health are measured periodically to regulate and control potential impacts.

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

natural radiation—Radiation from cosmic and other naturally occurring radionuclide (such as radon) sources in the environment.

nuclide—An atom specified by its atomic weight, atomic number, and energy state. A radionuclide is a radioactive nuclide.

outfall—The point of conveyance (e.g., drain or pipe) of wastewater or other effluents into a ditch, pond, or river.

personal property—Property of any kind, except for real property.

person-rem—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 greater than 7.

polychlorinated biphenyl (PCB)—Any chemical substance that is limited to the biphenyl molecule and that has been chlorinated to varying degrees.

process water—Water used within a system process.

quality assurance (QA)—Any action in environmental monitoring to ensure the reliability of monitoring and measurement data.

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

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

rad—An acronym for radiation absorbed dose. The rad is a basic unit of absorbed radiation dose. (This is being replaced by the "gray," which is equivalent to 100 rad.)

radioactivity—The spontaneous discharge of radiation from atomic nuclei. This is usually in the form of beta or alpha radiation, together with gamma radiation. Beta or alpha emission results in transformation of the atom into a different element, changing the atomic number by +1 or -2 respectively.

radionuclide—An unstable nuclide capable of spontaneous transformation into other nuclides by changing its nuclear configuration or energy level. This transformation is accompanied by the emission of photons or particles.

real property—Land and anything permanently affixed to the land such as buildings, fences, and those things attached to the buildings, such as light fixtures, plumbing, and heating fixtures, or other such items, that would be personal property, if not attached.

record of decision (ROD)—A public document that explains which cleanup alternatives will be used to clean up a Superfund site.

release—Any discharge to the environment. Environment is broadly defined as any water, land, or ambient air.

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

remediation—The correction of a problem. See Environmental Restoration.

reportable quantity—An amount set by a regulation in which release to the environment must be reported to regulatory agencies.

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

sievert (SV)—The SI (International System of Units) unit of dose equivalent; 1 SV = 100 rem.

source—A point or object from which radiation or contamination emanates. **stable**—Not radioactive or not easily decomposed or otherwise modified chemically. **storm water runoff**—Surface streams that appear after precipitation.
strata—Beds, layers, or zones of rocks.

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

suspended solids—Mixture of fine, nonsettling particles of any solid within a liquid or gas.

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

thermoluminescent dosimeter (TLD)—A device used to measure external gamma radiation.

total solids—The sum of total dissolved solids and suspended solids.

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

upgradient—In the direction of increasing hydrostatic head.

volatile organic compound (VOC)—Any organic compound that has a low boiling point and readily volatilizes into air (e.g., trichloroethane, tetrachloroethene, and trichloroethene).

watershed—The region draining into a river, river system, or body of water.

wetland—A lowland area, such as a marsh or swamp, inundated or saturated by surface or groundwater sufficiently to support hydrophytic vegetation typically adapted to life in saturated soils.

Classroom and Field Activities

Figure 44. MCHS Student examines a trap during WKWMA field day, Sept. 2019

Figure 45. MCHS Students collecting samples during WKWMA field day, Sept. 2019

Figure 46. Dr. Price presenting to MCHS Students in the field during WKWMA field day, Sept. 2019

Figure 47. MCHS Students handling wildlife during WKWMA field day, Sept. 2019

Figure 48. WKWMA field day presentation at WKWMA Lodge, Sept. 2019

Figure 49. MCHS Student retrieves a wildlife trap during WKWMA field day, Sept. 2019

Figure 50. MCHS Students in a tupelo swamp during WKWMA field day, Sept. 2019

Figure 51. MCHS Students unloading sample collection supplies during WKWMA field day, Sept. 2019

Figure 52. MCHS Student examines a turtle during Dr. Price's field presentation at WKWMA field day, Sept. 2019

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