Legacy Waste Management by U.S. Department of Energy

“This fossilized body was not the only one in this vast plain of bones−the cemetery of an extinct world.”

—Henry Lawson in “Journey to the Center of the Earth” by Jules Verne.

Nuclear Weapons Production

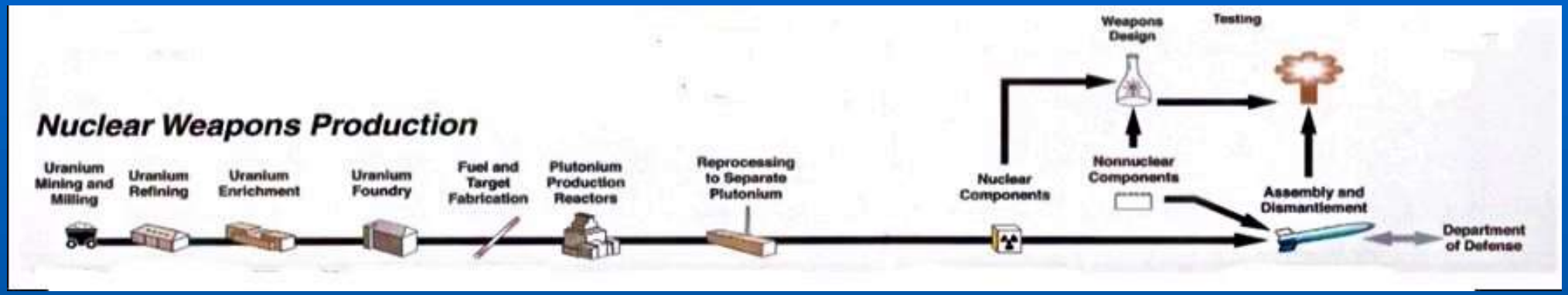
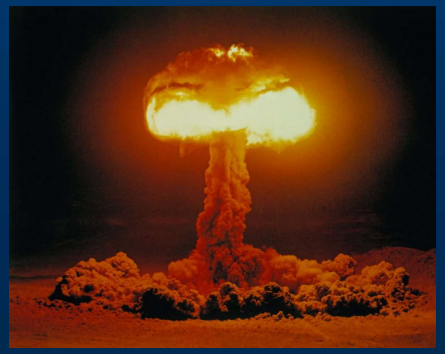


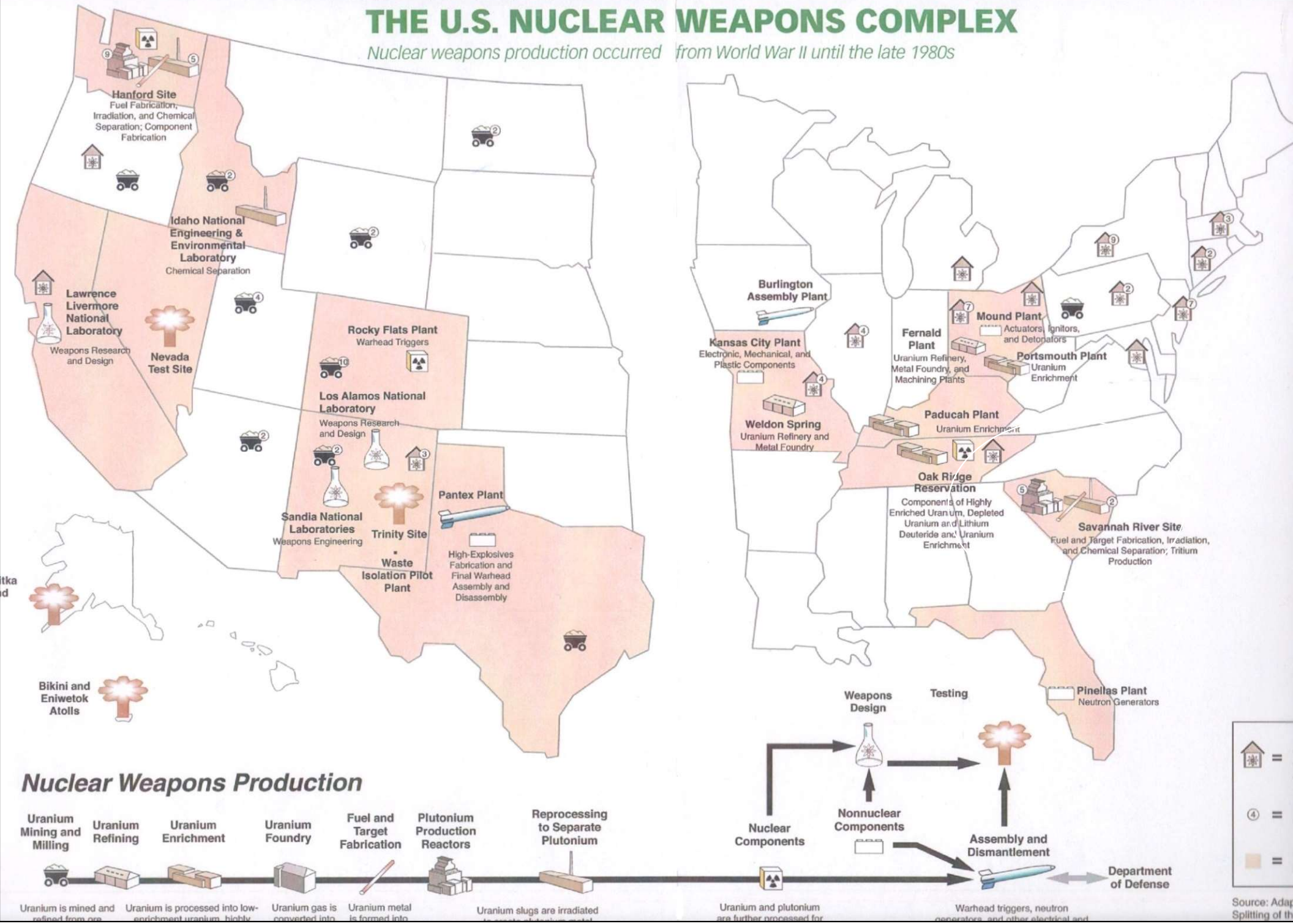
Figure 15. Yellow Cat District, Utah—Unstable, Unprotected Mine Opening



nuclear weapons complex at the height of production capacity.

THE U.S. NUCLEAR WEAPONS COMPLEX

Nuclear weapons production occurred from World War II until the late 1980s



Nuclear Weapons Production

Source: Adap
Splitting of th

Office of Legacy Management

The U.S. Department of Energy (DOE) is responsible for wastes associated with the legacy of World War II and the Cold War. This legacy includes radioactive and chemical wastes, environmental contamination, and hazardous materials at 100+ sites across the country. The Office of Legacy Management was formally established in 2003.

Website: http://energy.gov/lm/office-legacy-management

Scope of DOE's program

DOE's budget for site cleanup is 6 billion dollars/year.

DOE acknowledges that some sites cannot be cleaned up enough to be released for unrestricted use.

"[complete cleanup is] often not technically or financially feasible."

Some wastes are left in landfills or the remaining contaminated soil or groundwater "will not threaten the public or the environment."

Scope of DOE's program

"DOE will provide long-term care for sites where complete cleanup to unrestricted levels is not possible"

Monitoring the migration of "residual contamination" and the effectiveness of remedies. Surveillance, inspections.

DOE acknowledges that "some wastes will persist for . . . millions of years."

From "Cleaning up America's Nuclear Weapons Complex." 2008. NGA

Six Examples of Environmental Restoration by U.S. DOE

Fernald, Ohio
Grand Junction, Colorado
Rifle, Colorado
Canonsburg, Pennsylvania
Rocky Flats, Colorado
Weldon Spring, Missouri

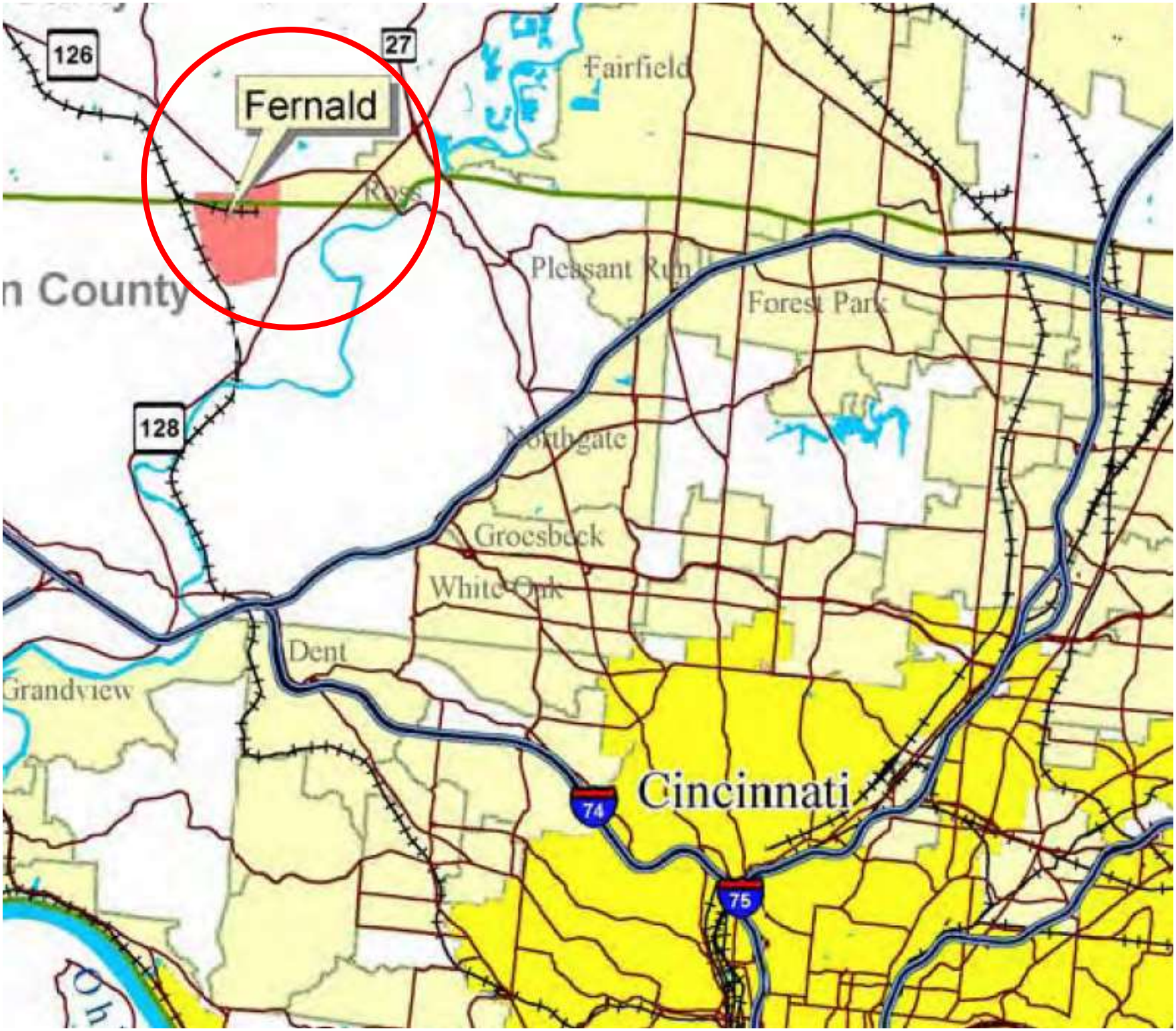
The Fernald Site

The Feed Materials Production Center (FMPC): a uranium processing plant.

Located near Fernald, Ohio.

Purpose: to produce uranium for the production of nuclear weapons.

Production began in 1953 under the direction of the Atomic Energy Commission.


126
27
Fernald
Fairfield
n County
Pleasant Run
Forest Park
128
Northgate
Grocesbeck
White Oak
Dent
Grandview
74
Cincinnati
75

FMPC operations

The FMPC stopped producing uranium in 1989 and closed in 1991 after the Cold War ended.

About 227,000 tonnes of uranium were processed.

There were 10 plants in operation sometime from 1953 to 1989.

Plant 1: crushed natural, enriched and depleted uranium.

FMPC operations

Plants 2 and 3. Uranium dissolved in nitric acid to make uranyl nitrate and then uranium trioxide by evaporation and heating.

Plant 4 converted UO_2 to UF_4 (green salt) by reaction with HF.

Plant 5 converted

UF_4 to uranium metal.

called "derbies"

Plant 6 created ingots

from the derbies.

Plants 2 and 3

Plant 4

Plant 5

"Waste management" at FMPC

Waste management was not a priority. Disposal operations were not documented. Chemical analysis of wastes were not conducted.

During the 1980s, it became apparent that the disposal practices resulted in air, soil surface water and groundwater contamination.

“Waste management” at FMPC

In 1989, FMPC was declared a Superfund site by the U.S. EPA, and DOE renamed the Fernald Environmental Management Project (FEMP).

Remediation of FEMP

FEMP was divided into "Operable Units" to remediate contamination.

Operable Unit 1 contained 6 waste storage pits. Two pits were lined with a plastic liner, the other four were lined with some type of clay. About 5,500 tons (5,000 tonnes) of uranium, thorium, radium, and tributyl-n-phosphate were dumped into the surface pits.

Waste storage silos

Operable Unit 4 contained 4 concrete waste storage "silos." The concrete silos are 80 feet (24.4 m) in diameter, 36 feet (11 m) high, and 8-inches (20.3 cm) thick.

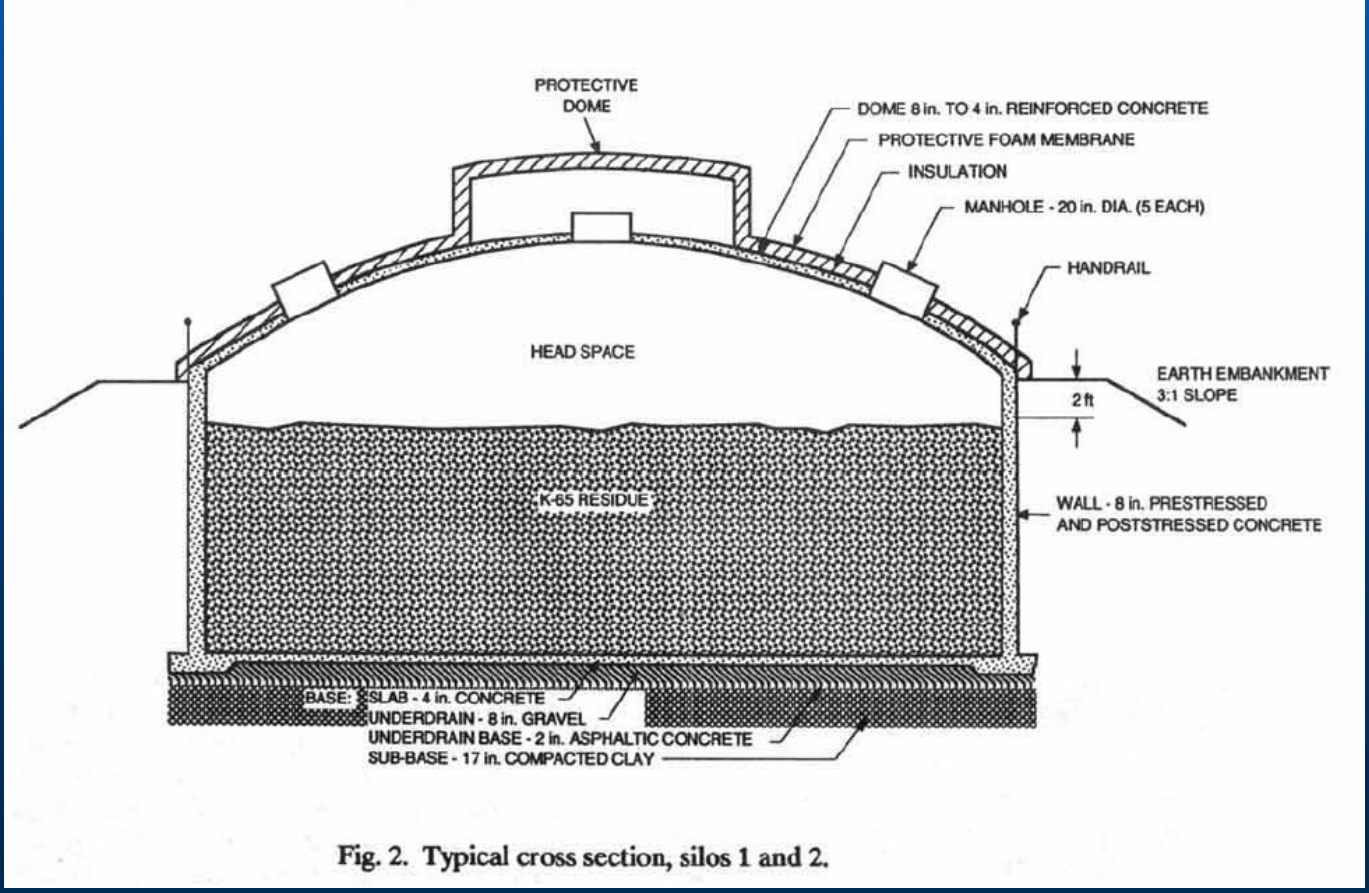
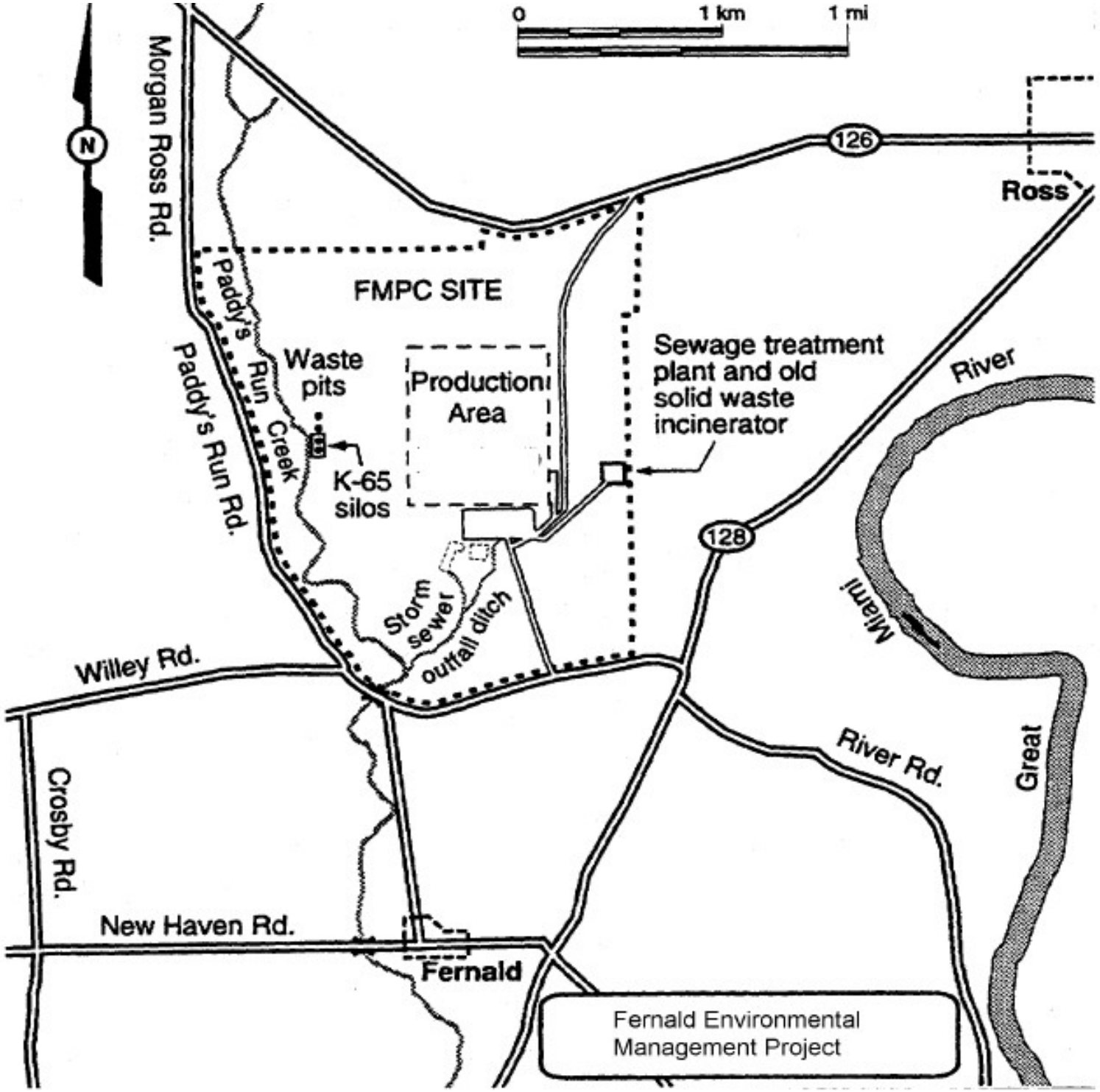


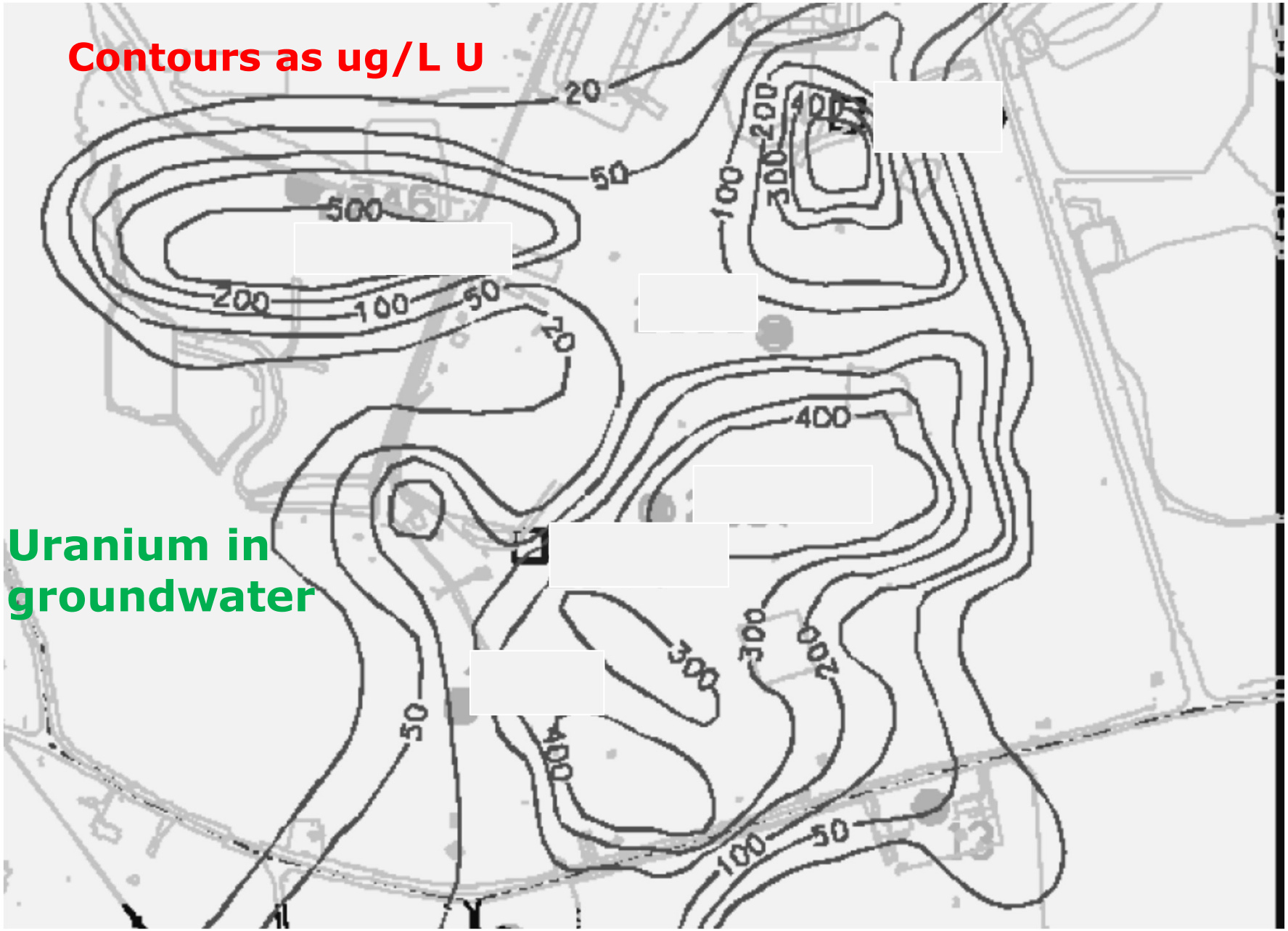
Fig. 2. Typical cross section, silos 1 and 2.

Waste storage silos

Silos 1 and 2 contained about 8,800 tonnes of solid residues of uranium ore from the former Belgian Congo containing about 3,300 Ci (122 TBq) of radium-226, 1,810 Ci (66.6 TBq) of thorium, and 7 Ci (0.26 TBq) of uranium,

Both silos produced about 4,100 Ci (152 TBq) of radon per year in the head space (Land *et al*., 2008).


0
1 km
1 mi
N
Morgan Ross Rd.
126
Ross
FMPC SITE
Paddy's Run Creek
Paddy's Run Rd.
Waste pits
K-65 silos
Production Area
Sewage treatment plant and old solid waste incinerator
River
128
Miami
Storm sewer outfall ditch
Willey Rd.
River Rd.
Great
Crosby Rd.
New Haven Rd.
Fernald
Fernald Environmental Management Project


Contours as ug/L U
Uranium in groundwater
20
50
500
200
100
50
20
400
200
100
300
400
300
200
300
50
400
100
50

Site cleanup

Site cleanup took 13 years, and $4.4 billion. "Completed" in 2005. All of the building were decontaminated and demolished.

The LLRW in the waste pits was excavated and sent to the Nevada National Security Site or Texas. About 979,000 tons (888,000 tonnes) were sent using 9,100 rail cars. About 8,900 yd^3 (6,800 m^3) of LLRW in silos 1 and 2 were removed and chemically stabilized with concrete and coal fly ash.

On-Site Disposal Facility (OSDF).

The OSDF

On-Site Disposal Facility (OSDF). The OSDF is an above-ground waste disposal facility constructed to permanently store low-level radioactive and mixed wastes generated by decommissioning and soil excavation.

The OSDF

The OSDF was designed to store 2,260,000 m^3, and it intended to isolate the wastes from the environment for at least 200 years and as long as 1,000 years to the extent possible.

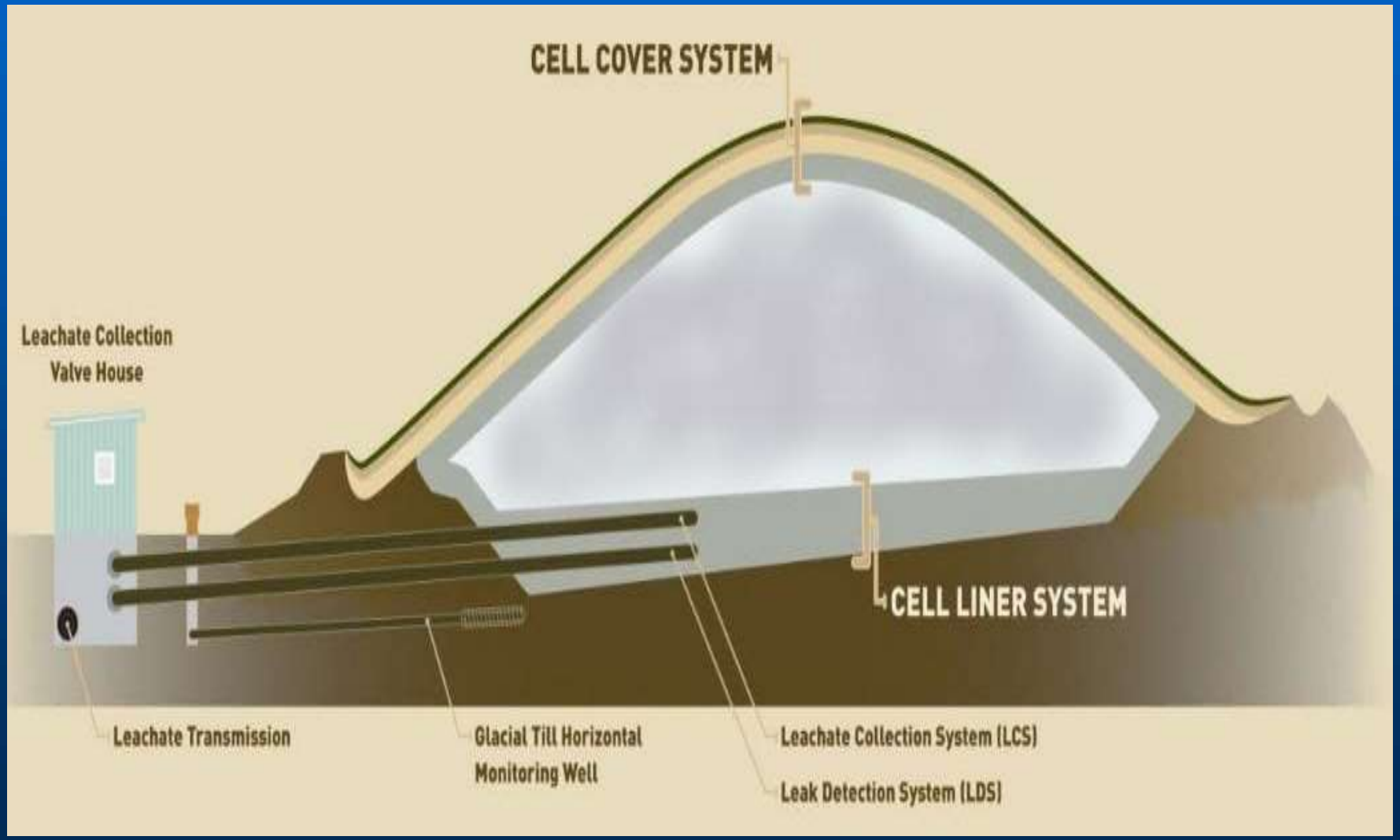
The OSDF

The OSDF consists of eight adjacent disposal cells and covers an area of 36 ha (89 acres). Construction of the OSDF began in 1997 and was completed in 2006. The eight cells were filled in sequence during site remediation.

The OSDF

It was estimated that about 85% by volume of the waste placed in the OSDF was contaminated soils, and that 15% was decommissioning debris such as broken concrete and scrap metal.

The OSDF


CELL COVER SYSTEM
Leachate Collection
Valve House
CELL LINER SYSTEM
Leachate Transmission
Glacial Till Horizontal
Monitoring Well
Leachate Collection System (LCS)
Leak Detection System (LDS)

Groundwater cleanup

Site groundwater is being extracted with extraction wells and treated to remove uranium to meet an EPA standard of 30 µg/L.

DOE plans to convert the FMPC into a nature preserve.

https://www.energy.gov/lm/fernald-preserve-ohio-site (2:36)

https://www.youtube.com/watch?v=kf7XQrJe7kI (4:38)

The Grand Junction Sites

Processing and disposal sites. First operated as a uranium and vanadium oxide refinery by the U.S. War Department for use in the Manhattan Engineer District from 1943 to 1946.

The Grand Junction Mill

Operated as a uranium and vanadium mill from 1950 to 1970. The mill produced about 2.2 million tons (2.0 million tonnes) of tailings. Until 1966, the tailings were given away to the public and contractors for fill.

The Grand Junction Mill

Milling operations resulted in soil and groundwater contamination. Concentrations of molybdenum, nitrate, selenium, and uranium exceeded Federal standards in surface and groundwater at the site.

The Grand Junction Mill

From 1970 to 1989, mill buildings were demolished. From 1989 to 1994, mill tailings and contaminated soil were removed.

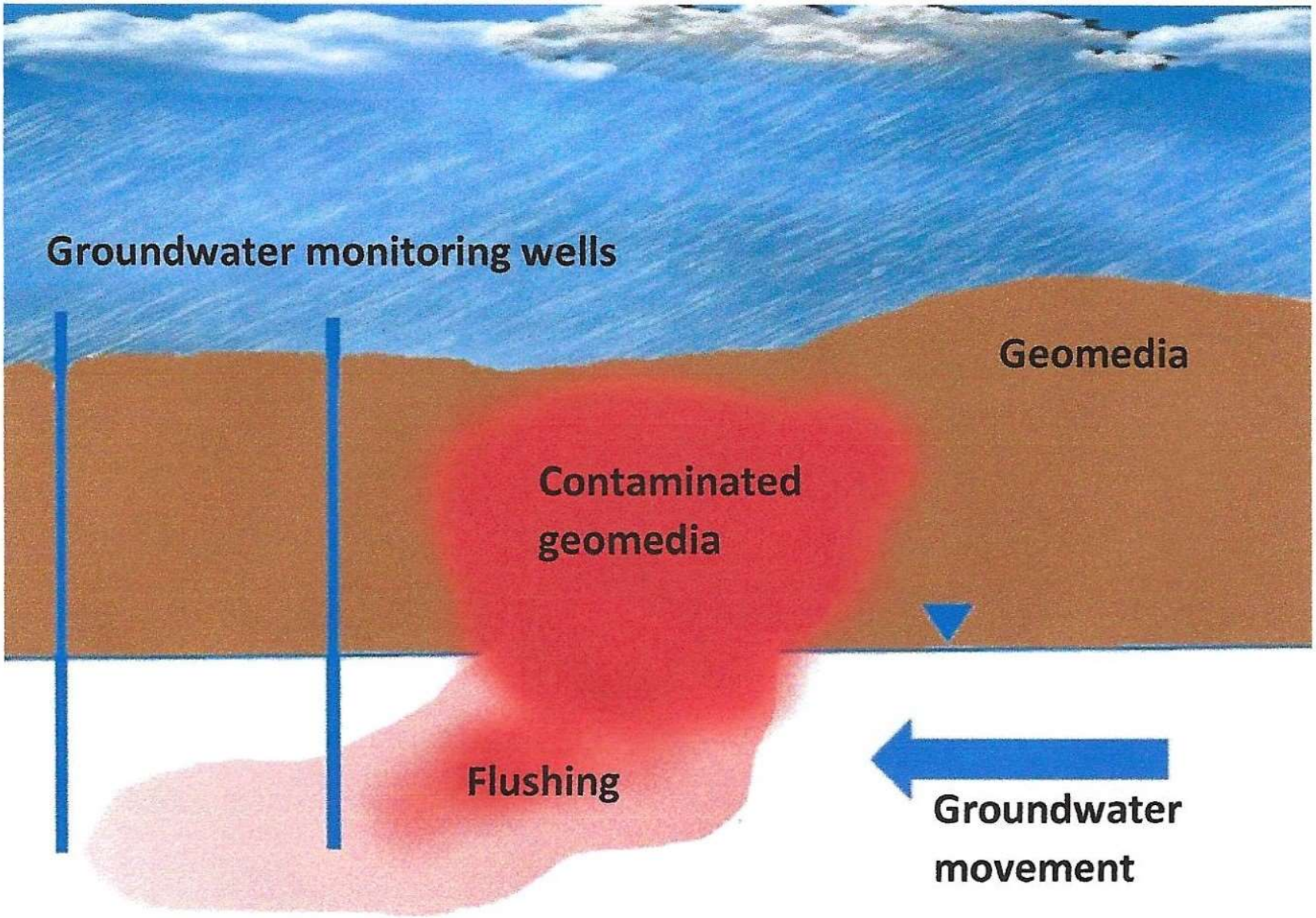
A 300-foot (91-m) deep borehole containing radium foil was left on-site. The borehole was filled with Portland cement, and a metal plaque was placed at the surface to say "do not disturb."

The Grand Junction Mill

Groundwater contamination extends about 3,300 feet (1,006 m) down gradient from the site. The compliance strategy for the contaminated surface and groundwater is "natural flushing" within a 50- to 80-year interval.

The Grand Junction Mill

This is a process in which precipitation flows through the contaminated sediments and soils, and desorbs, transports, and dilutes contaminants to acceptable levels within a 100-year time frame allowed in 40 CFR 192.


Groundwater monitoring wells
Geomedia
Contaminated geomedia
Flushing
Groundwater movement

The Grand Junction Disposal Site

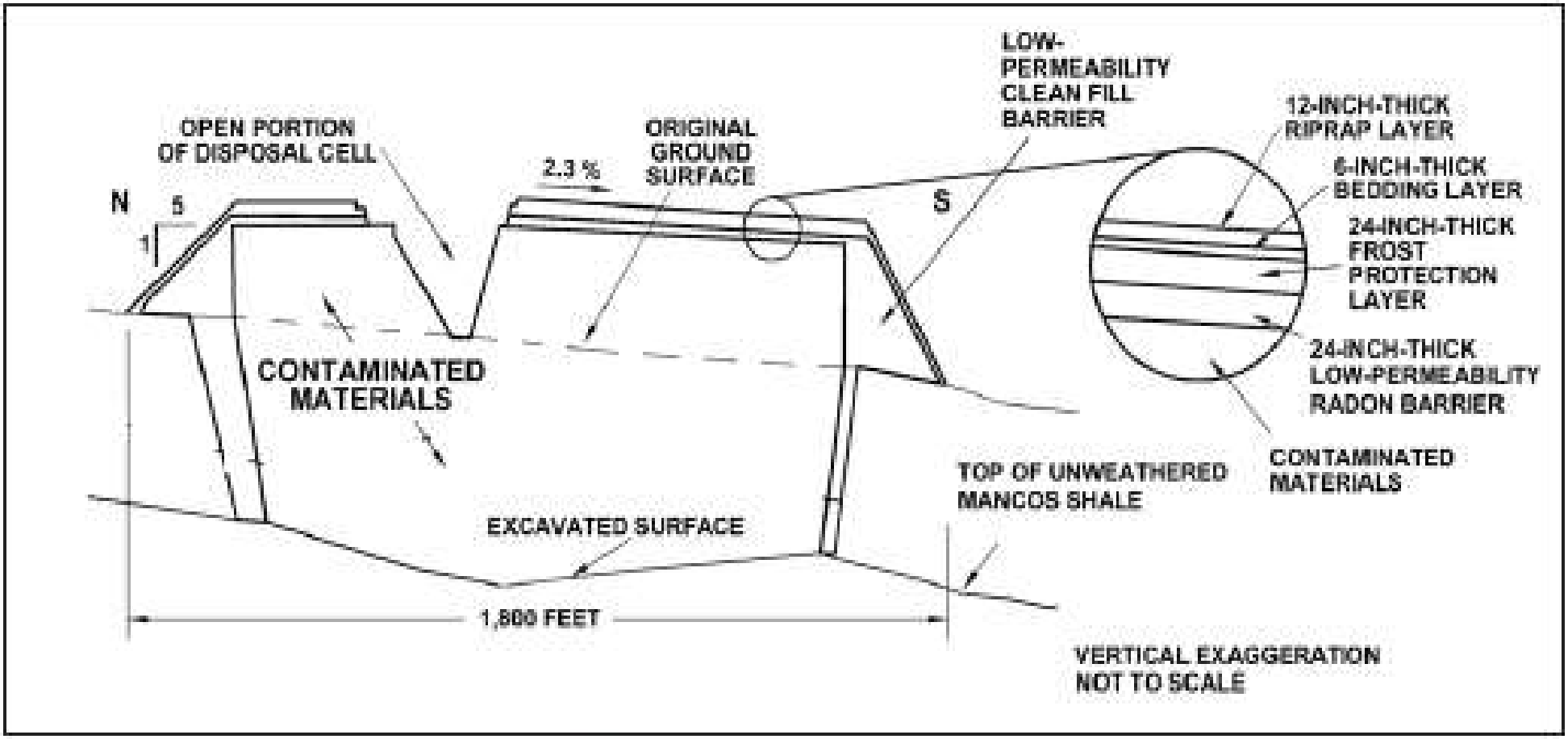
Construction of a disposal cell began in 1990. The cell covers 94 acres (38 ha), and about 3.36 million m^3 of contaminated materials were placed in the cell.

Site geology: alluvium and terrace gravel above shale.

The Grand Junction Disposal Site

Location chosen on the basis of remoteness, lack of significant groundwater, and the thick, relatively water-impermeable shale under the cell. The cell will remain open until filled or 2031.

The Grand Junction Disposal Site



North-South Cross Section of the Disposal Cell

The Rifle Sites (Colorado)

Two processing mills and one disposal site.

Old Rifle operated from 1924 to 1932 then from 1942 to 1958.

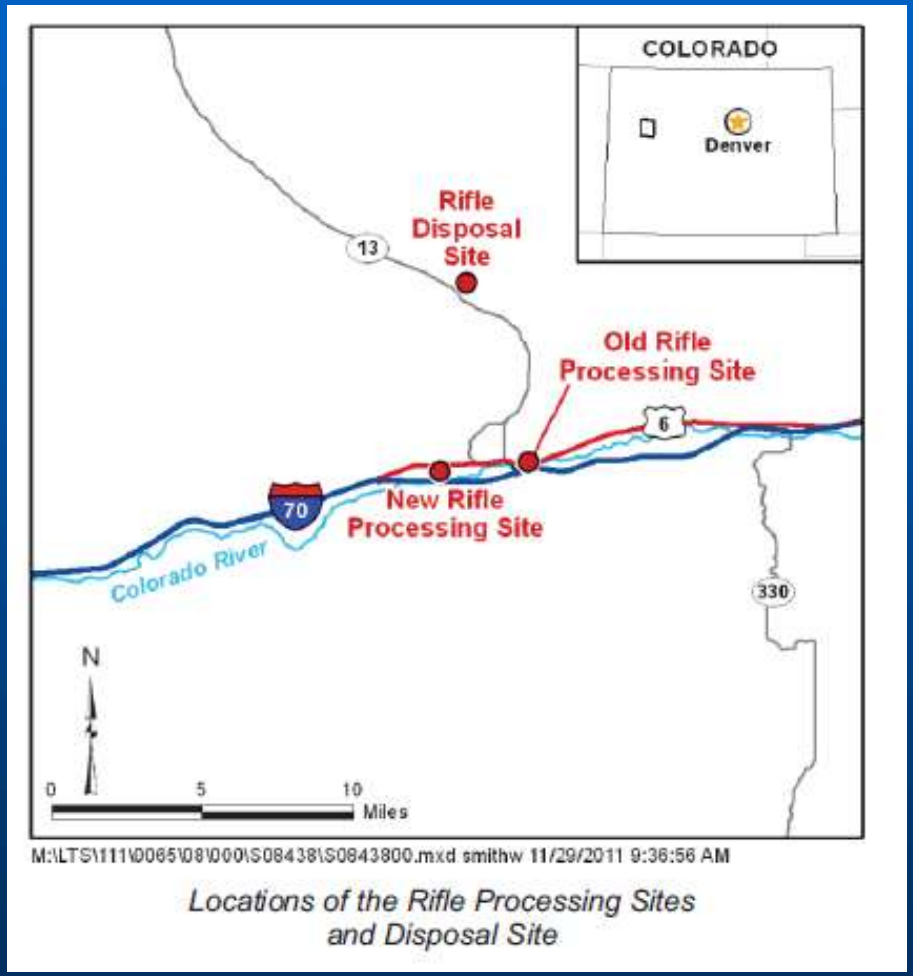
New Rifle operated from 1958 to 1984.

Both mills processed vanadium and uranium ores and created tailings.

Groundwater contaminated with arsenic, molybdenum, nitrate, selenium, uranium and vanadium.

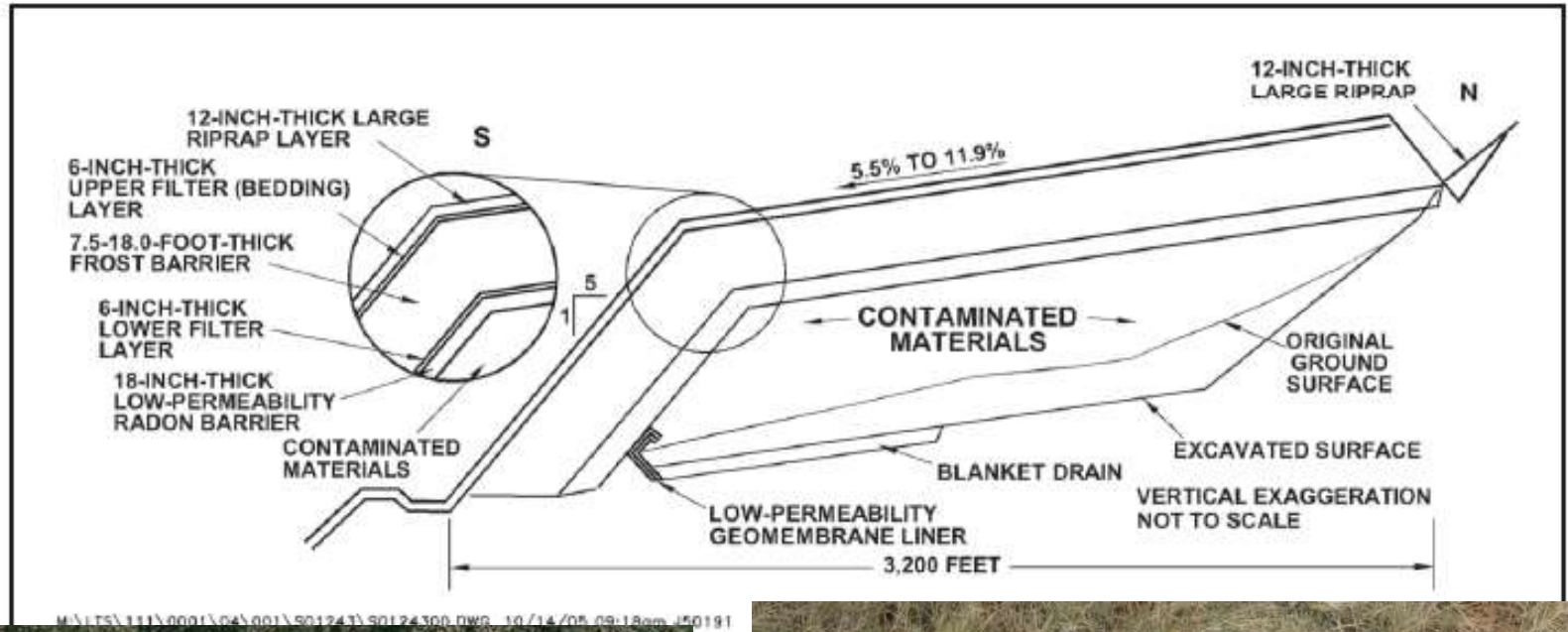
The Rifle Sites

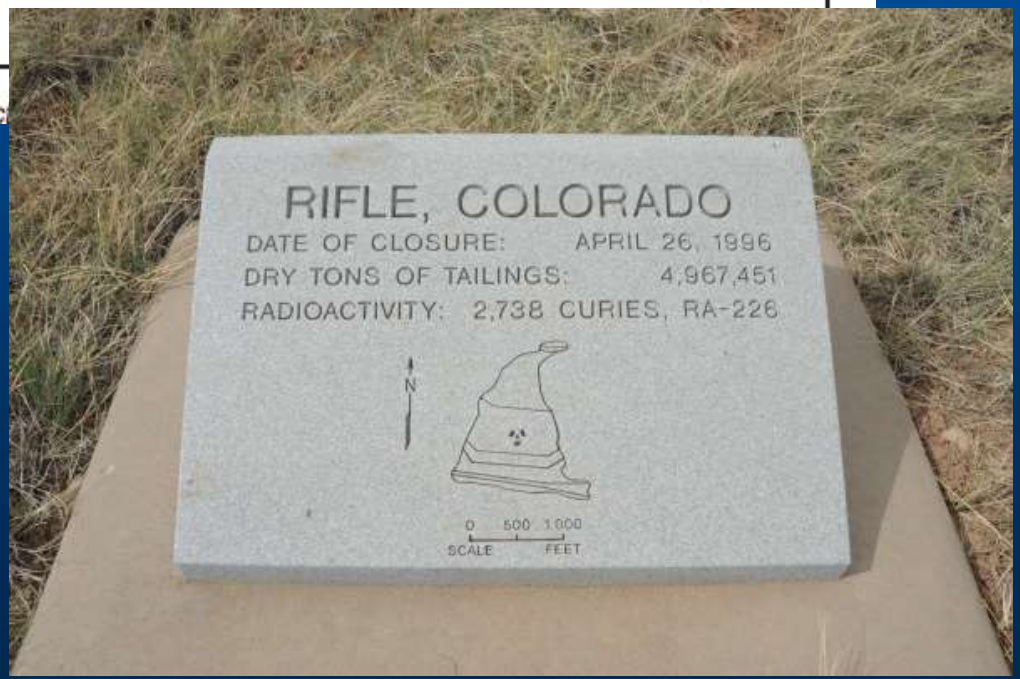
In 1991, the construction of a 71-acre (28.7 ha) disposal cell was begun to dispose tailings, soil, and pond sediments.



Locations of the Rifle Processing Sites and Disposal Site

The Rifle Disposal Site





Site restoration

New Rifle in 1974 (above), and in 2008 (below).

Groundwater issues remain

In 2002, the compliance strategy chosen for the contaminated groundwater at both Old and New Rifle was natural flushing. Groundwater modeling predicted that once the sources were removed, the concentrations of contaminants would decrease to acceptable levels within 100 years.

However, monitoring data collected from 1998 to 2011 indicated that the concentrations were NOT decreasing.

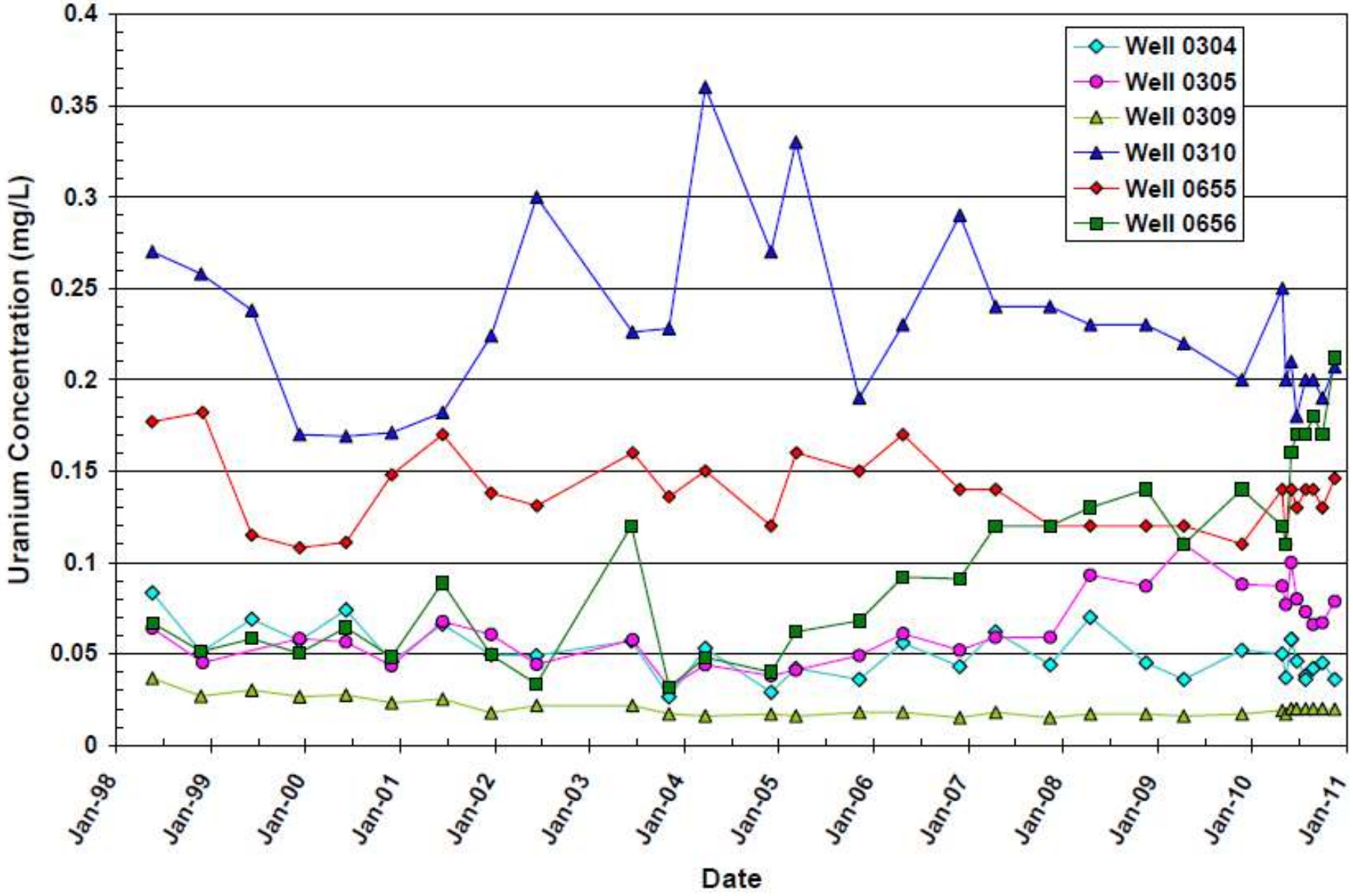


Figure 8. Uranium Concentration Histories at Several On-Site Wells

Why isn't the natural flushing approach working?

1. Not enough time has passed to see a trend in the monitoring data.
2. The reversibility of the adsorbed uranium was over-predicted.
3. The monitoring wells were installed in the wrong locations/depths.
4. Not all of the residual uranium has been removed.

DOE's analysis

DOE submitted a report to the NRC which outlined a "new" strategy for groundwater remediation. The report is currently being reviewed by NRC. DOE concluded that:

1. Flow, geochemical and biological processes in the subsurface more complex than initially thought in the 2001 modeling study.

DOE's analysis

2. Recent modeling indicated that the adsorption constants (K_d) for uranium in the alluvium should have been from 0.5 to 20 L/kg (0.2 L/kg were used in the 2001 study).

3. Slow diffusion of uranium from low-permeable sediments had not been taken into account.

DOE's analysis

4. Mobilization of uranium in the vadose zone had been ignored.

5. Natural sources of uranium off-site.

DOE's conclusions

1. Natural flushing of uranium contamination at Old Rifle cannot be reliably predicted by existing numerical models.

2. Install several new monitoring wells, and collect more data to "consider alternative compliance strategies."

Reducing Environmental Impacts of Nuclear Materials at the Future Micro-Modular Reactor

A presentation for the

Institute of Nuclear Materials Management, University of Illinois Urbana-Champaign Student Chapter

Prof. W. R. Roy
Department of Nuclear, Plasma, and Radiological Engineering

April 3rd at 4 pm in 1036 CIF

Canonsburg Disposal Site

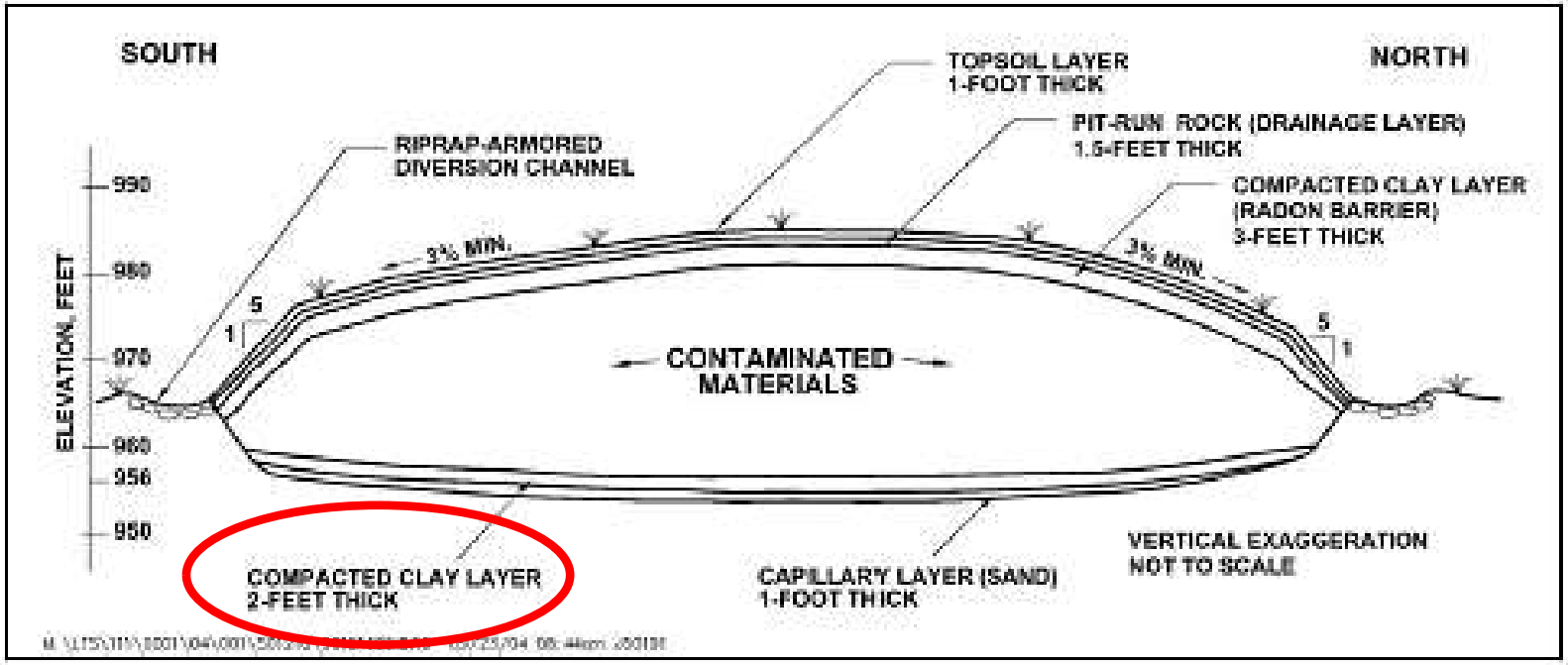
Former mill that processed uranium from ore and scrap from 1911 to 1957. Extracted radium from 1911 to 1922.

Canonsburg Disposal Site

Operations created tailings

which were placed in a 6 acre (2.4 ha) disposal cell. The cell was closed in 1985 and holds 123,000 m^3 of contaminated material with a total activity of 100 Ci (3.7 TBq) ^{226}Ra.

Canonsburg Disposal Site



Canonsburg Disposal Site

Like each example today, the disposal cell is designed to be effective for 1,000 years "to the extent reasonable achievable."

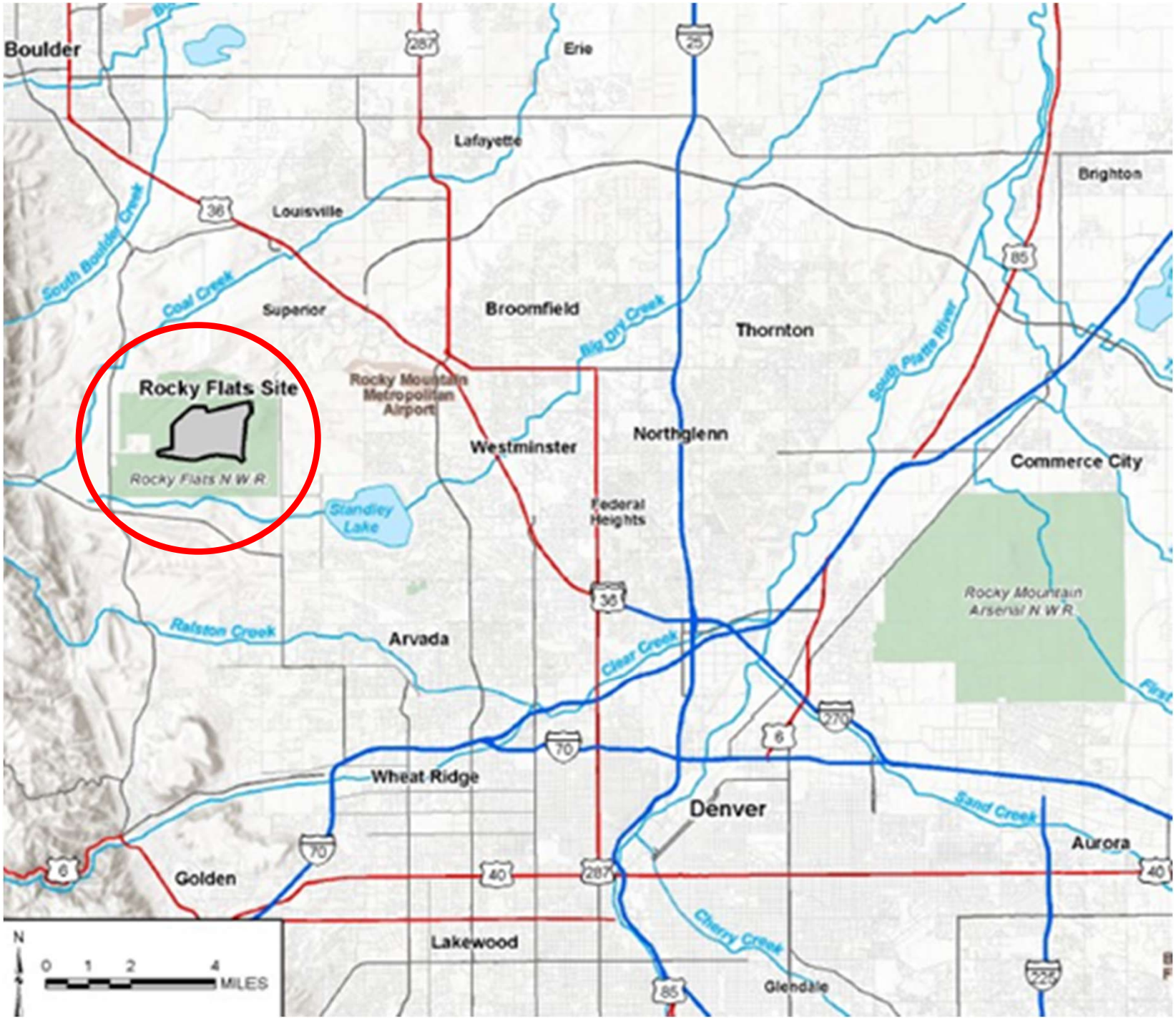
The DOE Office of Legacy Management will be responsible for the Canonsburg disposal site (and all others) "indefinitely."

Rocky Flats Plant

The Rocky Flats Plant was located about 25 km northwest of Denver, Colorado. The plant was in operation from about 1952 to 1989. The primary purpose of the Rocky Flats Plant was the production of parts for nuclear weapons.

Rocky Flats Plant

Specifically, plutonium, beryllium, uranium, and stainless steel were machined into fission cores that were used to initiate a nuclear reaction. These fission cores were often called "triggers" or "pits" to obfuscate their function.


Boulder
Erie
Lafayette
Brighton
Louisville
South Boulder Creek
Coal Creek
Superior
Broomfield
Big Dry Creek
Thornton
South Platte River
Rocky Flats Site
Rocky Flats N.W.R.
Rocky Mountain Metropolitan Airport
Westminster
Northglenn
Commerce City
Standley Lake
Federal Heights
Rocky Mountain Arsenal N.W.R.
Ralston Creek
Arvada
Clear Creek
Wheat Ridge
Denver
Sand Creek
Aurora
Golden
Lakewood
Cherry Creek
Glendale
N
0 1 2 4
MILES

Rocky Flats Plant in c. 1981

Problems at Rocky Flats

In 1989, the Federal Bureau of Investigations and the U.S. EPA conducted an armed raid at the Plant because of suspicions about numerous releases of radionuclides and hazardous chemicals. The production of nuclear cores was halted, and the Plant was placed on the EPA National Priorities List as a Superfund Site.

Incidents at Rocky Flats

Two fires in which plutonium shavings in glove boxes ignited in 1957 and 1969. Soil contamination resulted from 55-gallon drums of machine-cutting oil that was contaminated plutonium and uranium.

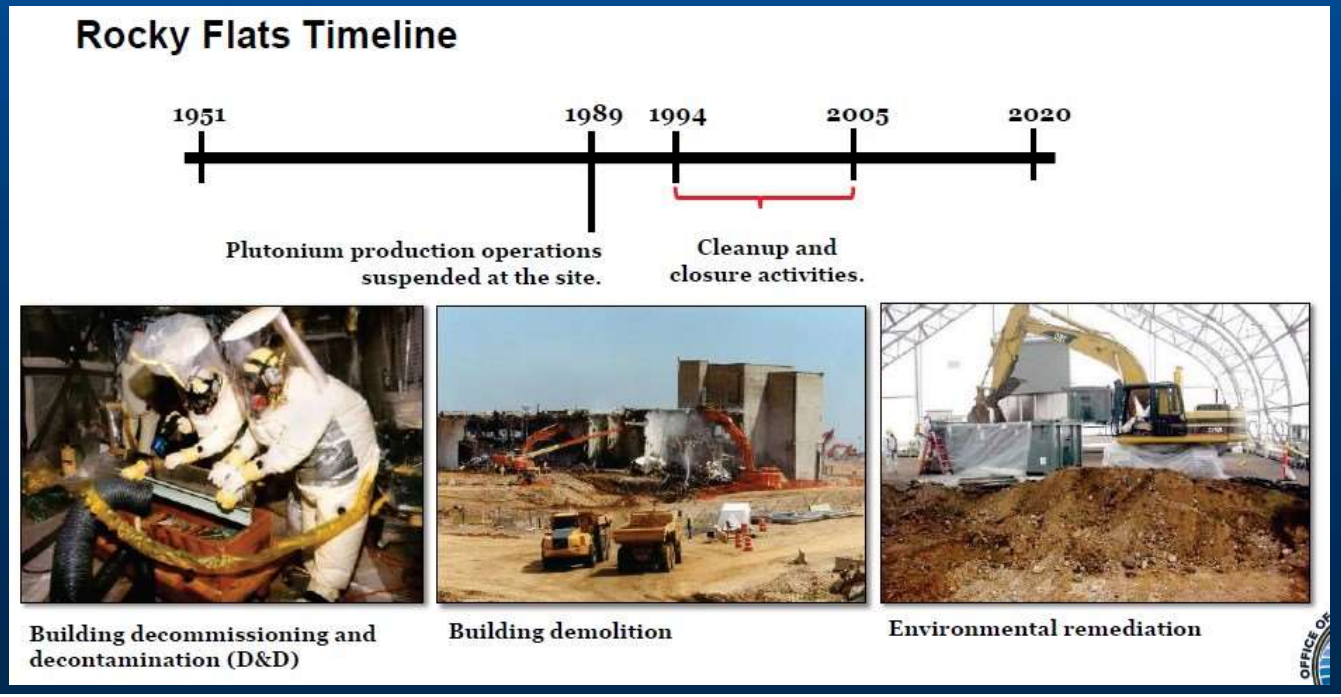
Incidents at Rocky Flats

The drums had been stored on Pad 903 and corroded from 1958 to 1967. About 19,000 L of the waste oil leached into the surface and subsurface soils.

Pad 903

Site Cleanup

Site decommissioning began in 1992, and the Plant was renamed the Rocky Flats Environmental Technology Site. About 150 permanent buildings, 90 trailers, temporary structures, and tanks were decommissioned and demolished. The demolitions included six plutonium-processing buildings.

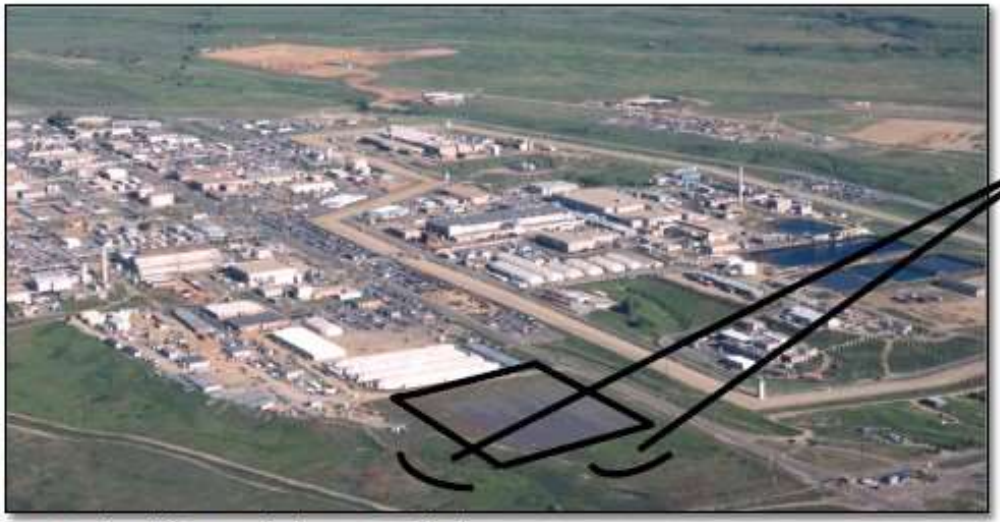


Soil excavated

The surface soils in the industrial area were "cleaned up" to a depth of 3 feet (0.9 m). The imposed soil-cleanup level was 50 pCi/g for plutonium-239, 240. Plutonium and americium were left in place below two concrete slabs and buried pipes that were filled with grout.

Example Project: 903 Lip Area Soil Remediation

- 903 Lip Area (east of 903 Pad)
  - Remove soil >50 pCi/g
  - Around 34 acres
  - Stringent dust and erosion controls
  - Completed September 2004



903 Pad and lip area before remediation

Erosion "blanket"

Waste disposal

About 500,000 m^3 of DOE-defined Low-Level waste and Low Level-Mixed waste were generated and disposed at the Nevada National Security Site, the Clive Disposal Facility in Utah, and Hanford Site in Washington. About 15,000 m^3 of transuranic wastes created during the decommissioning of the site were sent to WIPP.

1994–2005: Cleanup and Closure
Shipping Special Nuclear Materials and Waste

DOE is done—almost

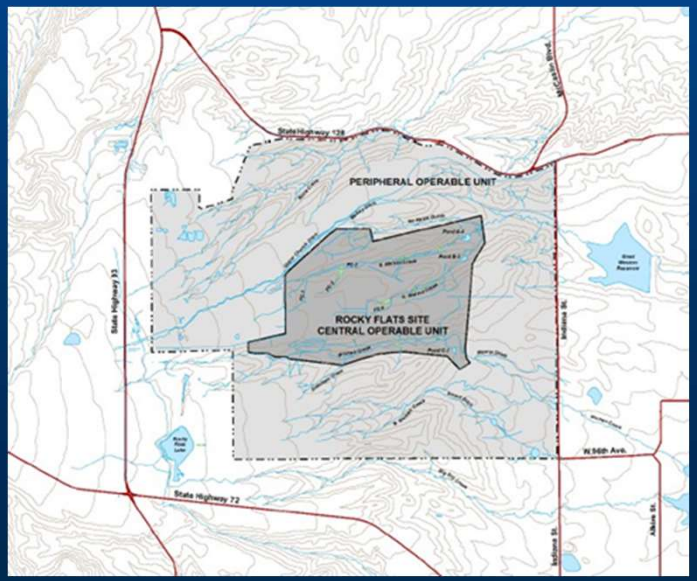
In 2005, DOE declared that site cleanup at the Rocky Flats Environmental Technology Site was "complete," and the site was transferred to the Office of Legacy Management. DOE will provide "institutional and physical controls and continued monitoring and maintenance."

Cleanup and closure activities complete.

POU and COU

1. The outer or Peripheral Operable Unit (POU). Judged to be relative free of contamination. Transferred to the U.S. Fish and Wildlife Service as the Rocky Flats National Wildlife Refuge.

2. The inner or Central Operable Unit (COU). Unsuitable for release to the public for unrestricted use (Includes Pad 903).



Groundwater treatment

The contaminated groundwater in the COU is being partially treated by passive, field-scale treatment systems. In an early approach, a deep French drain with a drainpipe was used collect shallow groundwater. The collected groundwater was fed into two reaction cells that were filled with zero-valence iron in the form of iron filings from cast iron.

Groundwater treatment

The zero-valent iron resulted in the dichlorination of some of the volatile organic contaminants. The reaction with trichloroethylene, for examples, can be generalized by beginning with the oxidation of the iron in contact with the groundwater:

$$3Fe^{0}\ (\text{iron filings}) \rightarrow 3Fe^{2+} + 6e^{-}$$

followed by the reduction and dechlorination of the trichloroethylene to form ethylene:

$$C_2HCl_3 + 3H^{+} + 6e^{-} \rightarrow C_2H_4 + 3Cl^{-}$$

Groundwater treatment

Each batch of iron filings must be replaced after 3 to 5 years. Because of the presence of dissolved radionuclides in the contaminated groundwater that may be sorbed by the iron, the spent filings often needed to be disposed as a low-level radioactive waste. This approach is no longer used.

Groundwater treatment

A second treatment system that is currently being used at four locations is air stripping. This approach is based on the property of volatile organic chemical dissolved in groundwater to partition from the liquid phase in the atmosphere. It is accomplished at the COU by simply spraying the contaminated into the air above a collection vessel.

Groundwater treatment

Neither treatment system was intended to completely remove the volatile organic contaminants. They are applied to qualitatively reduce the overall impact of the contaminated water on surface and groundwater quality.

Rocky Flats is a not a popular topic in Denver

The Rocky Flats Environmental Technology Site remains controversial to the nearby residents. In 2019, plutonium was detected in a soil sample in a concentration of 264 pCi/g. The sample was collected outside the POU. A local community group "Candelas Glows" calls the area south of the Wildlife Refuge the "plutonium dust bowl."

ROCKY FLATS IS FOR RADIATION...NOT RECREATION

DOE on Rocky Flats

https://www.youtube.com/watch?v=KTcSgQDJrew (4:40)

The Weldon Spring Site

Former TNT production plant during World War II, then a uranium processing facility during the Cold War.

Located near St. Charles, Missouri.

In 1941, the government seized 17,232 acres (6,974 ha) to establish the Weldon Spring Ordnance Works. Three small villages were displaced. In 1956, the U.S. Atomic Energy Commission constructed the Weldon Spring Uranium Feed Materials Plant (later the Chemical Plant).

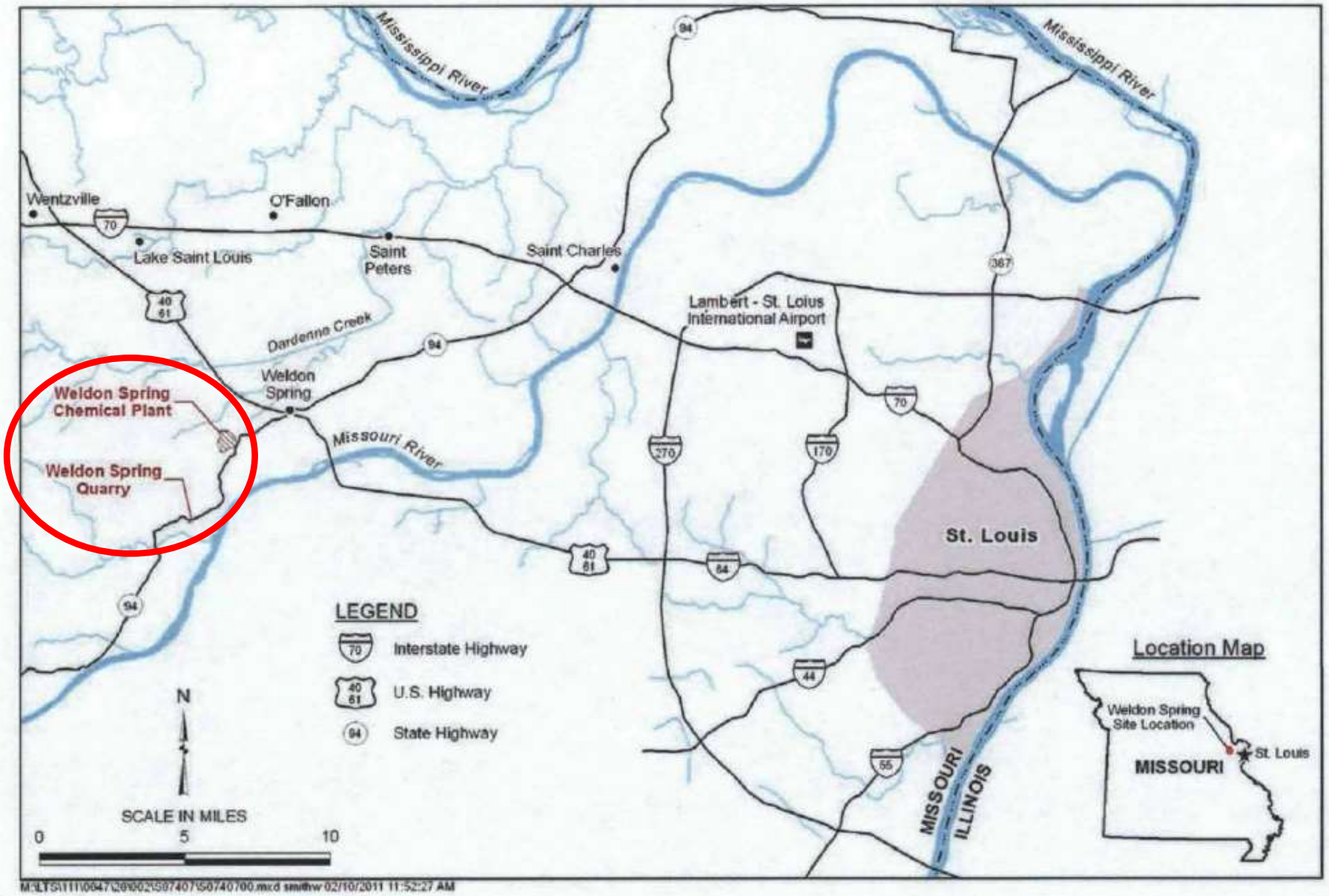


Figure 1. Location of the Weldon Spring, Missouri, Site

The Weldon Spring Site

Radioactive wastes

The process sludges, residues, building debris, and discarded process equipment were contaminated with uranium and thorium and their decay products.

Wastes were stored in four on-site ponds and in a near-by limestone quarry.

The radioactive wastes were disposed with TNT wastes and others which contained heavy metals (mixed wastes).

Waste drums from the Ordnance Works Site disposed in the limestone quarry by the U.S. Army

Forgotten wastes

As typical for that era, waste management was crude and undocumented.

Uranium processing ended in 1966, and the U.S Army began to convert the Chemical Plant to produce Agent Orange for the Vietnam Conflict (project cancelled).

The Chemical Plant, wastes ponds, and quarry were dormant for two decades.

Site remediation

In 1984, the Army transferred custody of Chemical Plant to DOE, making DOE responsible for site cleanup. They renamed it the Weldon Spring Site Remedial Action Project. Cleanup began in 1986.

In 1987, the U.S. EPA placed the quarry on the National Priorities List (for cleanup) because of concerns about groundwater contamination.

Site remediation

44 buildings were demolished.

The pits were dewatered, and the solids were removed.

The mixed (heavy metals, TNT, uranium and thorium) wastes in the quarry were removed, and the quarry was backfilled with clean, local soil.

Remediation was completed in 1995.

What did they do with all the wastes?

The DOE disposal cell

Beginning in 1997, DOE constructed a 45-acre (18.2-ha) disposal cell in the area of the former Chemical Plant.

Completed in 2001, about 1.48 million yd^3 (1.13 million m^3) of waste from the quarry and the Chemical Plant site were placed in the disposal cell.

Waste volumes

Contaminated soil: 1.18 million yd^3 (902,000 m^3); or 79.5% of the waste.

Grout solidified contaminated sludge: 194,200 yd^3 (149,000 m^3); or 13% of the waste

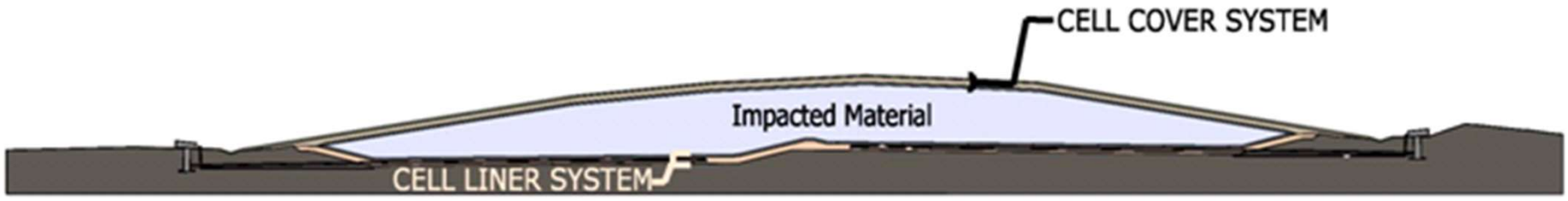
Concrete/Rubble: 85,200 yd^3 (65,140 m^3) or some 6% of the waste.

Wood: 1,100 yd^3 (840 m^3)

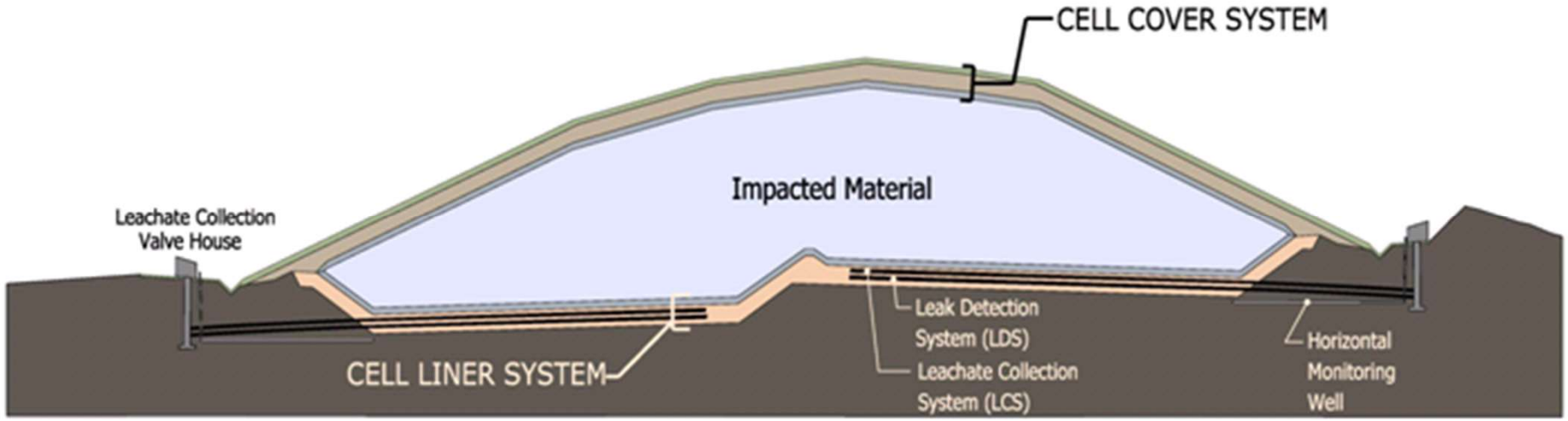
Metals: 13,000 yd^3 (9,900 m^3)

Other (boxes, containers): 9,000 yd^3 (6,900 m^3).

Design of the disposal cell



PRELIMINARY ON-SITE DISPOSAL CELL CROSS SECTION
(NO VERTICAL EXAGGERATION)



PRELIMINARY ON-SITE DISPOSAL CELL CROSS SECTION
(3X EXAGGERATION)

Design of the disposal cell

The disposal cell designed to deter the migration of contaminants and to remain stable for 1,000 years.

Exposed surfaces engineered to resist long-term erosion.

Side slopes and waste placement methods designed to withstand a Maximum Credible Earthquake (MCE) that considered the New Madrid fault system earthquake potential.

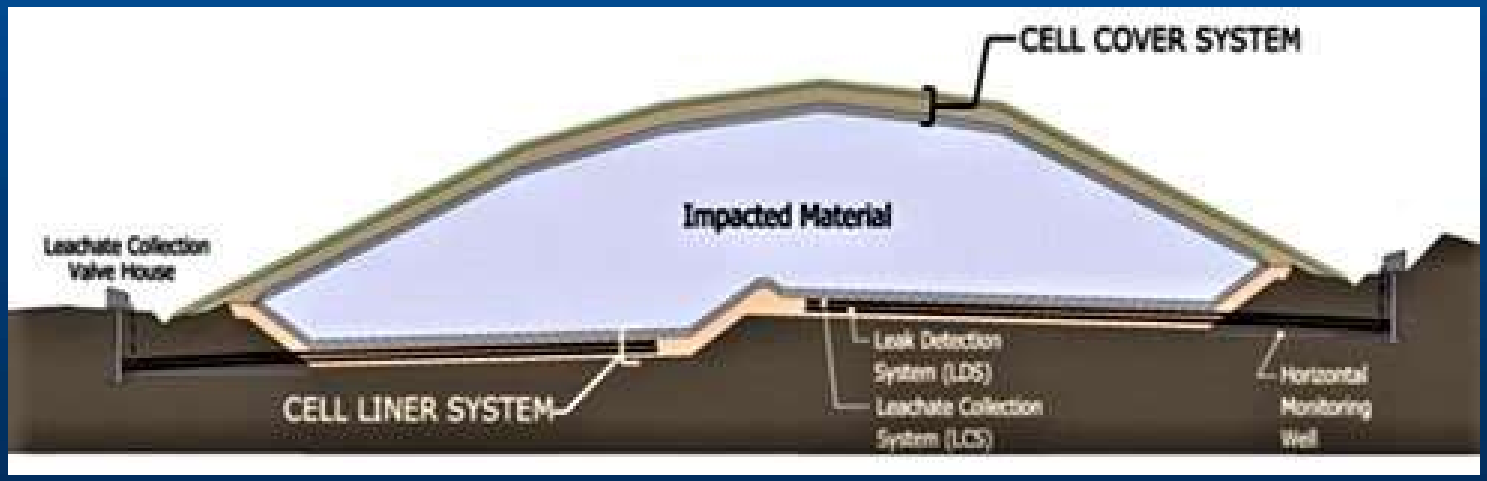
Design of the disposal cell

A geographic location with no geological faults within a 10-mile (16-km) radius appearing to have experienced movement in the past 8,000 years.

Located in a geologically stable area with no significant potential for catastrophic collapse because of voids (such as caverns) in the soil or bedrock (limestone).

Design of the disposal cell

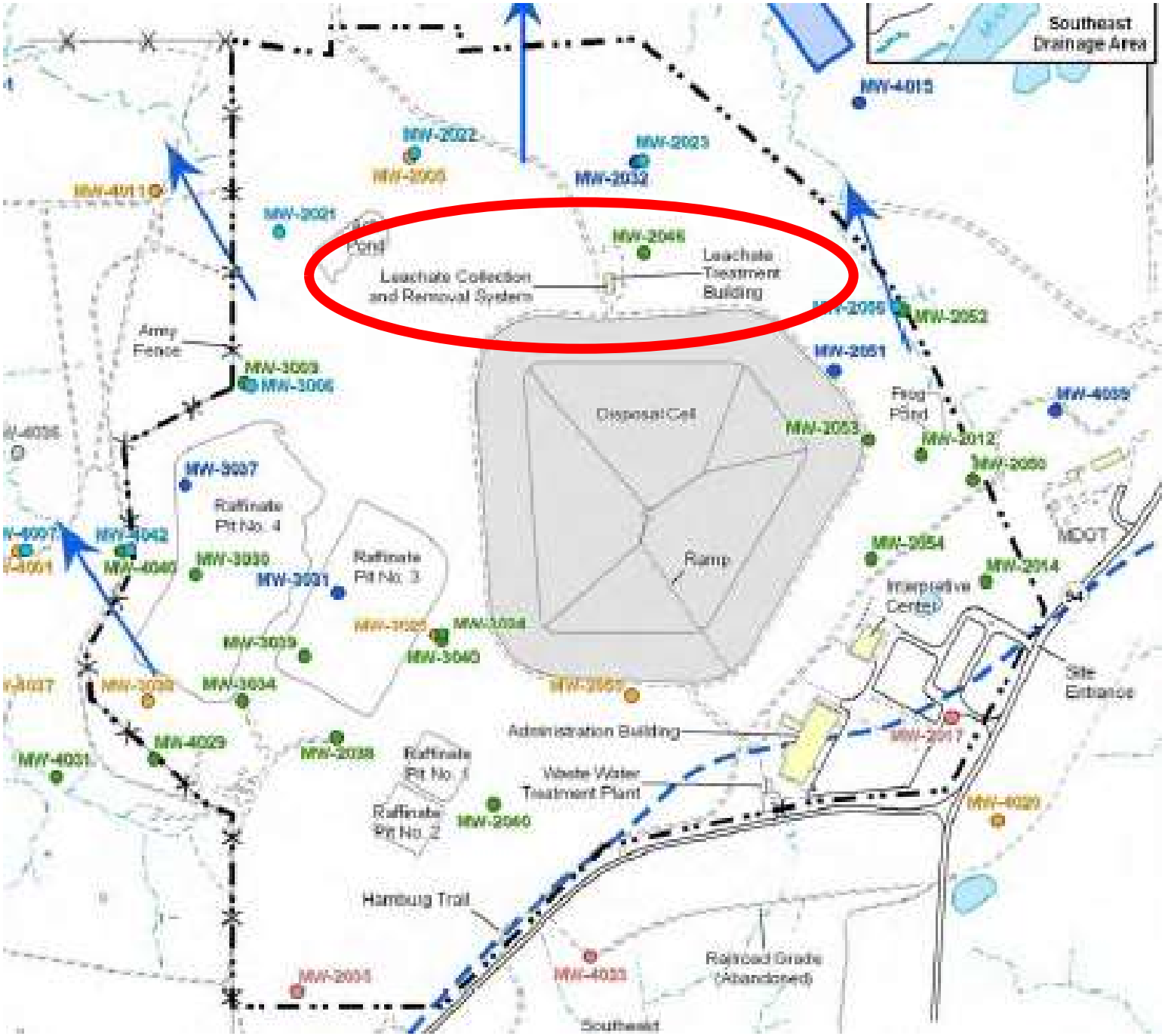
The base liner with leachate collection and removal systems designed to prevent leachate migration from the bottom of the cell.



Design of the disposal cell

The contaminated wastes, consisting of treated and untreated wastes, were placed and stabilized within the cell in a controlled and engineered manner to reduce settling, minimize volume, and retard radon emissions.

Groundwater monitoring wells were installed to detect potential leaks from the cell.


Southeast
Drainage Area
MW-4015
MW-2022
MW-2023
MW-2032
MW-4011
MW-2021
Pond
MW-2046
Leachate Collection
and Removal System
Leachate
Treatment
Building
Army
Fence
MW-3009
MW-3006
MW-2035
MW-2052
MW-2051
Disposal Cell
Frog
Pond
MW-4039
MW-2053
MW-2012
MW-2050
MW-3037
Raffinate
Pit No. 4
MW-3042
MW-4040
MW-3030
MW-3031
Raffinate
Pit No. 3
Ramp
MW-2054
MW-2014
MDOT
Interpretive
Center
MW-3035
MW-3034
MW-3040
MW-3039
MW-3033
MW-3034
MW-2037
Site
Entrance
Administration Building
MW-4029
MW-2038
MW-4031
Raffinate
Pit No. 1
Waste Water
Treatment Plant
Raffinate
Pit No. 2
MW-2040
MW-4028
Hamburg Trail
MW-2041
MW-4033
Railroad Grade
(Abandoned)
Southeast

Be sure to visit the . . .

The Weldon Spring Site Interpretive Center

http://www.lm.doe.gov/default.aspx?id=1921

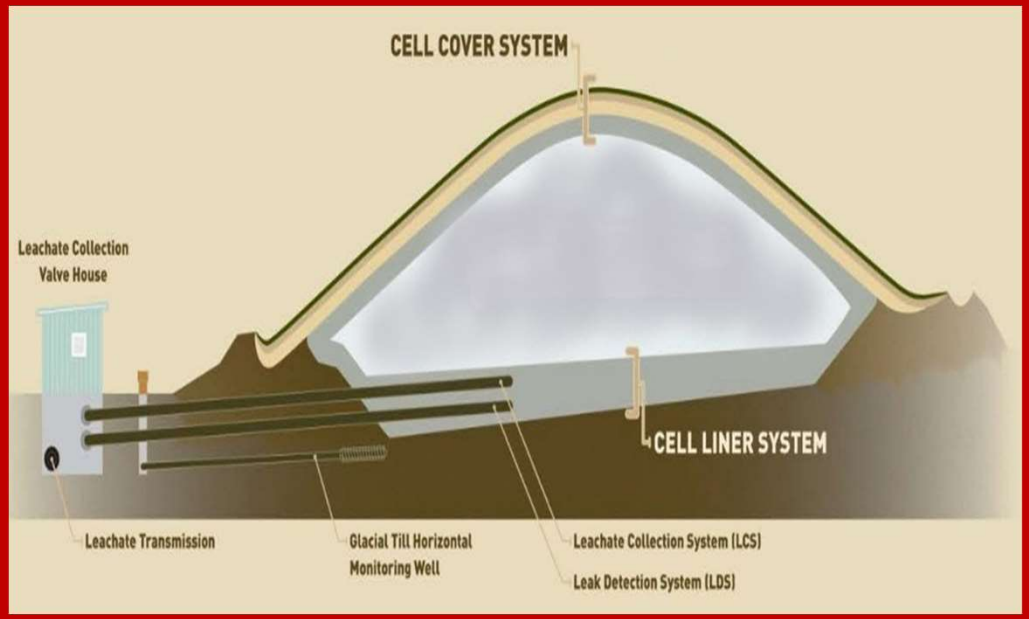
The Nuclear Waste Adventure Trail

https://www.roadsideamerica.com/story/14614

DOE on Weldon Spring

https://www.youtube.com/watch?v=8unEfYoXByA (4:17)

Questions?


CELL COVER SYSTEM
Leachate Collection
Valve House
CELL LINER SYSTEM
Leachate Transmission
Glacial Till Horizontal
Monitoring Well
Leachate Collection System (LCS)
Leak Detection System (LDS)