PADUCAH GASEOUS DIFFUSION PLANT

2017-18 Environmental Science ASER PROJECT

Marshall County High School

September 27th, 2017

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1950's Paducah-PGDP Post Card

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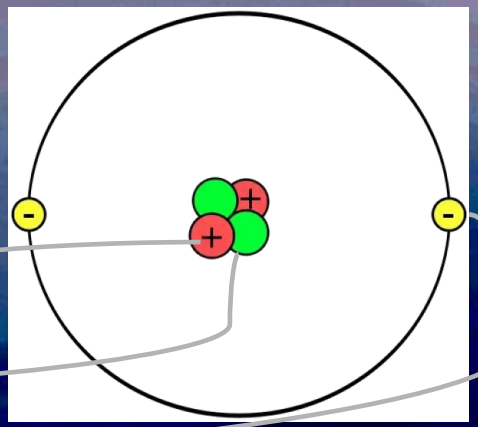
An Introduction to

the PADUCAH GASEOUS DIFFUSION PLANT

- ATOM – smallest unit of matter
  - 1/100,000th size of human hair
- ATOM contains
  - PROTONS (+)
  - NEUTRONS (0)
  - ELECTRONS (-)



Helium Atom

- ATOM Structure
  - NUCLEUS – contains PROTONs and NEUTRONS
  - ELECTRONs - orbit the NUCLEUS
  - # PROTONS in NUCLEUS = # ELECTRONS in orbit
- ELEMENT – Atoms that have the same # of PROTONS in NUCLEUS

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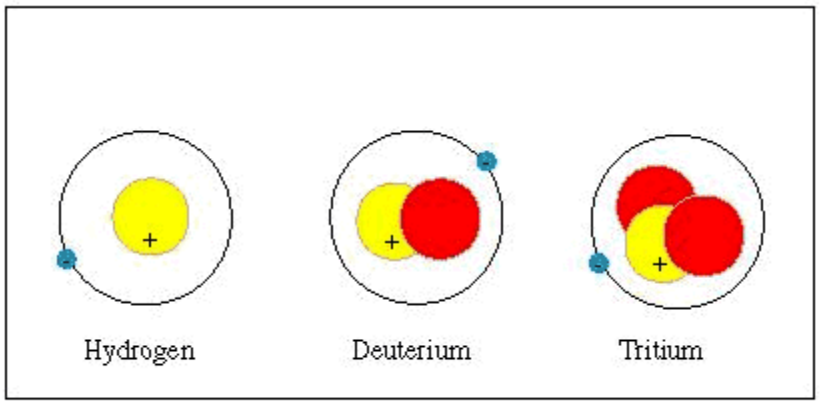
An Introduction to

the PADUCAH GASEOUS DIFFUSION PLANT

- ELEMENT – Atoms that each have the same # of PROTONS in NUCLEUS
- ISOTOPES = VARIATIONS of an ELEMENT
  - Have same # of PROTONS in NUCLEUS
  - Have different # of NEUTRONS in NUCLEUS



Bohr model of the hydrogen isotope atoms

An Introduction to

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  - Have same number of PROTONS in NUCLEUS
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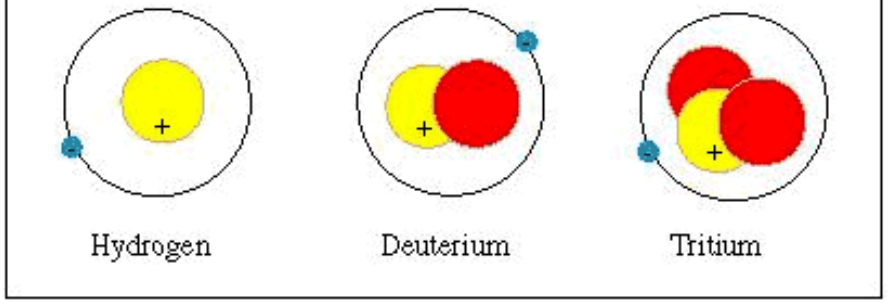

Bohr model of the hydrogen isotope atoms

- STABLE ISOTOPES
  - # PROTONS = # NEUTRONS
- UNSTABLE ISOTOPES
  - # PROTONS < or > # NEUTRONS

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An Introduction to

the PADUCAH GASEOUS DIFFUSION PLANT

- UNSTABLE ISOTOPES
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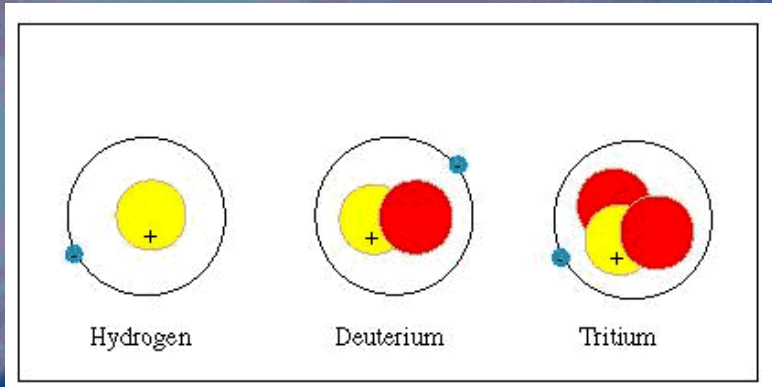


Bohr model of the hydrogen isotope atoms

  - Naturally split and lose PROTONS OR NEUTRONS until STABLE
- Loss releases Proton or Neutron + ENERGY

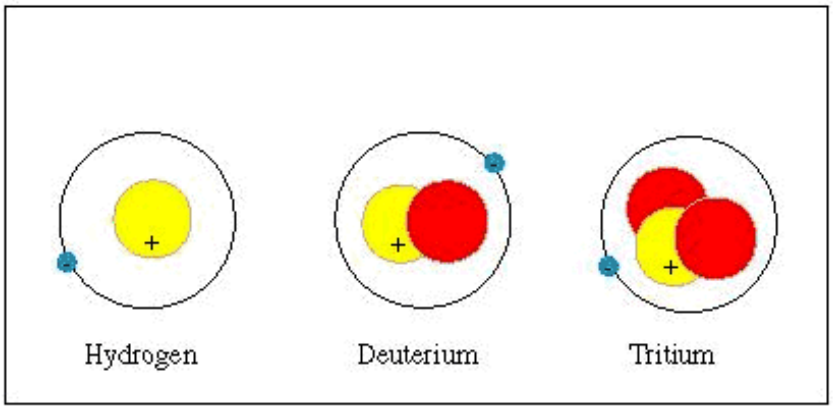
UNSTABLE ISOTOPES ARE RADIOACTIVE

LOSE Proton +/or Neutron, + Energy and 'DECAY' to STABLE FORM

An Introduction to

the PADUCAH GASEOUS DIFFUSION PLANT

- UNSTABLE ISOTOPES
  - # PROTONS < or > # NEUTRONS



Bohr model of the hydrogen isotope atoms

  - LOSS of PROTONS OR NEUTRONS + ENERGY until STABLE
- UNSTABLE ISOTOPES ARE RADIOACTIVE
- LOSE Proton +/or Neutron, + ENERGY to become STABLE……

An Introduction to

the PADUCAH GASEOUS DIFFUSION PLANT

Why Nuclear (Atomic) Energy?

- USE THE ENERGY Release
- ENERGY CREATES HEAT
- HEAT USED TO BOIL WATER & Generate Steam
  - USED TO DRIVE TURBINES
    - To Propel NUCLEAR - powered NAVY ships
    - To Create ELECTRICITY
- USE ENERGY AS AN INSTANT 'EXPLOSIVE' RELEASE IN BOMBS

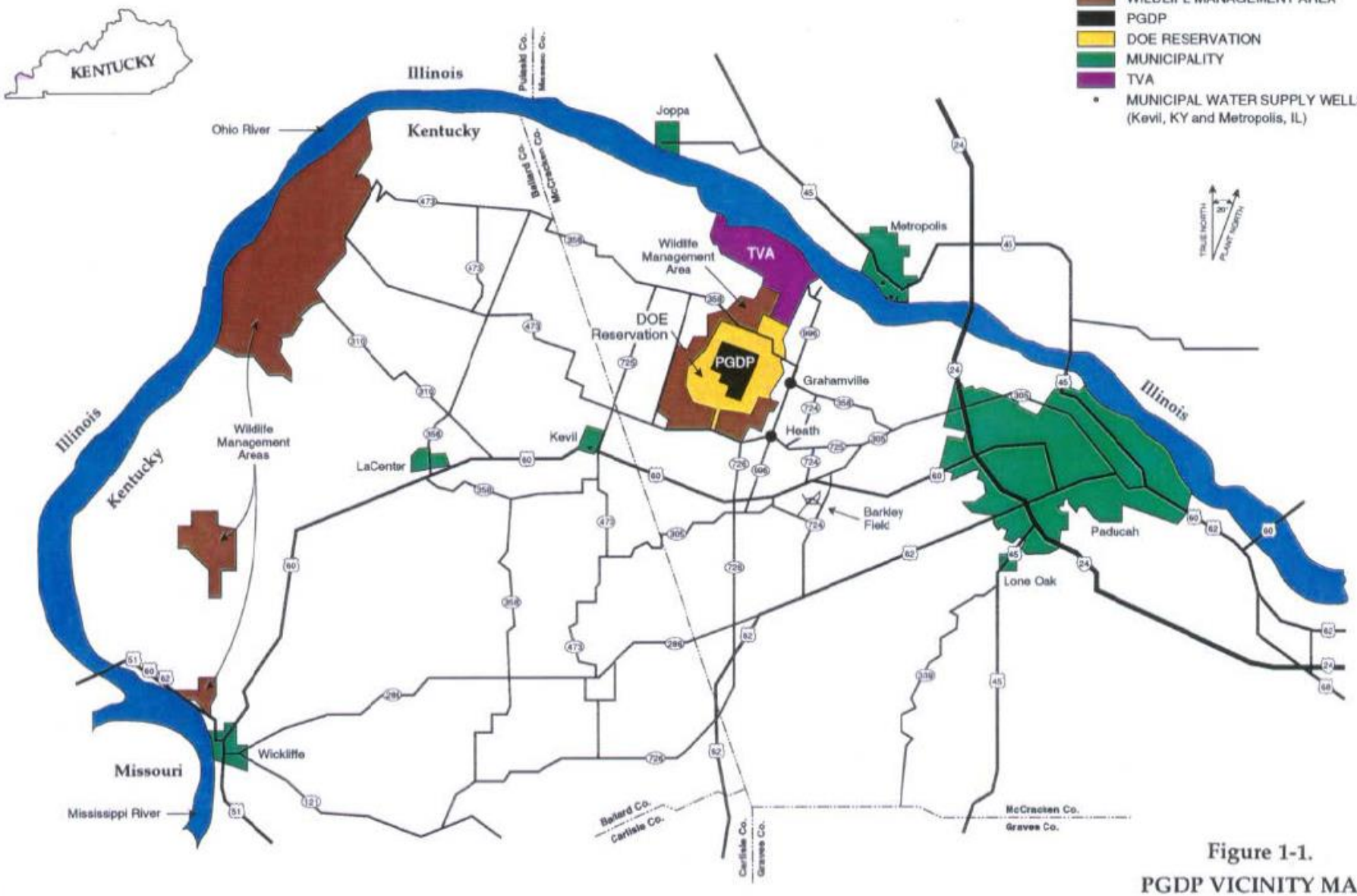


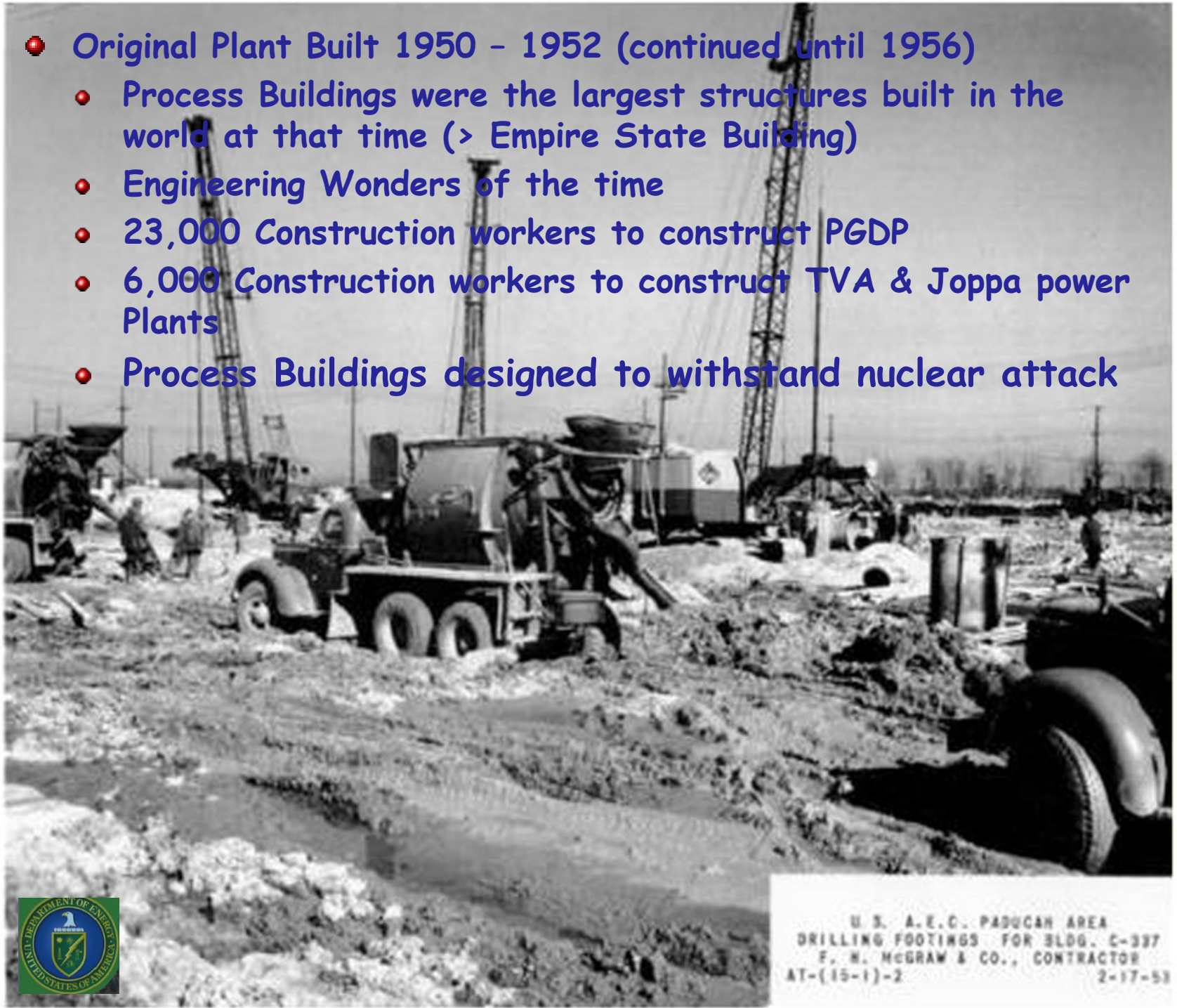
Figure 1-1.
PGDP VICINITY MAP

Paducah Gaseous Diffusion Plant
Paducah, Kentucky

Paducah Gaseous Diffusion Plant (PGDP)

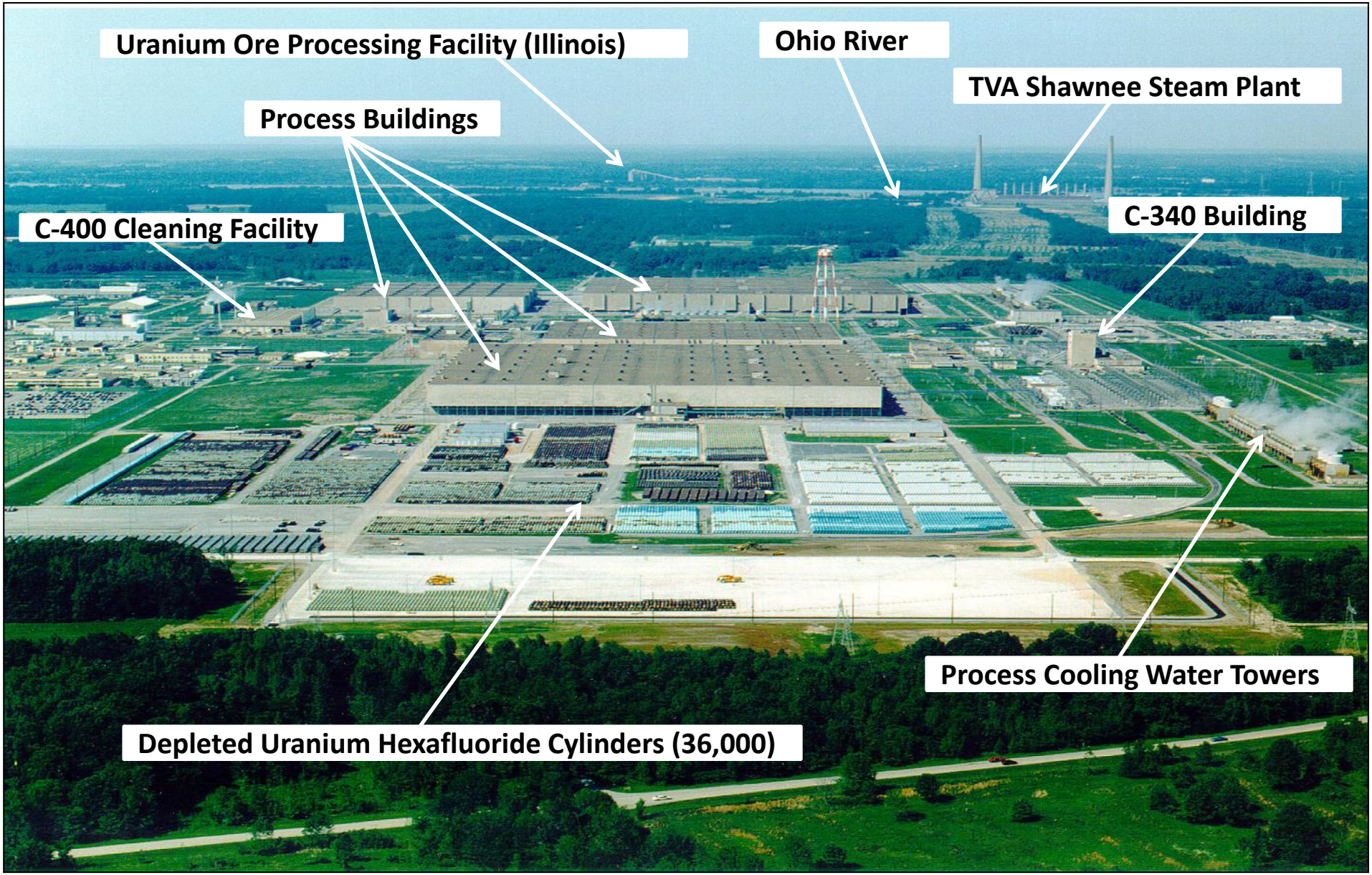
- **URANIUM ENRICHMENT FACILITY**
  - Owned by United States Government
    - Department of Energy (DOE)
  - United States Enrichment Corp. (USEC) operated facility for DOE
  - Was last operating government enrichment facility
  - Began Shutdown of Enrichment Operations April, 2013
- **Enriched** uranium for military, weapons, and starting in 1960's, the nuclear energy industry (electricity)
- A **COLD WAR** Military-Industrial Facility
  - Nuclear high tech originating in Manhattan Project
  - High Security (No Fly Zone after 9/11)
- **Largest** industrial complex in W. Kentucky
- **Largest** employer in W. Kentucky (past)
- **Largest** stockpile of mined uranium in world
- Very skilled workforce

- Original Plant Built 1950 – 1952 (continued until 1956)
  - Process Buildings were the largest structures built in the world at that time (> Empire State Building)
  - Engineering Wonders of the time
  - 23,000 Construction workers to construct PGDP
  - 6,000 Construction workers to construct TVA & Joppa power Plants
  - Process Buildings designed to withstand nuclear attack



Paducah Gaseous Diffusion Plant (PGDP)

- **Heavy Industrial Plant Complex** (1 square mile)
  - Process Buildings (where uranium enrichment process occurs)
  - Preparation & Maintenance Buildings
  - Cleaning Facilities
  - Water Treatment (@ 11 -32 million gallons per day)
  - Process Cooling Water, Fire Water, Storm Water, & Sanitary Water Systems
  - Sewage & Wastewater Treatment Systems
  - Landfills
  - Burial Grounds
  - Electrical Power Facilities (electric use/day = St. Louis)
  - TVA Shawnee Steam Plant built to supply PGDP electricity



PGDP Site Feature Flyover

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Background: Uranium Enrichment

- Naturally Occurring Uranium has 3 isotopes with similar chemical but different nuclear properties
  - **U-238** The most plentiful/abundant; over 99% of natural U
  - **U-235** The only FISSILE uranium isotope; approximately 0.72% of natural U
  - **U-234** Less plentiful U isotope; approximately 0.0055% of natural U
- FISSILE material can sustain a nuclear reaction which results in a release of ENERGY
- **FISSION** is a self-sustaining nuclear reaction caused by radioactive decay or induced by bombardment with neutrons
- The HEAT from FISSION is used to drive turbines and generate electricity
- PGDP INCREASED (ENRICHED) THE NATURAL ABUNDANCE OF FISSILE U-235 TO USE AS A FUEL SOURCE (from 0.7 % to 5%)

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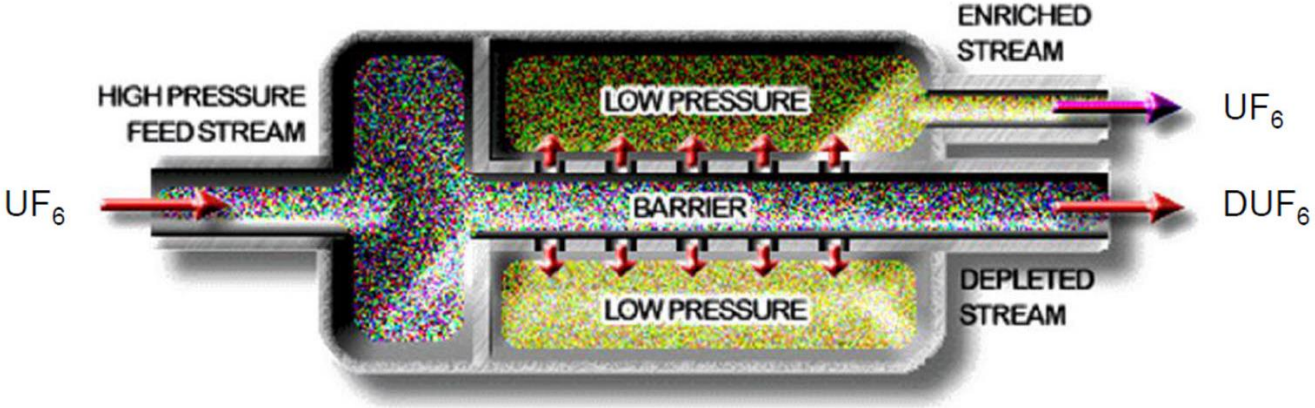
Background: Uranium Enrichment

- The GASEOUS DIFFUSION PROCESS was used at PGDP to increase the abundance of U-235
- URANIUM is blended with FLUORINE GAS at high temperature and pressure to produce URANIUM HEXAFLUORIDE GAS (UF6)
- U-235 separated from U-238 by molecular DIFFUSION thru membrane (a STAGE)
- A volume of UF6 gas is passed thru 1,760 STAGES to complete enrichment

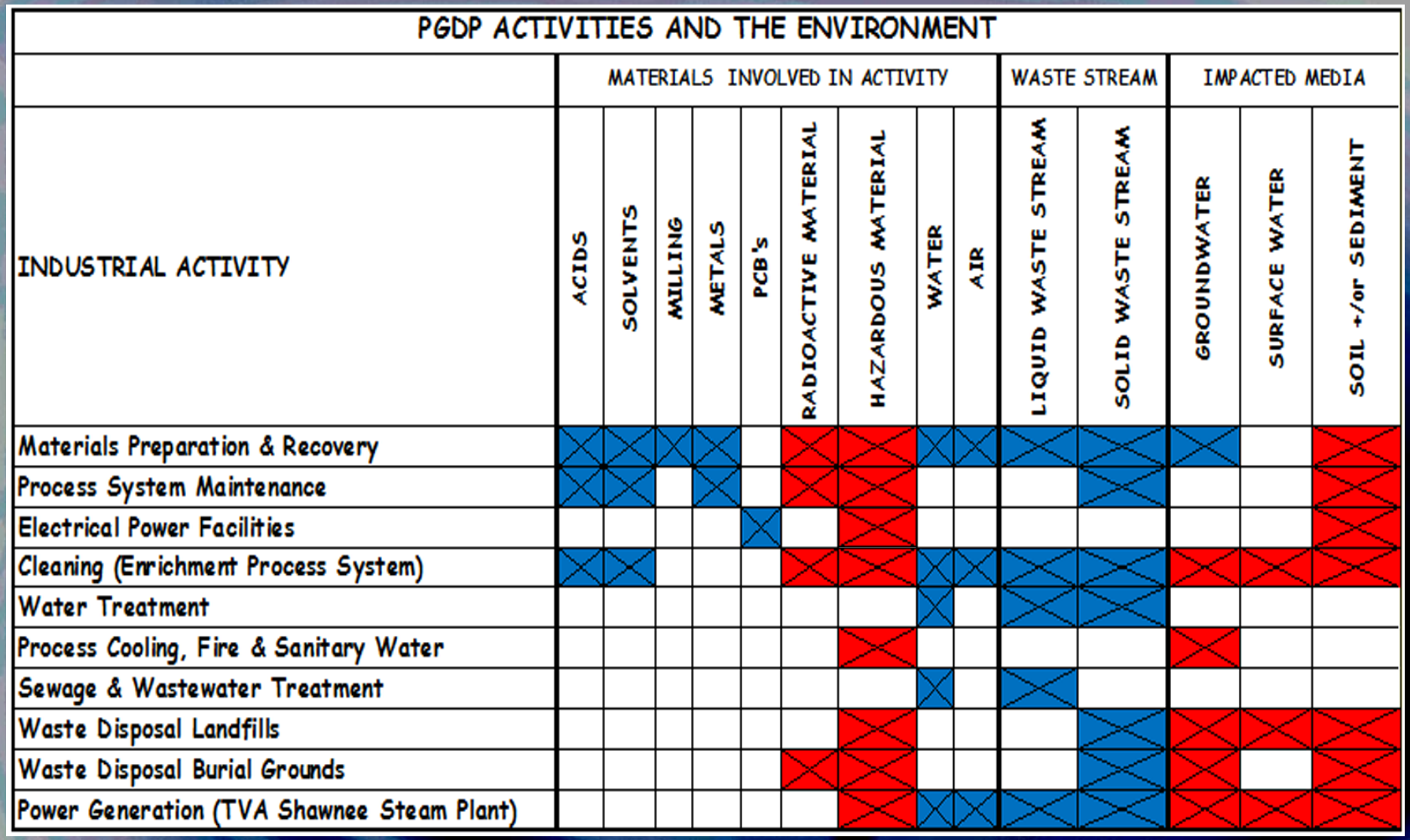


This process of uranium enrichment increases the concentration of U-235 from 0.7% up to 5.0%

Background: Uranium Enrichment

The 8th Stage Compressor (of 1,760) from PGDP's diffusion process

PGDP & the Environment

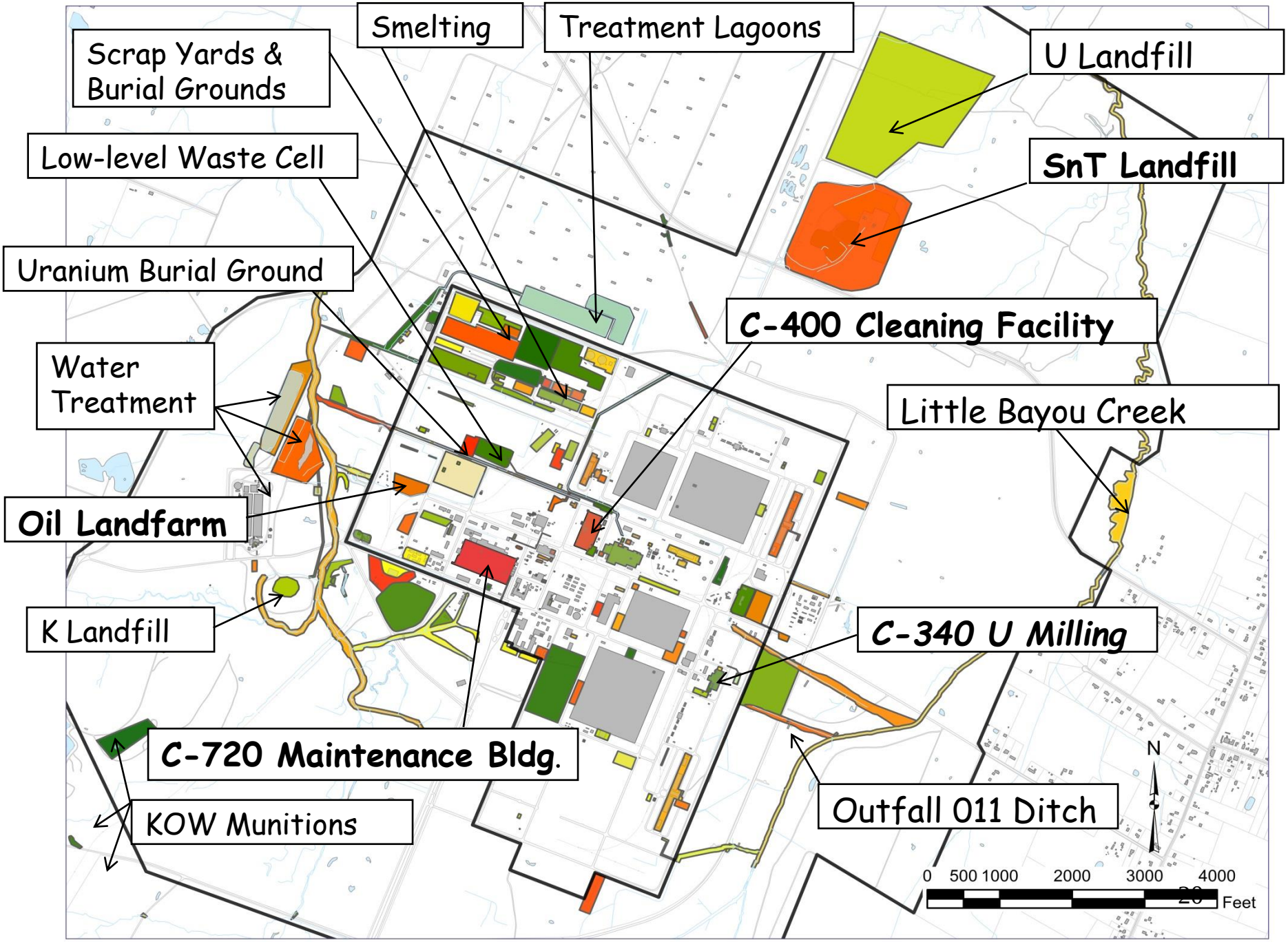


PGDP ACTIVITIES AND THE ENVIRONMENT

	MATERIALS INVOLVED IN ACTIVITY									WASTE STREAM		IMPACTED MEDIA		
INDUSTRIAL ACTIVITY	ACIDS	SOLVENTS	MILLING	METALS	PCB's	RADIOACTIVE MATERIAL	HAZARDOUS MATERIAL	WATER	AIR	LIQUID WASTE STREAM	SOLID WASTE STREAM	GROUNDWATER	SURFACE WATER	SOIL +/or SEDIMENT
Materials Preparation & Recovery	X	X	X	X		X	X	X	X	X	X	X		X
Process System Maintenance	X	X		X		X	X				X			X
Electrical Power Facilities					X		X							X
Cleaning (Enrichment Process System)	X	X				X	X	X	X	X	X	X	X	X
Water Treatment								X		X	X			
Process Cooling, Fire & Sanitary Water							X					X		
Sewage & Wastewater Treatment								X		X				
Waste Disposal Landfills							X				X	X	X	X
Waste Disposal Burial Grounds						X	X				X	X		X
Power Generation (TVA Shawnee Steam Plant)							X	X	X	X	X	X	X	X

Paducah Gaseous Diffusion Plant (MAPS)

- SWMUs –
  - Burial Grounds
  - Landfills
  - Leak Sites
  - Spill Sites
  - Soil Contamination
  - Underground Storage Tanks
  - Sediment Contamination
  - PCB Contamination
- Trichloroethene Groundwater Plumes 2010
- Technetium-99 Groundwater Plumes 2007


Smelting
Treatment Lagoons
Scrap Yards & Burial Grounds
U Landfill
Low-level Waste Cell
SnT Landfill
Uranium Burial Ground
C-400 Cleaning Facility
Water Treatment
Little Bayou Creek
Oil Landfarm
K Landfill
C-340 U Milling
C-720 Maintenance Bldg.
KOW Munitions
Outfall 011 Ditch
N
0 500 1000 2000 3000 4000
Feet

Conceptual Models (CMs)

- **Conceptual Models (CMs)** are systematic representations of the theoretical or known relationships between the variables that constitute a problem
  - Connect or hypothesize the relationship between independent and dependent variables

- **Environmental Science (CMs)**
  - Conceptual Site Model (CSM) – represents the mechanisms that impact the environment, human and ecological health at a site
    - CSMs may be complicated when they involve all media, pathways, and receptors related to a site

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Conceptual Models for TCE release to groundwater at PGDP

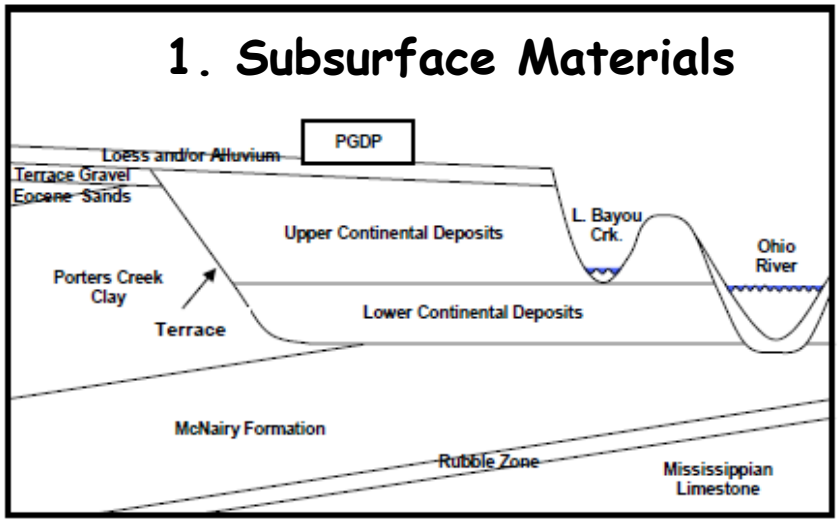


Figure 3. Conceptual Geologic Model for the PGDP and Eenvirons.

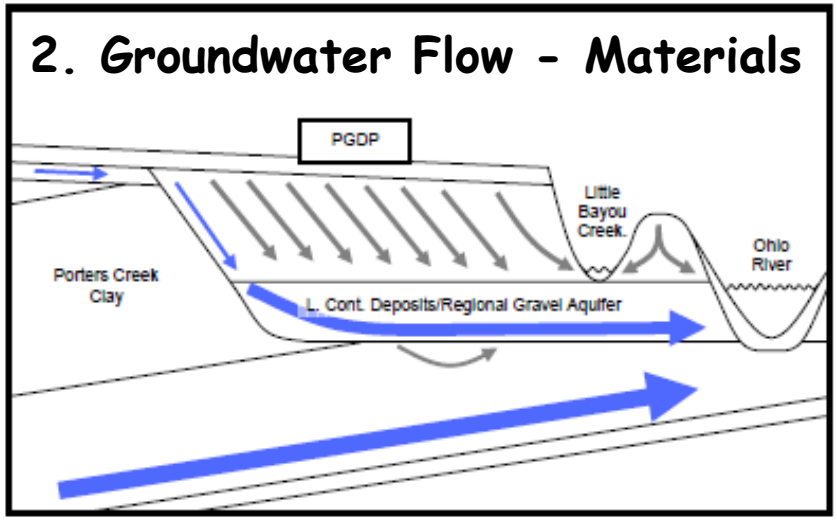


Figure 4. Generalized Groundwater Flow Model for the PGDP and it's environs

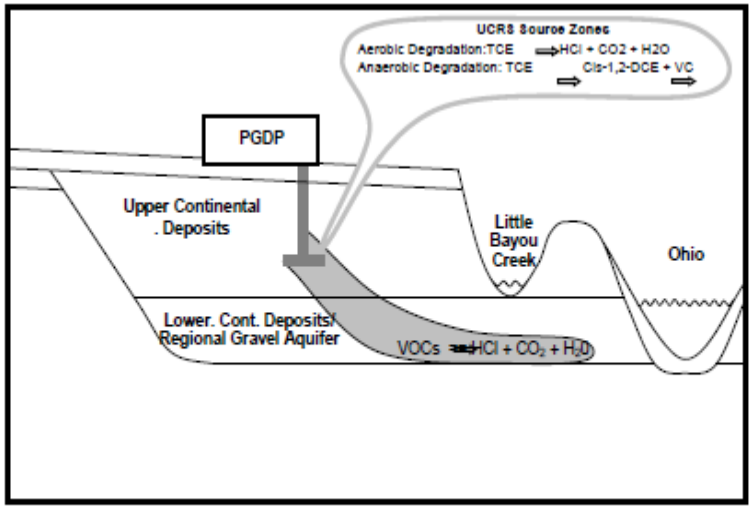


Figure 12. Conceptual TCE Contaminant Transport Model for the PGDP and Environs

PGDP Trichloroethene (TCE)

- Trichloroethene (TCE), a manufactured volatile organic compound (VOC), used extensively to degrease enrichment process equipment
  - routinely cleaned more than 400 miles of diffusion process piping & equipment
- TCE is a dense non-aqueous phase liquid (DNAPL)
  - More dense than water.
  - Density causes it to sink through porous soil, aquifer materials, and groundwater.
  - Some left in interstitial pore spaces where it remains as it is slowly dissolved.
  - Downward movement continues until they encounter impermeable materials (clay) and pool.
- Pooled DNAPL will remain a long-term source to groundwater contamination.

Trichloroethene

2007

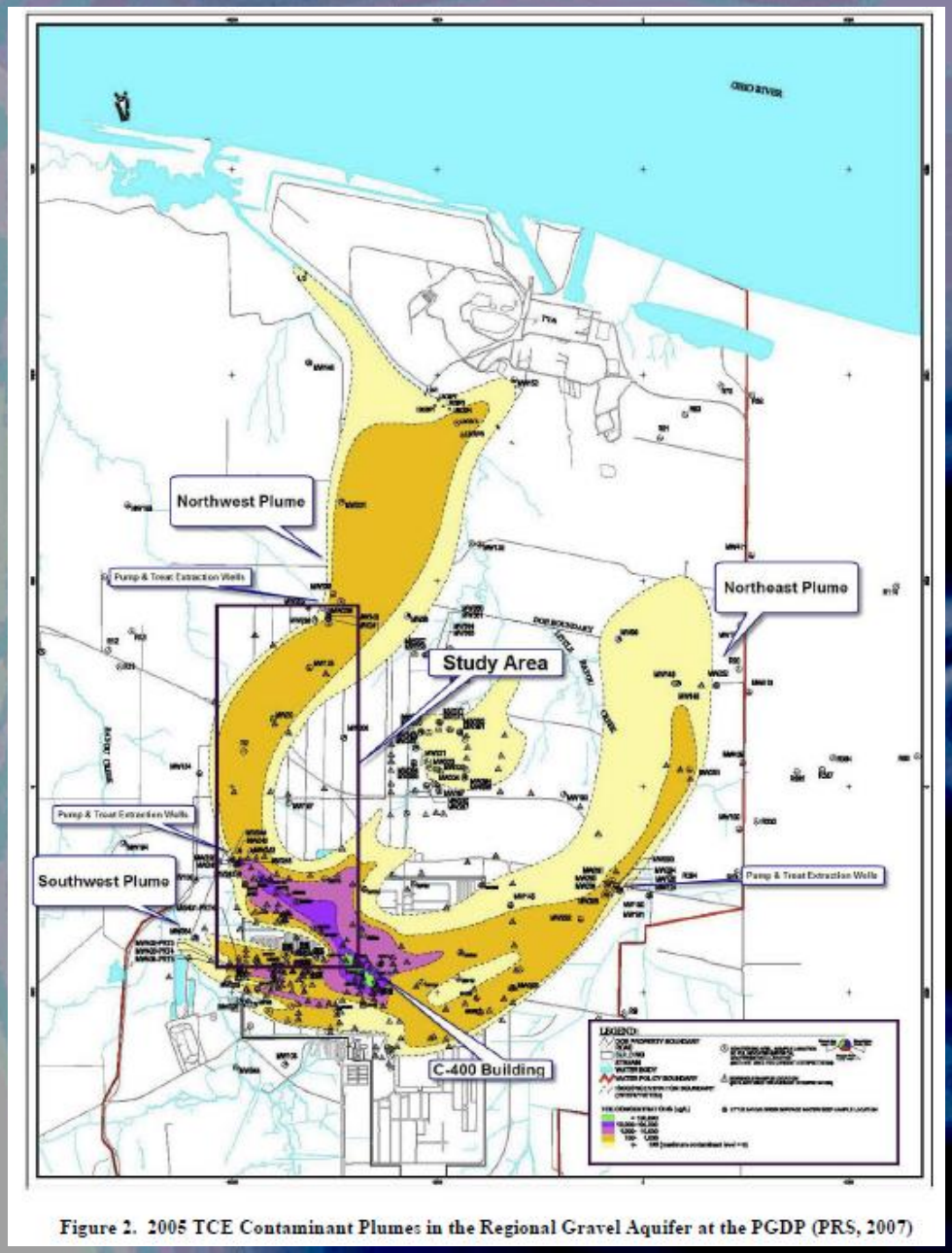
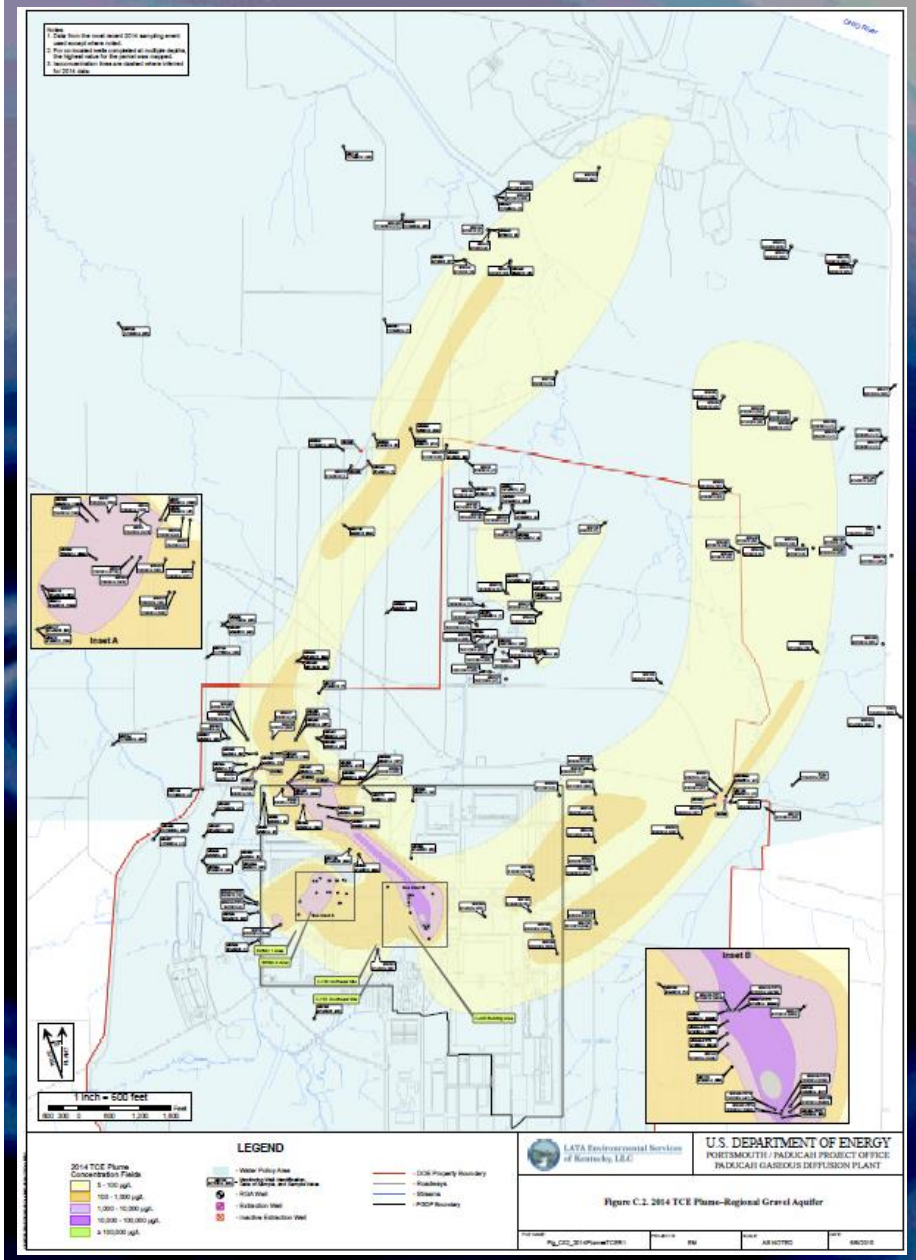


Figure 2. 2005 TCE Contaminant Plumes in the Regional Gravel Aquifer at the PGDP (PRS, 2007)

2014



Trichloroethene Plume 2007 Northwest Plume Detail

Trichloroethylene (TCE)
2007 Regional Gravel
Aquifer Plume

WQ Std. = 5 ug/L
Yellow= 5 ug/L
Orange= 100 ug/L
Blue = 1,000 ug/L
Lt. Gray = 10,000 ug/L

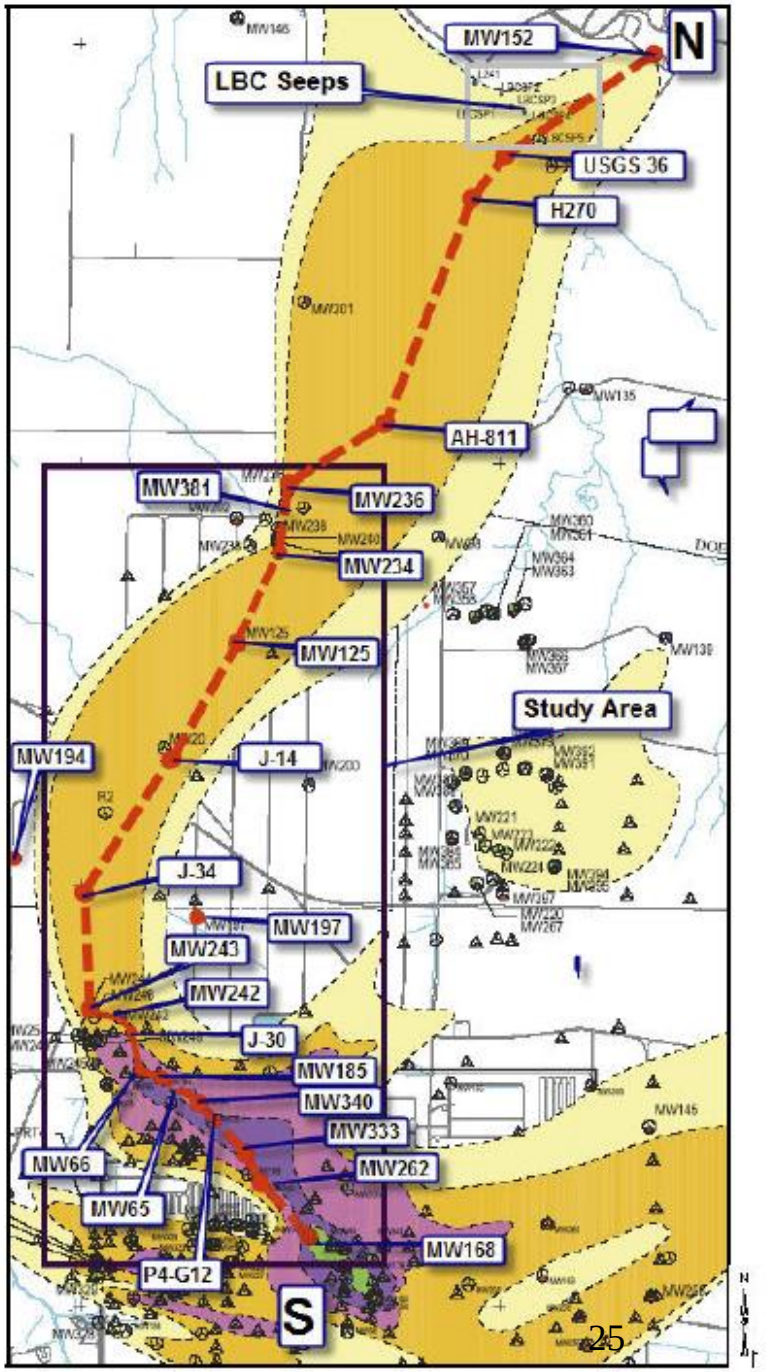


Figure 15. NWP cross-section location.

Trichloroethene Plume 2007 Northwest Plume Detail

Cross-section of aquifer material along plume center

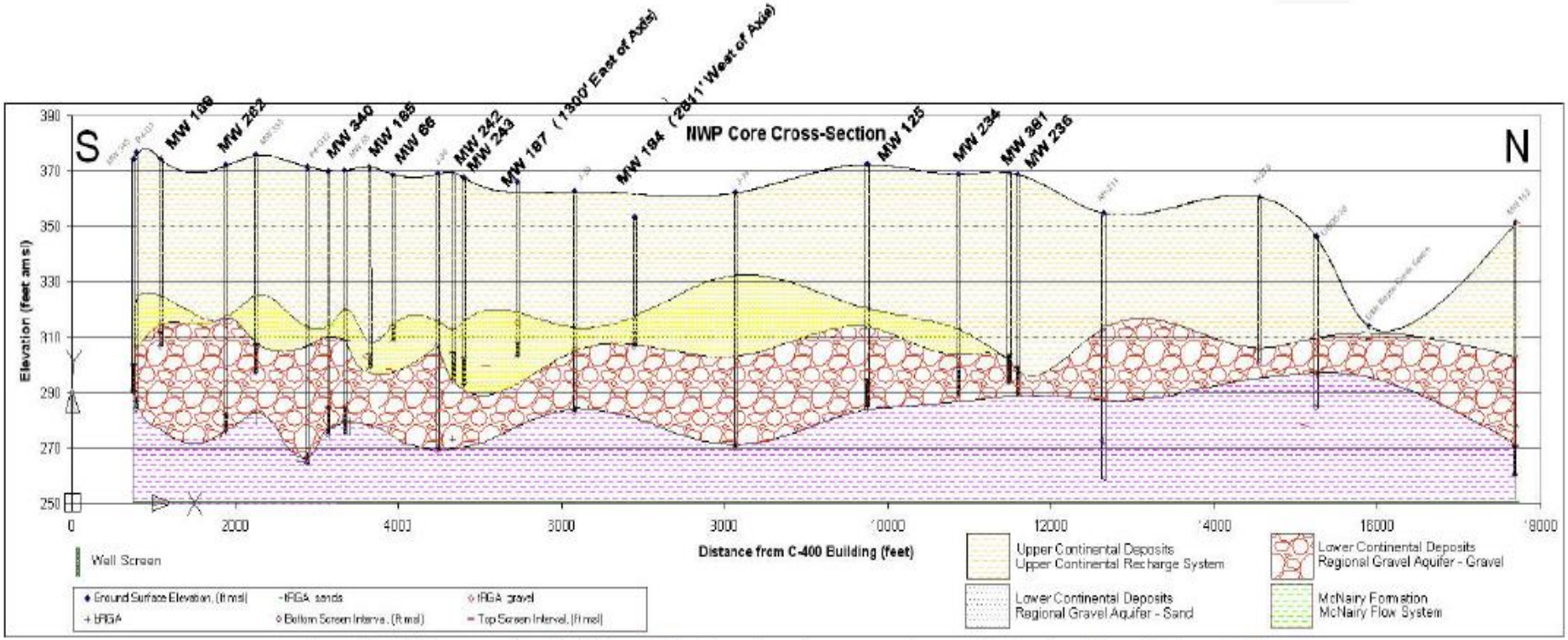
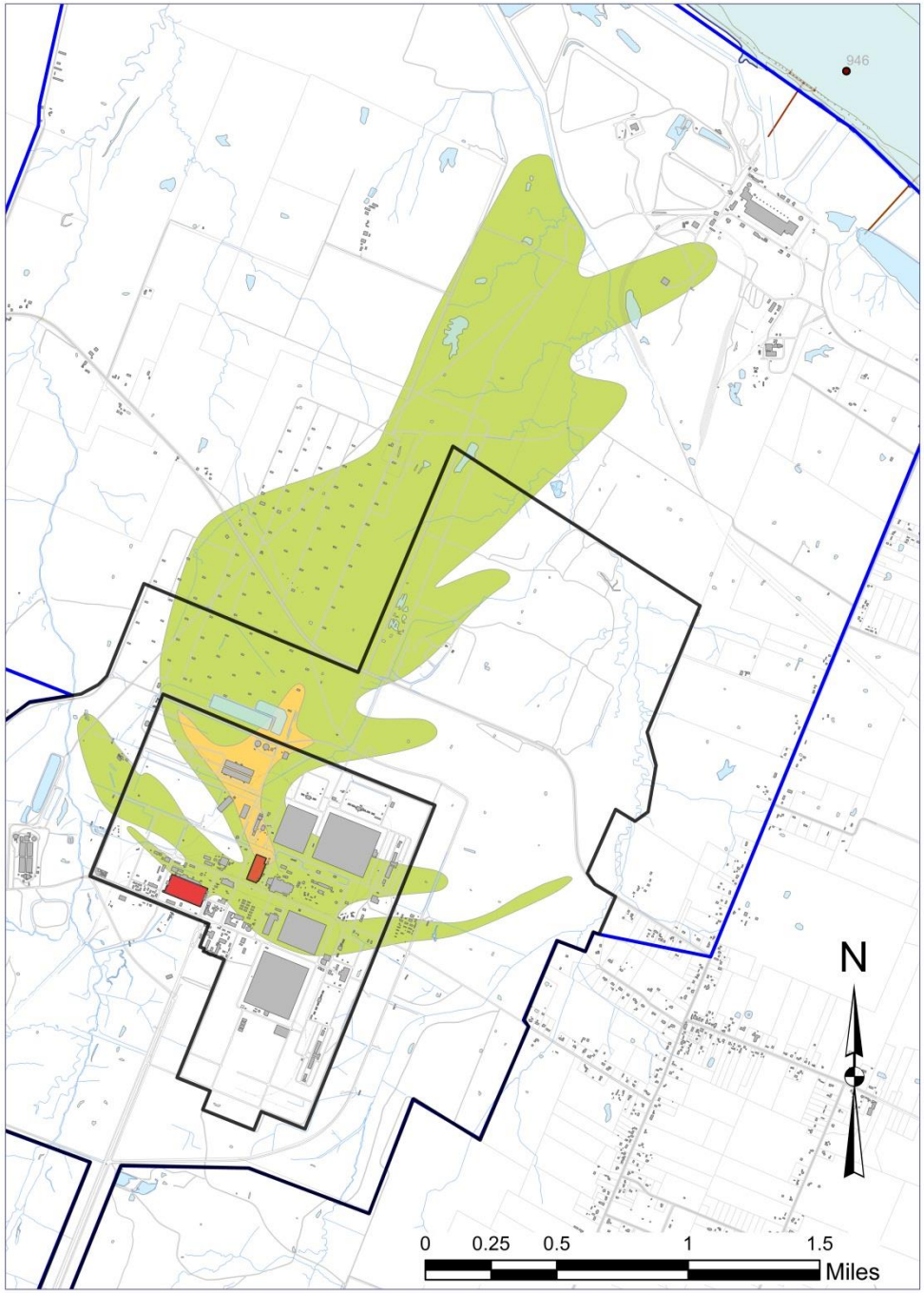


Figure 16. NWP cross-section identifying well locations along plume core and screened intervals relative to RGA materials

PGDP Technetium-99 (^{99}Tc)

- PGDP feed plant REPROCESSED spent nuclear fuel rod material containing uranium from 1953 to 1976
- REPROCESSING resulted in the introduction of technetium-99 (^{99}Tc or Tc-99),
  - artificial fission radioisotope
  - other radioactive materials not associated with naturally occurring uranium.
- Deposition in process equipment, piping and transfer equipment as well as transfer and storage of ^{99}Tc-bearing liquids introduced ^{99}Tc to PGDP waste & water streams & the ENVIRONMENT.
- Technetium-99 (^{99}Tc) is a unique radionuclide in environmental settings because it easily dissolves in water where it forms the pertechnetate ion (TcO_4^-).
- The pertechnetate ion is relatively unreactive with aquifer materials and very mobile in groundwater.



Technetium-99 Regional Gravel Aquifer Plume 2007

Orange=>900 pCi/L
Orange= Regulatory Limit
Green = >25 pCi/L

Groundwater exceeding 900 pCi/L contained on site.

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PGDP Uranium (U)

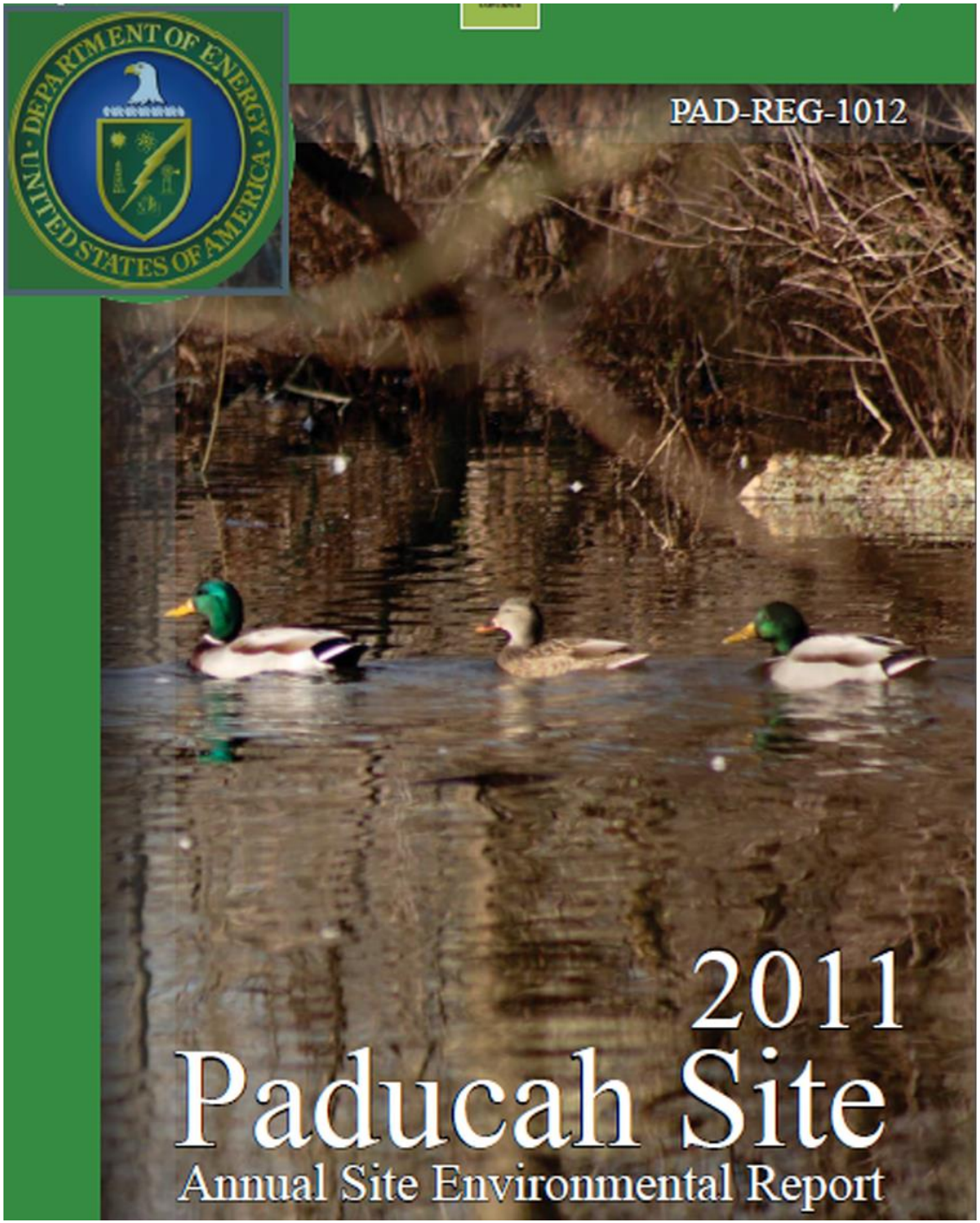
- Enriched Uranium was the product of the gaseous diffusion process at PGDP.
- Depleted Uranium (DU), en masse, was a primary by-product.
- DU Can still be exploited for enrichment of U-235
- Pyrophoric Uranium in 1 burial ground
- U + Oils in RCRA-closed "landfill"
- U not mobile in groundwater under natural site geochemical conditions
- Some U in sediment loads associated with shallow land disposal (Ditches on site)

Environmental Impact = Regulatory Compliance

- The discovery of technetium-99 in water wells north of the plant in 1988:
  - Kicked off process to make the PGDP a CERCLA "Superfund Site" = (NPL)
  - Placed on National Priorities List (NPL) for cleanup
  - Began Regulatory Compliance and Oversight from a number of State and Federal Agencies.

Environmental Impact = Regulatory Compliance

- Ky. Environmental Protection Cabinet – RCRA
- RESOURCE CONSERVATION AND RECOVERY ACT
  - Hazardous Waste Branch-Federal Facilities Section
  - Solid Waste Branch – waste disposal/landfills
  - Division of Water – groundwater & surface water
  - Division of Air – air quality
- U.S. Environmental Protection Agency - CERCLA
- COMPREHENSIVE ENVIRONMENTAL CLEANUP & LIABILITY ACT
  - USEPA Region IV Federal Facilities
- AEC eventually became DOE + NRC
  - NRC has regulatory responsibility for enrichment operations (USEC)
  - DOE retains responsibility for legacy waste and environmental cleanup.
  - DOE sets standards for Operations, Cleanup, H & S and nuclear safety under DOE Orders.
- Ky. Radiation Control Program - Off-site Radiation Impacts (NRC)



ASER

Summarizes PGDP's Site-Wide Environmental Activities: compliance, remediation, and health and safety projects for a calendar year.

PGDP Site ASER
Calendar Year 2015

- COMPLIANCE SUMMARY
- ENVIRONMENTAL PROGRAM
- ENVIRONMENTAL RADIOLOGICAL PROTECTION PROGRAM
- ENVIRONMENTAL NONRADIOLOGICAL PROGRAM
- GROUNDWATER PROTECTION PROGRAM

PGDP ASER
What's to be done?

- What will we do?
  - Read 2015 Paducah Site ASER (each student)
  - Summarize Sections (student and groups)
  - Illustrate activities in ASER (site photos/maps)
  - Document Project Activities
    - Photos/Art (?)
  - Produce summary ASER Document from Class
    - Publish hard copy
    - Publish on web

UK & PGDP Contacts

- Ask Questions
- Send email

  Steve.Hampson@uky.edu
- UK/KRCEE Website
  - http://www.ukrcee.org/
  - ASER Tab at top of KRCEE homepage

http://www.ukrcee.org/Marshall/Edu.aspx

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NEXT

- ASER & SITE TOPICS PRESENTATIONS
- TOPICS
  - Site Regulatory/Environmental Management/DOE Science/ Opportunities
  - Site Radiation Health and Safety
    - Health Physicist (HP) or Site HP Program
  - Groundwater Protection Program
    - Physical System/Sources/Monitoring/Remediation
  - Ecological Monitoring (Field Trip)
    - Field Studies Summary
    - UK Research Faculty & Staff/Emeritus SIU Faculty
    - WKWMA Scientist

NEXT

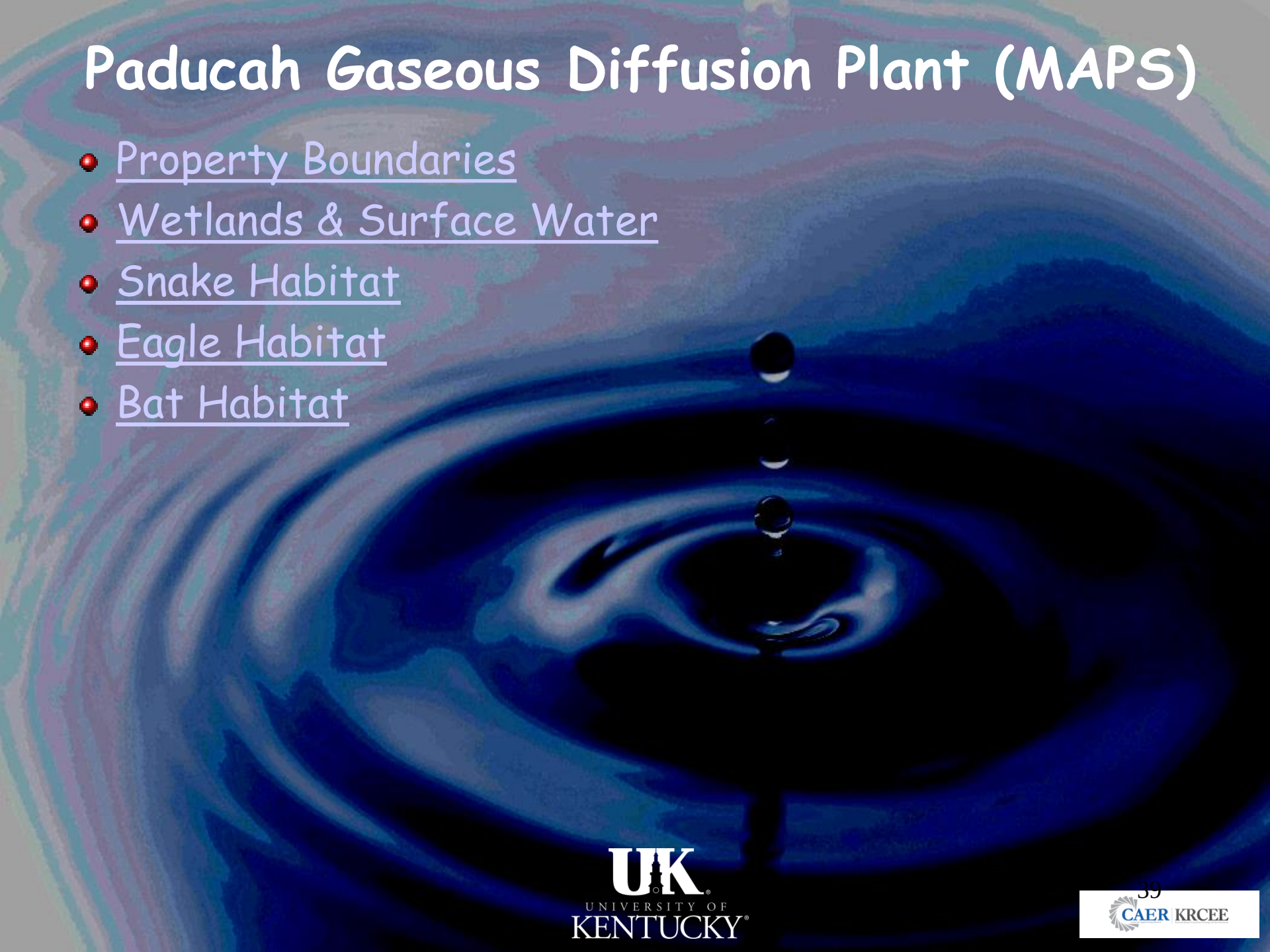
- ASER & SITE TOPICS PRESENTATIONS
- **Additional Topics TBD**
  - PGDP Site Visit
  - Energy (production/future)
    - CAER Researchers
  - Decontamination and Decommissioning (D&D) – The process that is about to go into full swing on the site.
  - Surface Water and Sediment – Impacts/Monitoring/Remediation
  - UK/KRCEE PROJECTS
    - Geology (Mapping)
    - Hydrogeology (GW Flow System, Biogeochemical Degradation of TCE)
    - Seismology (New Madrid Seismic Zone – Recent developments were presented at AGU last week)
    - Geophysics (Use of electrical resistivity, SH and P-wave ground-surface-based studies to map sub-surfaces, trends, faults

PGDP Challenges to Environmental Science

- State of applied environmental science
  - Physical Environment (Extent, Depth, Paleo-Seismic)
  - Geochemical Environment (Contaminants, GW Chemistry)
- General Scale of Industrial Operations (1 square mile)
- Until recently, was an OPERATING facility with active surface and subsurface infrastructure
  - Prevented ability to characterize and / or remediate areas
- Facility began SHUTDOWN of operations in April 2013
- Increasing requirements for environmental compliance
  - Cost
  - Time
- Future direction and funding of environmental restoration

Paducah Gaseous Diffusion Plant (MAPS)

- Property Boundaries
- Wetlands & Surface Water
- Snake Habitat
- Eagle Habitat
- Bat Habitat



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