Legacy Radioactive 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.
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 on December 15, 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
Five Examples of Environmental Restoration by U.S. DOE

<table>
<thead>
<tr>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fernald, Ohio</td>
</tr>
<tr>
<td>Grand Junction, Colorado</td>
</tr>
<tr>
<td>Rifle, Colorado</td>
</tr>
<tr>
<td>Canonsburg, Pennsylvania</td>
</tr>
<tr>
<td>Weldon Spring, Missouri</td>
</tr>
</tbody>
</table>
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.
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.
“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.

In 1989, FMPC was declared a Superfund site and renamed the Fernald Environmental Management Project (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.
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, (“high-activity, low-level radioactive wastes”). Both silos produced about 4,100 Ci (152 TBq) of radon per year in the head space (Land et al., 2008).
Contours as ug/L U

Uranium in groundwater
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 Andrews County, 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. Currently stored on-site in drums.
Site cleanup

Site groundwater is currently being extracted with extraction wells and treated to remove uranium to meet an EPA standard of 30 µg/L. As of 2006, 7,500 lbs (3,400 kg) of uranium have been removed. DOE plans to convert the FMPC into a nature preserve.
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.

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.”
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. 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.
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.

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 2023.
The Grand Junction Disposal Site
The Rifle Sites

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.
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.

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.”
Canonsburg Disposal Site

Former mill that processed uranium from ore and scrap from 1911 to 1957. Extracted radium from 1911 to 1922. 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 m³ of contaminated material with a total activity of 100 Ci (3.7 TBq) $^{226}\text{Ra}$. 
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.”
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 pits near the two Weldon Spring wildlife areas are filled with uranium, thorium, radium and nitrates. Ducks and geese light on water in the pits.
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.
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 concern about groundwater contamination.
<table>
<thead>
<tr>
<th>Source Area</th>
<th>Chemical Contaminants</th>
<th>Radiological Contaminants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical Plant Soils</td>
<td>Non-friable asbestos-containing material (ACM), PCBs, heavy metals, nitroaromatics, PAHs, nitrates, sulfates</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>North Dump</td>
<td>Non-friable ACM</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>South Dump</td>
<td>Non-friable ACM</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Ash Pond</td>
<td>Non-friable ACM</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Raffinate Pit Berms</td>
<td>PCBs, lead chromium, cadmium, tetrachloroethylene, nitrates</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Raffinate Pit Water</td>
<td>Antimony, arsenic, magnesium, manganese, molybdenum, selenium, zinc, mercury</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Raffinate Pit Sludge</td>
<td>PCBs, heavy metals, mercury</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Chemical Plant Building</td>
<td>Friable ACM, non-friable ACM, PCBs, nitric acid, hydrofluoric acid, sodium hydroxide, tributyl phosphate, heavy metals, calcium hydroxide, potassium hydroxide, ethylene glycol, mercury, perchloric acid, magnesium, magnesium fluoride</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Frog Pond Water</td>
<td>Arsenic, lead, chromium, mercury, magnesium, magnesium fluoride, nitroaromatics</td>
<td>Uranium</td>
</tr>
<tr>
<td>Frog Pond Sediment</td>
<td>Lead, cadmium, chromium, mercury</td>
<td>Uranium</td>
</tr>
<tr>
<td>Quarry Pond Water</td>
<td>Friable ACM, PCBs, arsenic, manganese, nitroaromatics, PAHs</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Quarry Pond Sediment</td>
<td>Friable ACM, arsenic, manganese, nitroaromatics, PAHs</td>
<td>Uranium, thorium, radium</td>
</tr>
<tr>
<td>Quarry Bulk Wastes</td>
<td>Friable ACM, PCBs, mercury, arsenic, lead, cadmium, nickel, selenium, nitroaromatics, PAHs</td>
<td>Uranium, thorium, radium</td>
</tr>
</tbody>
</table>
Table 6. Concentration Ranges and Locations of Radioactive Contaminants of Concern

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>On-Site Concentration Range</th>
<th>Off-Site Concentration Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Soil (pCi/g)</td>
<td>Surface Water (pCi/L)</td>
</tr>
<tr>
<td>Pb-210</td>
<td>0.4–450</td>
<td>-</td>
</tr>
<tr>
<td>Ra-226</td>
<td>0.4–450</td>
<td>3.4–130</td>
</tr>
<tr>
<td>Ra-228</td>
<td>0.4–450</td>
<td>1.5–25</td>
</tr>
<tr>
<td>Rn-220 progeny</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rn-222 progeny</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Th-228</td>
<td>0.4–450</td>
<td>1.5–25</td>
</tr>
<tr>
<td>Th-230</td>
<td>0.3–97</td>
<td>1.4–760</td>
</tr>
<tr>
<td>Th-232</td>
<td>0.4–150</td>
<td>0.2–7.6</td>
</tr>
<tr>
<td>U-234c</td>
<td>0.3–2,300</td>
<td>28–1,300</td>
</tr>
<tr>
<td>U-235</td>
<td>0.01–110</td>
<td>1.3–60</td>
</tr>
<tr>
<td>U-238</td>
<td>0.3–2,300</td>
<td>28–1,300</td>
</tr>
</tbody>
</table>

*a The term "on-site" refers to all areas, contaminated or otherwise, within the physical boundaries of the Chemical Plant and Quarry.

*b The term "off-site" refers to Busch Conservation Area vicinity properties, Weldon Spring Training Area vicinity properties, Weldon Spring Conservation Area vicinity properties, Burgermeister Spring, and the Southeast Drainage.

*c Estimated on the basis of expected equilibrium conditions.

ND = not detected
pCi/g = picocuries per gram
pCi/L = picocuries per liter
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 excavated, and the quarry was backfilled with clean, local soil.
Remediation was completed in 1995.

What did they do with all the wastes?
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

Soil, treated sludge: 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

The disposal cell is 75 feet tall at the apex.
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.

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.
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
http://www.roadsideamerica.com/tip/10044