Low-Level Radioactive Waste Management

"Why," said the Professor hotly, "one would say you were already beginning to be afraid."
—Prof. Von Hardwigg in "Journey to the Center of the Earth" by Jules Verne.

Waste Characterization

The process of determining the physical, chemical, and radiological properties of a waste prior to disposal.

There are five approaches:

1. **Acceptable or Process Knowledge.**
2. **Dose-to-Curie methods.**
3. **Non-destructive analysis.**
4. **Direct sampling and analysis.**
5. **Scaling factors.**

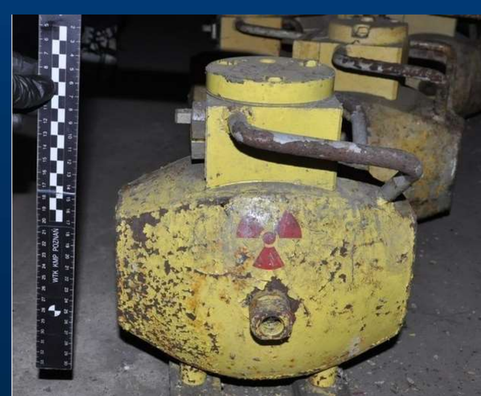
Acceptable Knowledge or Process Knowledge

The history of waste site or waste-generating process is known.

Example: wastes created from an controlled laboratory experiment in which the type and amount of radionuclides can be defined. Relatively inexpensive and little radiological exposure, but cannot be used for poorly-defined wastes streams.

Dose-to-Curie methods

Measure the dose rate (activity), then use conversion software to characterize the sample. Example: a sealed source that lacks the initial manufacturing data (activity, age), is missing, but the type of radionuclide is known.



Dose-to-Curie methods

Relatively inexpensive approach with minimal radiological exposure.
Such methods assume that the waste material is homogenous.

May be best applied in conjunction with the other methods.

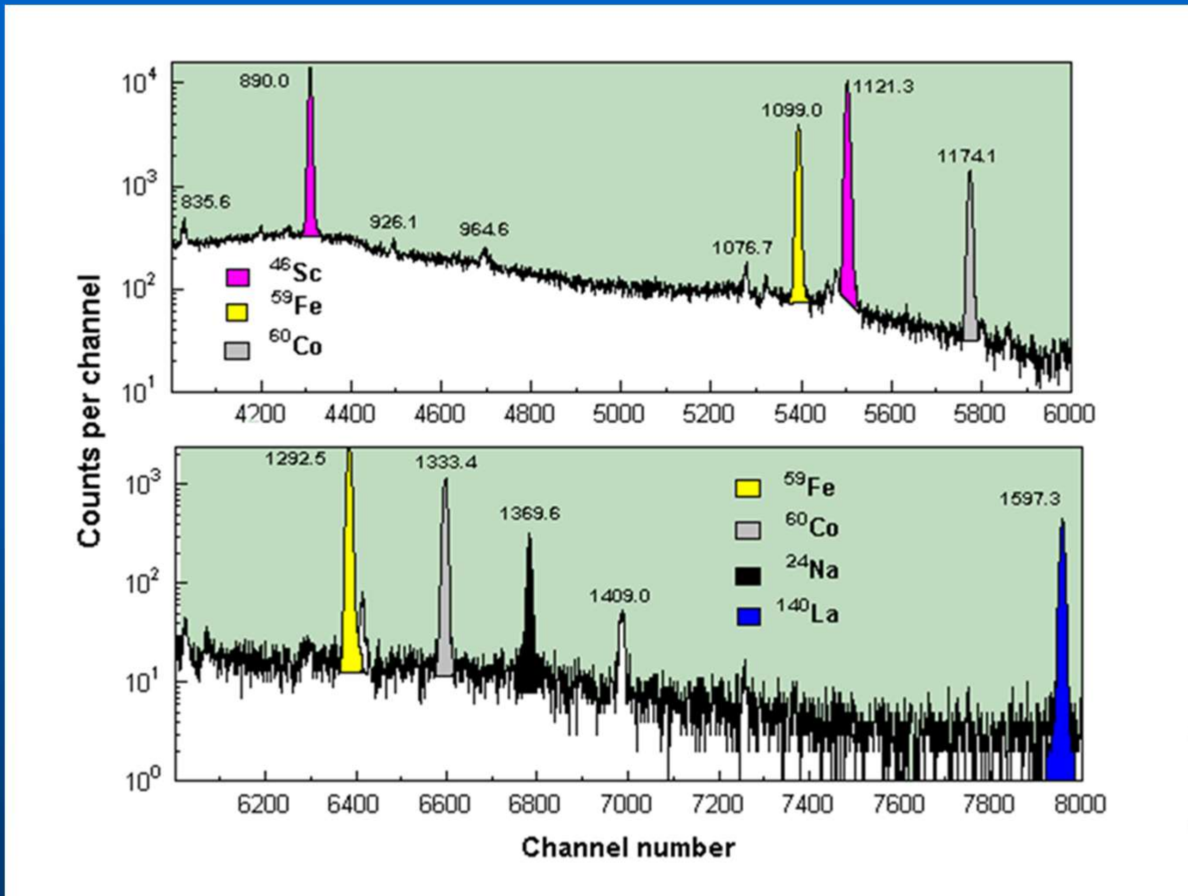
Non-Destructive Analysis

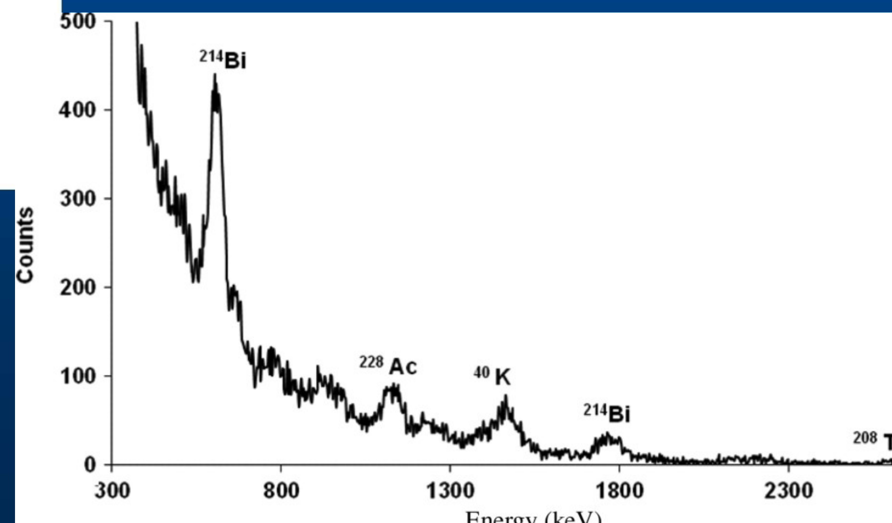
The waste container is opened and a sample is collected, but not altered by the analysis such as being dissolved in an acid. A common method is gamma-ray spectroscopy. Many radioactive sources produce gamma rays of various energies and intensities.

Non-Destructive Analysis

When these emissions are collected and analyzed with a gamma-ray spectroscopic system, a gamma-ray energy spectrum can be produced. A detailed analysis of this spectrum is typically used to determine the identity and quantity of gamma emitters present in the source.

Non-Destructive Analysis



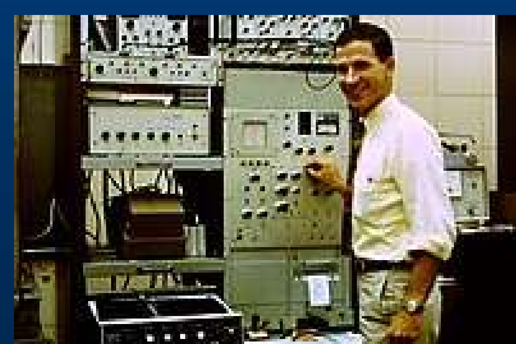


Non-Destructive Analysis

Example of application: a sealed source with no information, including the type of radionuclide. It will yield no information about low-level beta and alpha sources. Most applicable to wastes streams that contain only radiological constituents; will yield no information about hazardous constituents.

Direct Sampling and Analysis

Physical samples are collected from the waste stream, and analyzed in a certified laboratory. The samples may be dried, ground, dissolved, or extracted, and be analyzed by gamma and beta counters, scintillation counters, ICP-MS, neutron activation, GC, and other instruments.



Direct Sampling and Analysis

This approach yields the most defensible analytical data possible. However, it is the most expensive approach for waste characterization. It also has the potential for the greatest exposure to the analysts. Also, it is not practical to analyze each and every sample. Often, about 10% of the samples submitted are analyzed depending on the level of definition needed.

Scaling Factors

A technique that uses ratios or statistical regressions to estimate the activity or concentration of difficult-to-measure radionuclides based on the activities (concentrations) of measured easy-to-measure radionuclides.

Scaling Factors

Easy-To-Measure (ETM) means a gamma-emitting radionuclide whose activity can be readily measured directly by non-destructive analysis.

Difficult-To-Measure (DTM) is a radionuclide whose activity is difficult to measure directly from outside the waste package by non-destructive analysis. Example: alpha-emitting radionuclides.

Scaling Factors

Limitations:

Based on data from sampling and analysis of a batch samples collected from the type of waste stream.

Examples: reactor-coolant filters.

Dry Active Waste (solid wastes from the same nuclear facility such as protective clothing, air filters, replacement equipment).

Scaling Factors

Limitations:

Most applicable when estimating DTMs radionuclides from ETM radionuclides that are produced by the same process and in the same materials.

Processes: fission, activation, transuranic, and activated coolant (^{3}H and ^{14}C).

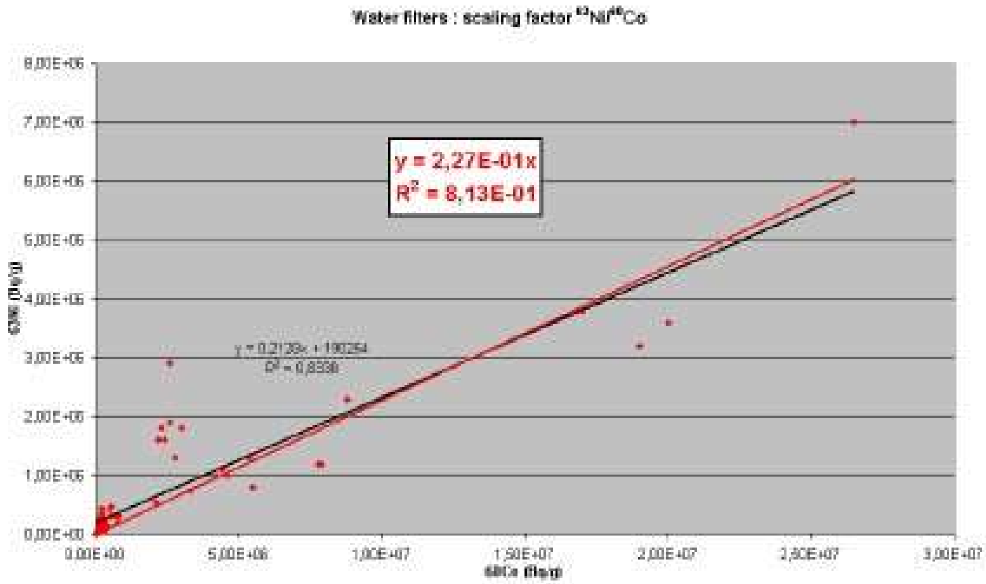


FIG. A–6. Example linear regression analysis.

$^{63}Ni/^{60}Co$ (beta/gamma)

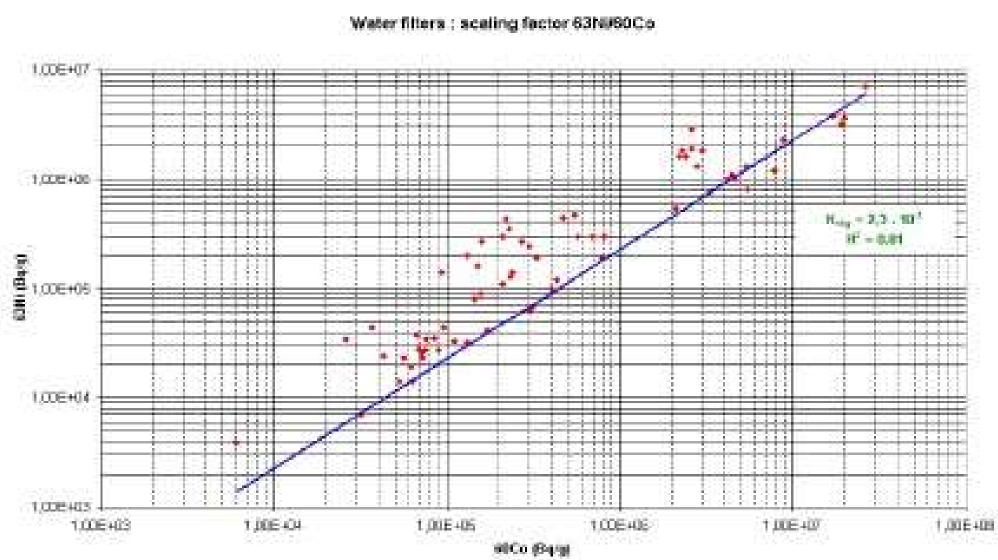


FIG. A–7. Example of SF correlation on log–log plot.

Early Disposal of Radioactive Wastes

Late 1940s to 1970

The Atomic Energy Commission placed both commercial and Federal radioactive wastes in 55-gallon steel drums, added cement or concrete and dumped them into the ocean at a depth > 6,000 feet (> 1,830 m).

There were about 21 disposal areas between the Pacific and Atlantic Oceans, and the Gulf.

Between 1951 to 1967, 79,483 Ci (2,971 TBq) were sunk.

Early Disposal of Radioactive Wastes

Cardboard boxes and open drums in unlined ditches at the Hanford Nuclear Reservation in c. 1950.

Early Disposal of Radioactive Wastes

By 1970, ocean disposal was phased out because of adverse public reaction.

1972. The U.S. signed the London Convention which banned ocean disposal of radioactive wastes.

The AEC endorsed the concept of shallow land disposal for commercial radioactive wastes. Land disposal had been used since the 1950s.

Desirable characteristics for shallow land burial

True for municipal wastes, coal ash, incinerator ash and hazardous solid wastes that contains potential groundwater contaminants:

1. Relatively water-impermeable soil to reduce the chance that radionuclides are leached and transported from the disposal area into groundwater.

Desirable characteristics for shallow-land burial

2. Disposal above water table; isolating the wastes from precipitation, groundwater, and surface water. <u>Humid climates require water management.</u>

3. Local geology is well known.

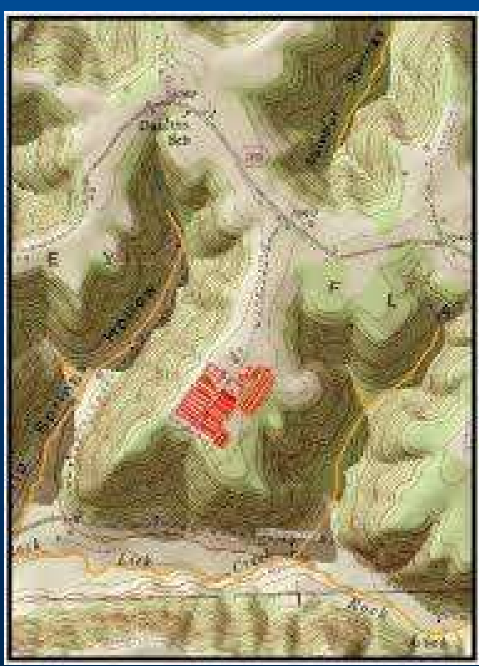
4. Stable area (no earthquakes, soil erosion, landslides)–flat.

Maxey Flats, Kentucky

In 1963, the Maxey Flats low-level radioactive wastes disposal site opened under a lease between the State of Kentucky and Nuclear Energy Company (now U.S. Ecology, Inc.).

The facility was located in a humid climate with annual precipitation of 46 inches (117 cm). Site geology: thin layers of shale, sandstone, siltstone.

Water table at 30 to 50 feet (9.1 to 15.2 m).

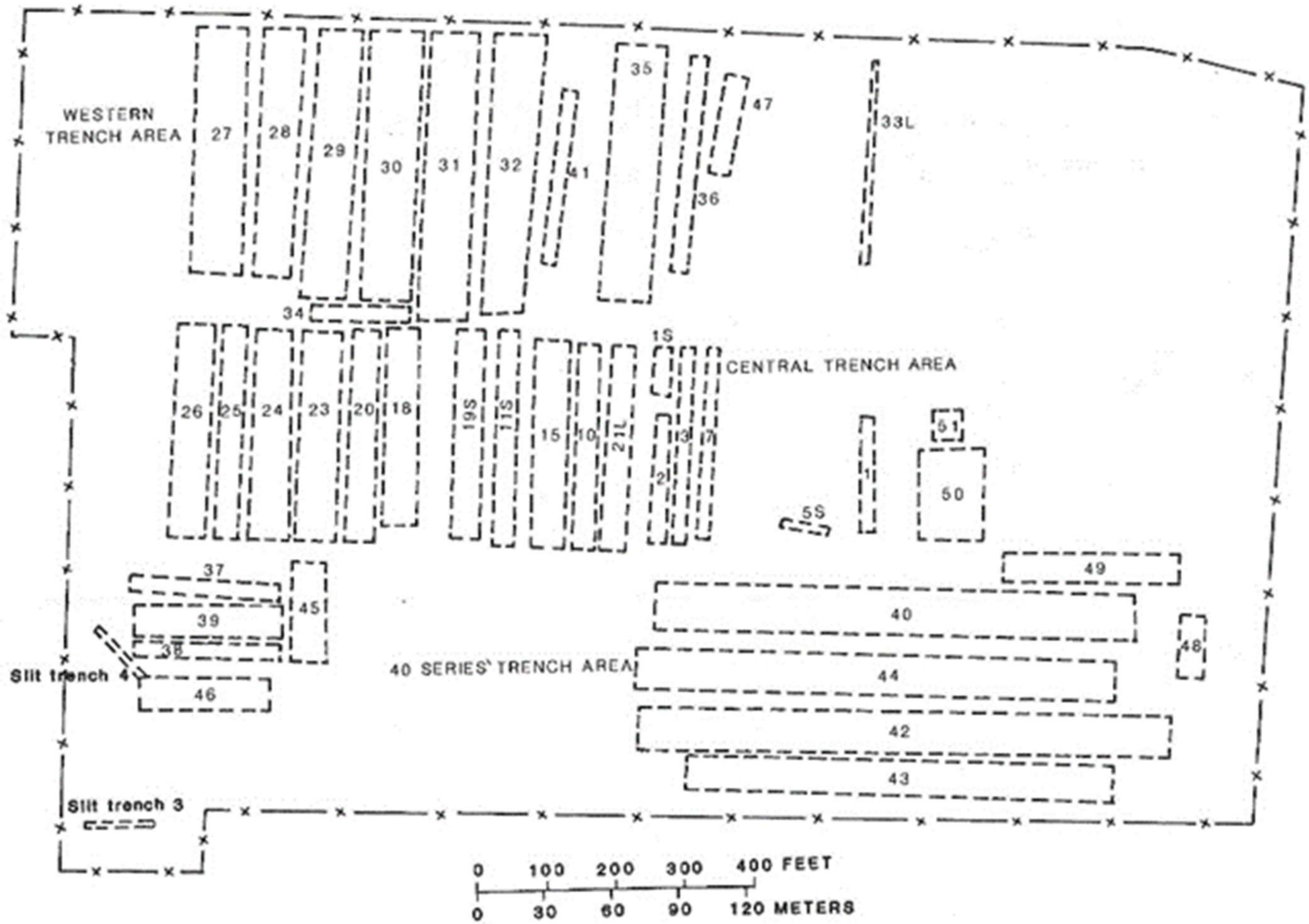



Maxey Flats
Disposal Site
Lexington
Kentucky

Maxey Flats

52 trenches; depths 9 to 30 feet (2.7 to 9.1 m). Smaller pits, 5 to 15 feet deep (1.5 to 4.6 m). Vertical disposal wells that were 15 feet (4.6 m) deep for "high-activity gamma sources."

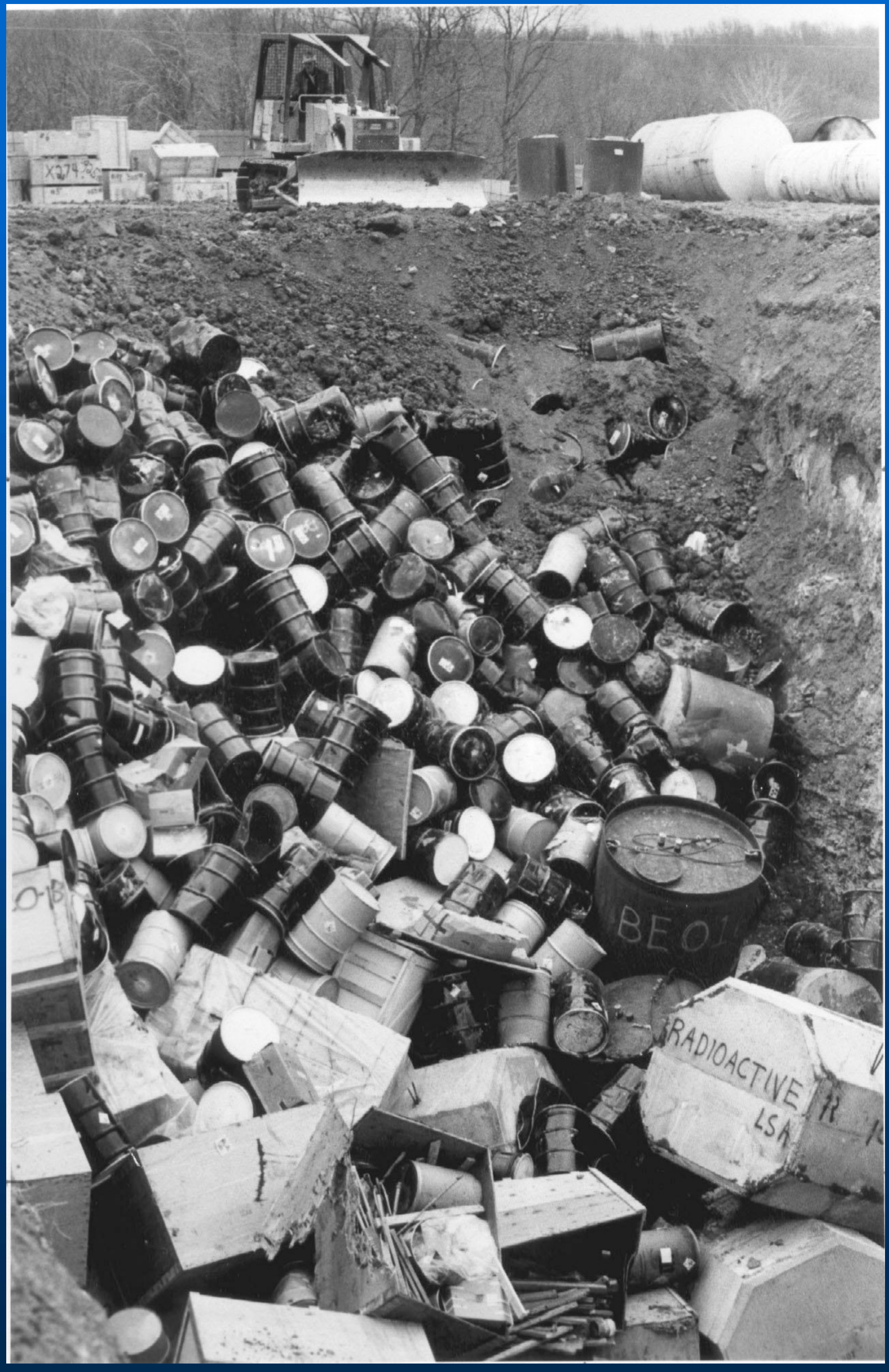
Between 1963 and 1977, 4.7 million ft^3 (133,000 m^3) of LLRW buried which was 2.4 million Ci (88,800 TBq) of activity. It became the largest commercial facility for LLRW in the U.S.


WESTERN TRENCH AREA
27
28
29
30
31
32
41
35
36
47
33L
34
1S
CENTRAL TRENCH AREA
26
25
24
23
20
18
19S
11S
15
10
21L
2
3
7
1
51
50
5S
49
37
45
39
38
40
48
Slit trench 4
46
40 SERIES TRENCH AREA
44
42
43
Slit trench 3
0 100 200 300 400 FEET
0 30 60 90 120 METERS

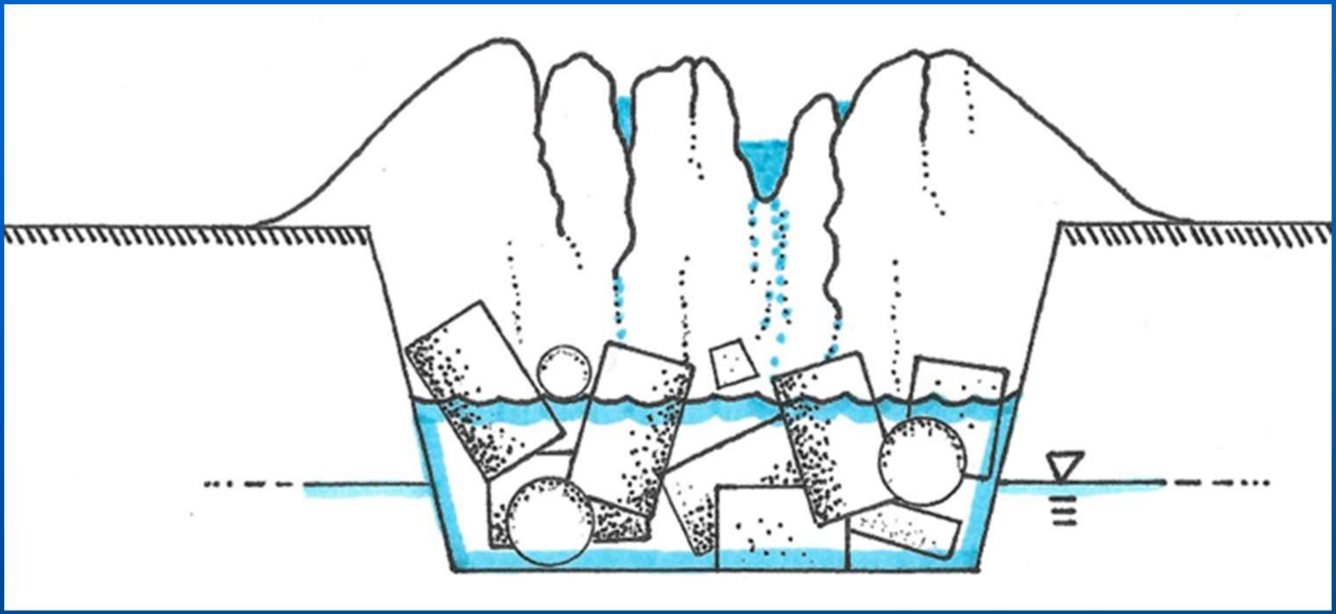
Operational problems at Maxey Flats

During the operation of the facility, workers covered each trench with a layer of soil after it was filled, but the soil covers eventually collapsed into the ditches as the backfill settled to fill the void spaces about the waste containers.

Because the trench covers failed, excessive precipitation accumulated in many of the trenches creating the "bathtub effect."


RADIOACTIVE
LSA

"Bathtub effect" at Maxey Flats



The waste containers were randomly placed in the disposal trench followed by settlement which compromises the trench cover, allowing precipitation to enter the trench. The zone of saturation is close to the surface providing groundwater to the trench. The trench fills with water/leachate and can overflow. The figure is not to scale.

Things get worse

In 1973, a water management program began to collect and pump leachate from the trenches into above-ground tanks; there were numerous spills.

In 1977, it was discovered that trench leachate was moving out of the old trenches and into the latest newly-dug trench.

The Commonwealth of Kentucky ordered the site closed.

And worse

In 1981, tritium was detected in surface water, groundwater, and in vegetation in the west side of the facility. In 1986, Maxey Flats was declared as a Superfund Site by the U.S. EPA.

Superfund sites are severely contaminated locations in the U.S. requiring a long-term response to clean up hazardous material contamination.

And worse

These sites were designated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980.

The EPA notified 832 Potential Responsible Parties for possible payment for site remediation **which included the University of Illinois!**

Covered and monitored

During site remediation, trench leachate was collected and pumped into tanks.

The LLRW were <u>not</u> exhumed.

A 45-mil geomembrane cover was placed over the trench area to prevent infiltration of more water into the trenches. Local soil was then layered across the surface.

The site will have to be monitored and maintained in perpetuity.

Geomembrane (left). Soil cover (right)

Environmental monitoring

Richland, Washington

The U.S. Ecology Richland Washington Facility for LLRW opened in 1965 as a commercial business. It is still open! Unique in that it is located on Federal land within the 560-mile^2 (1,450 km^2) U.S. DOE Hanford Site (more about Hanford later).

Richland, Washington

Located on a semi-arid river plain. Average annual precipitation is about 6.3 inches (16 cm). Site geology: 200 feet (61m) of a mixture of sand, silt, and gravel.

Water table at about 245 feet (75 m).

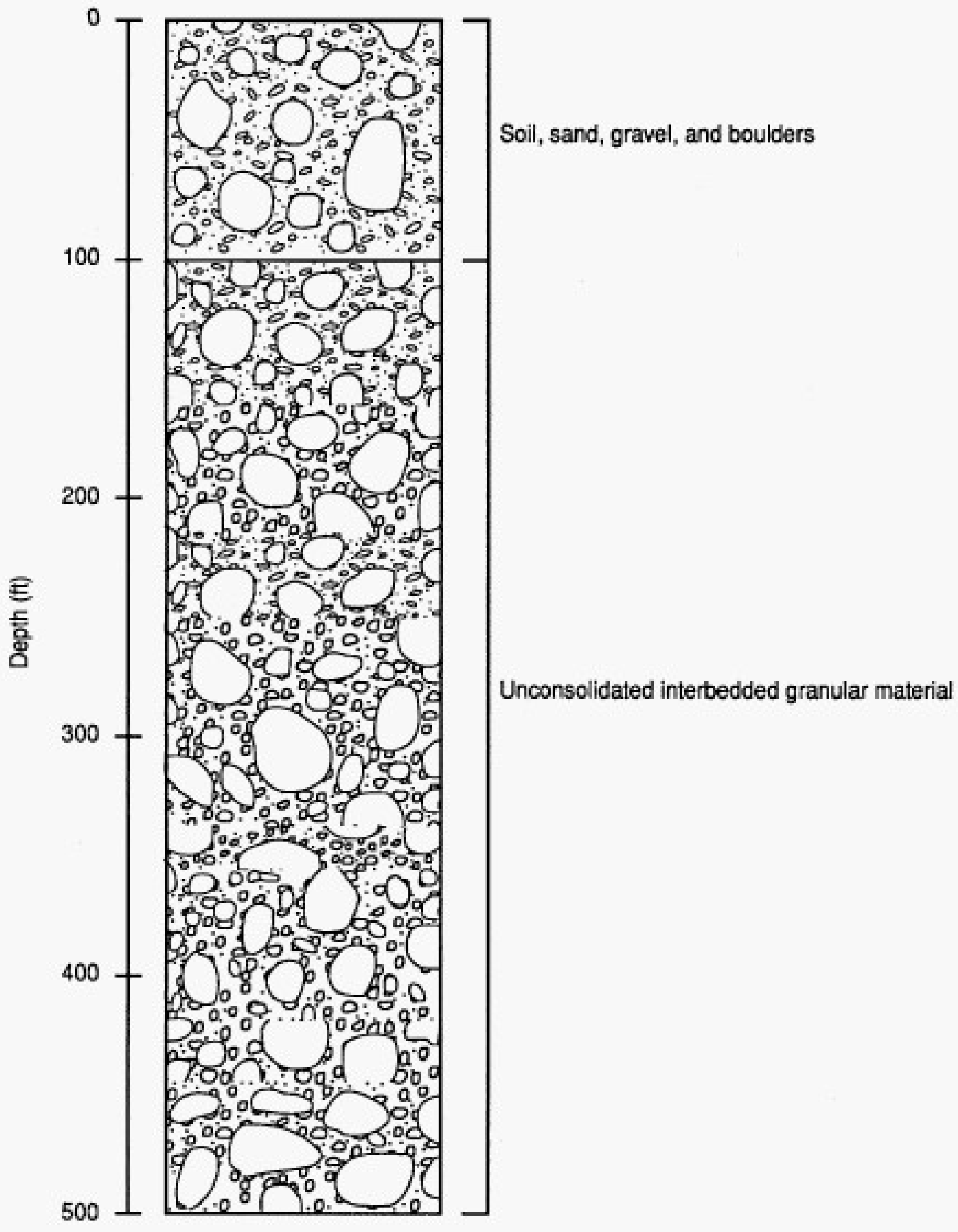
Richland

The site consists of 18 disposal trenches, 300 to 1,000 feet (91.4 to 304.8 m) long, 20 to 45 feet (6.1 to 13.7 m) deep.

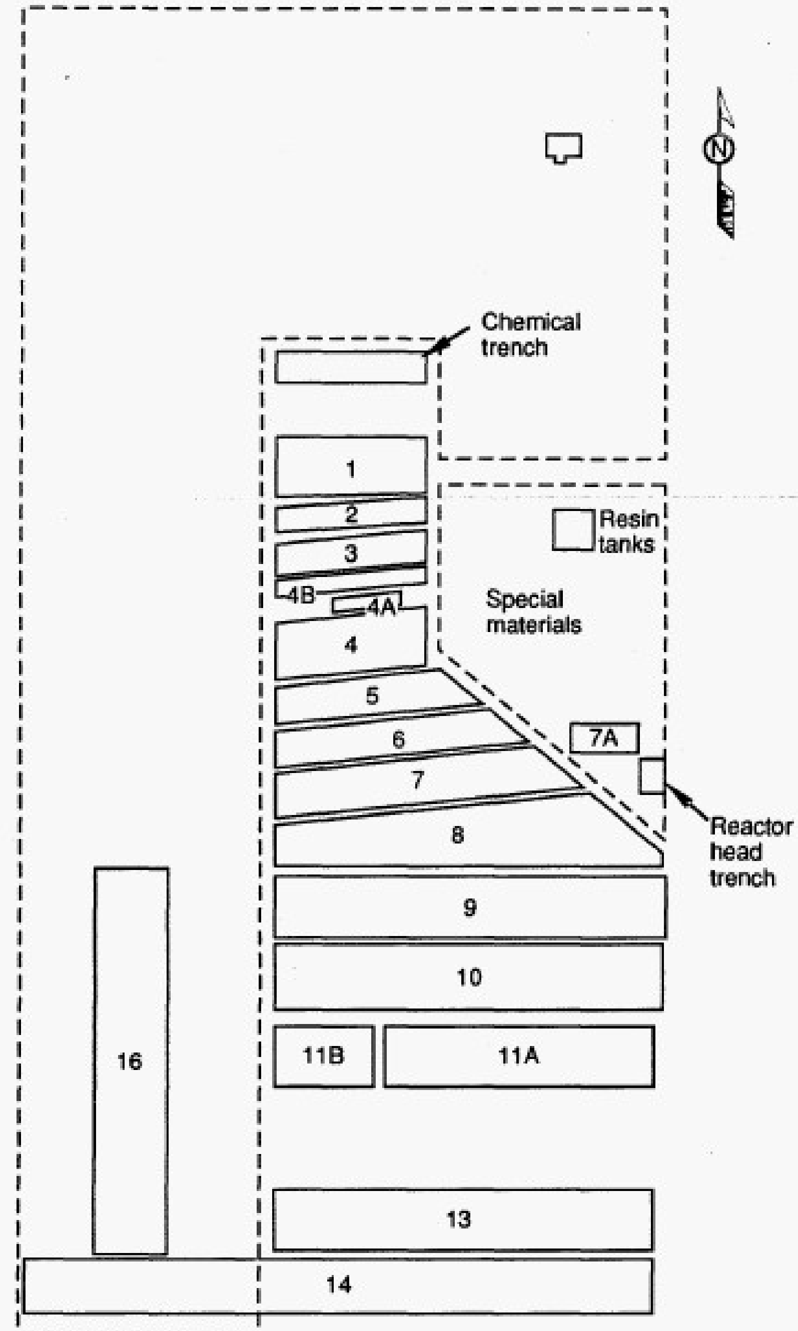
Four, 30-foot (9.1 m) deep caissons (wells).

Three underground steel tanks (1,000 to 20,000 gallon [3,800 to 76,000 L] capacity).

Because of its proximity to Hanford, it is difficult to assess environmental impacts by LLRW at Richland.



R94 0613



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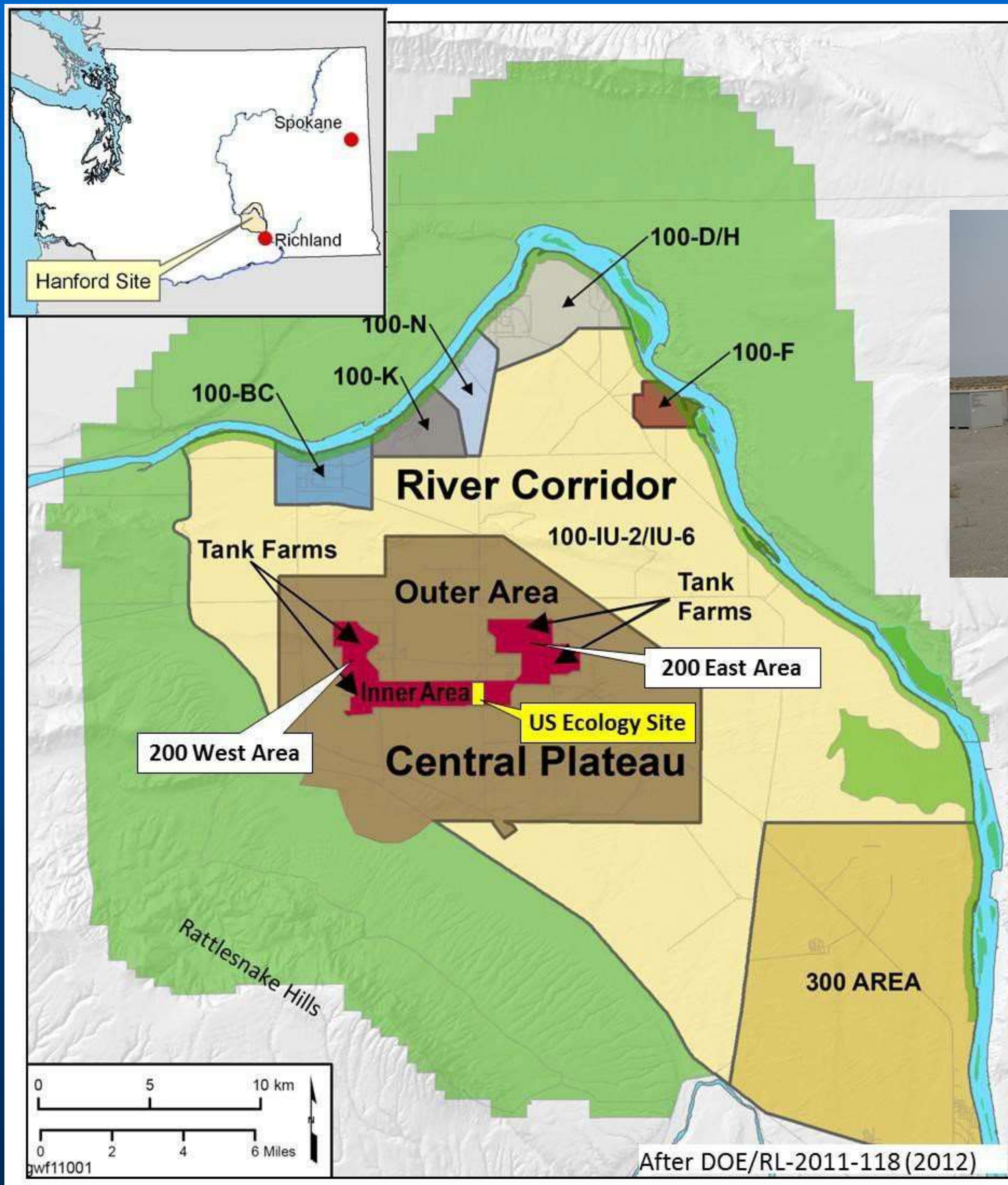

Spokane
Richland
Hanford Site
100-D/H
100-N
100-F
100-K
100-BC
River Corridor
100-IU-2/IU-6
Tank Farms
Outer Area
Tank
Farms
200 East Area
Inner Area
US Ecology Site
200 West Area
Central Plateau
Rattlesnake Hills
300 AREA
0
5
10 km
0
2
4
6 Miles
gwf11001
After DOE/RL-2011-118 (2012)

Richland

Richland currently accepts Class A, B, and C LLRW from 11 Compact (Northwest and Rocky Mountain) states: Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Washington, Colorado, Nevada, and New Mexico.

It also accepts NORM, NARM, high-activity Ra wastes, smoke detectors, and Exempt Wastes from all 50 States.

https://www.usecology.com/location/us-ecology-washington

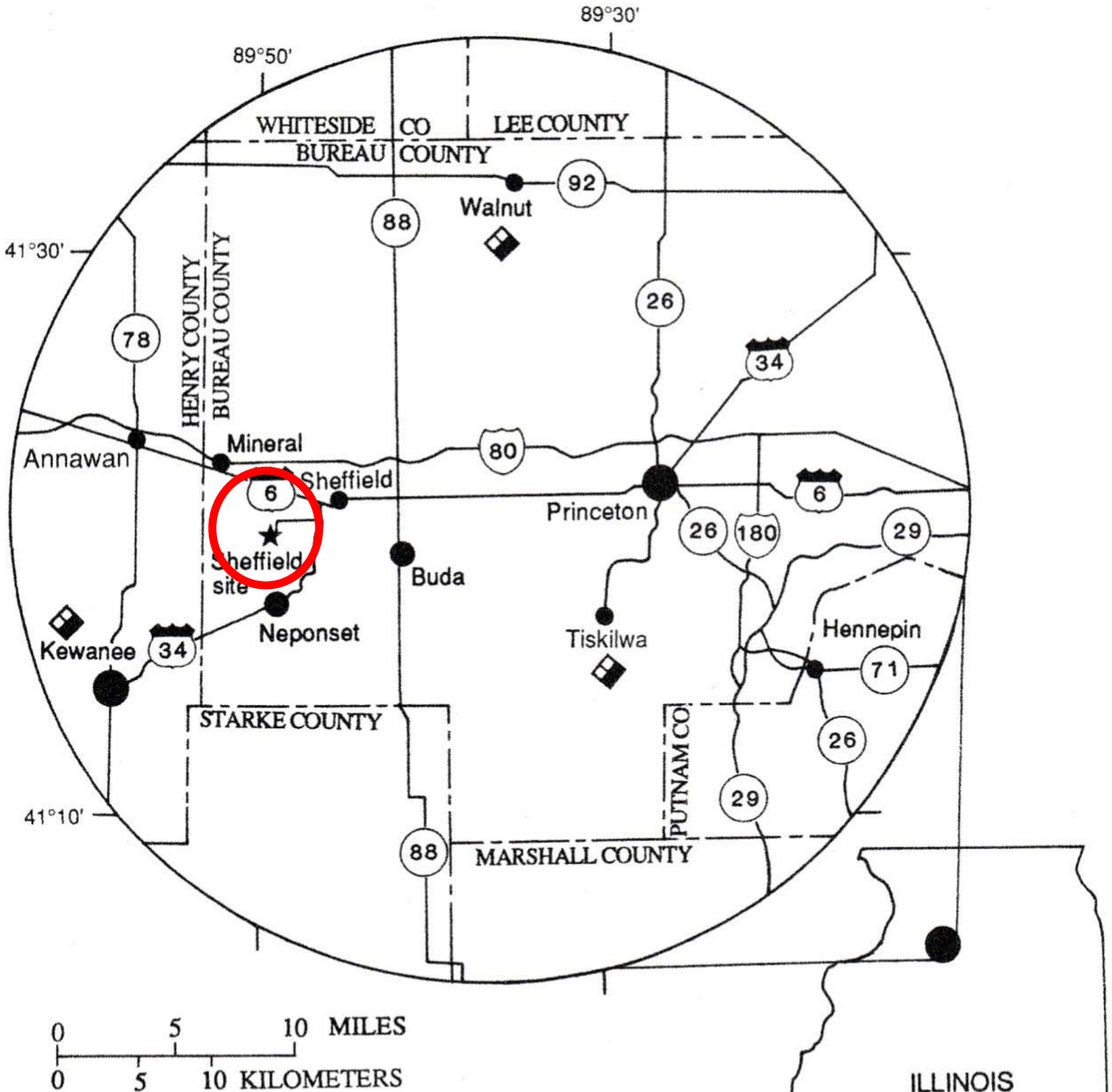
Sheffield, Illinois

The Sheffield Low-Level Radioactive Waste Disposal Facility opened in 1968 and was first operated by California Nuclear, Inc.

Site geology: sand over lake silt over sand to a depth of 200 feet (61.0 m). Bedrock: shale.

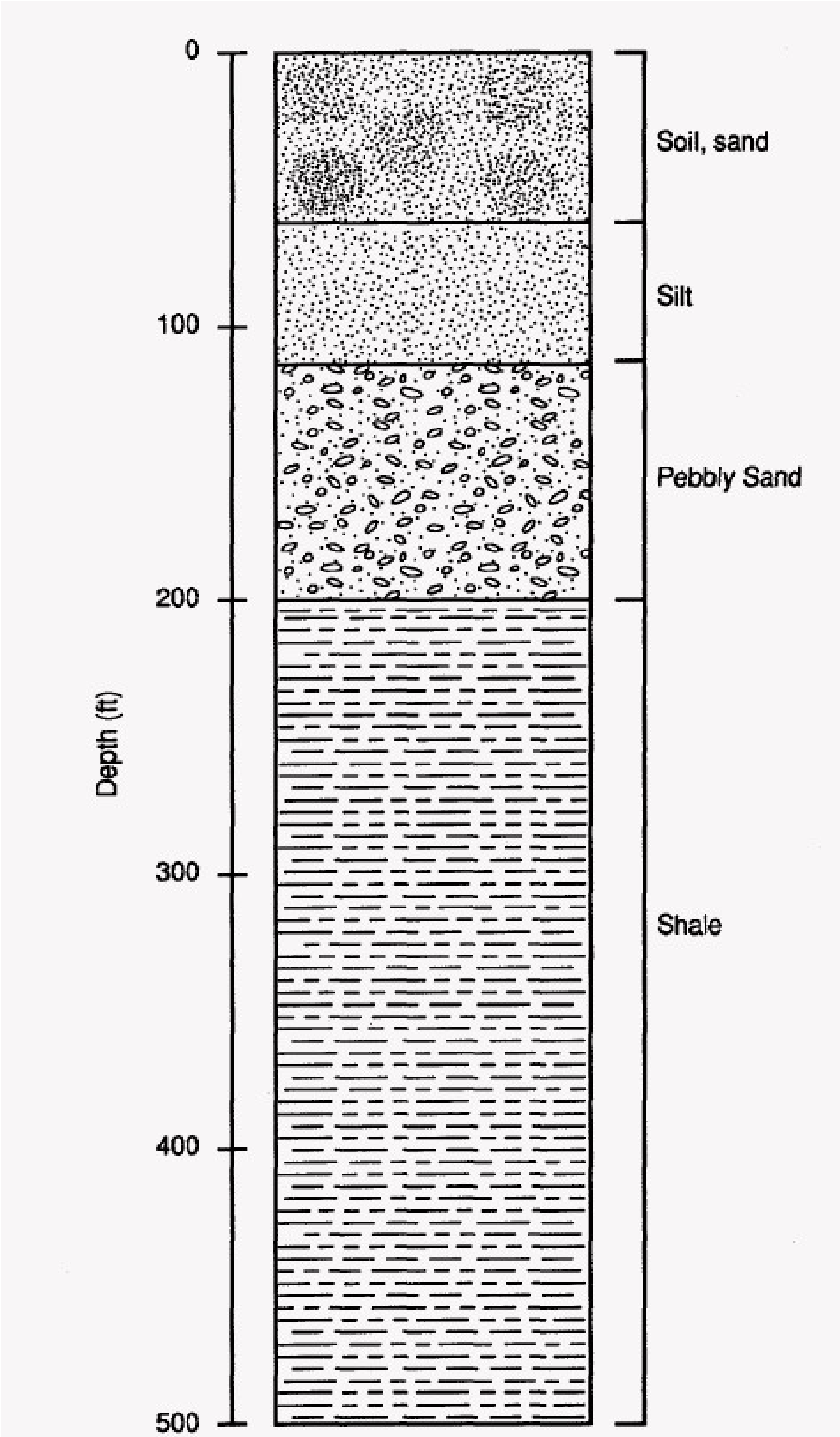
Climate: humid with mean annual precipitation of 35 inches (88.9 cm).

Depth to saturated zone: 25 feet (7.6 m).

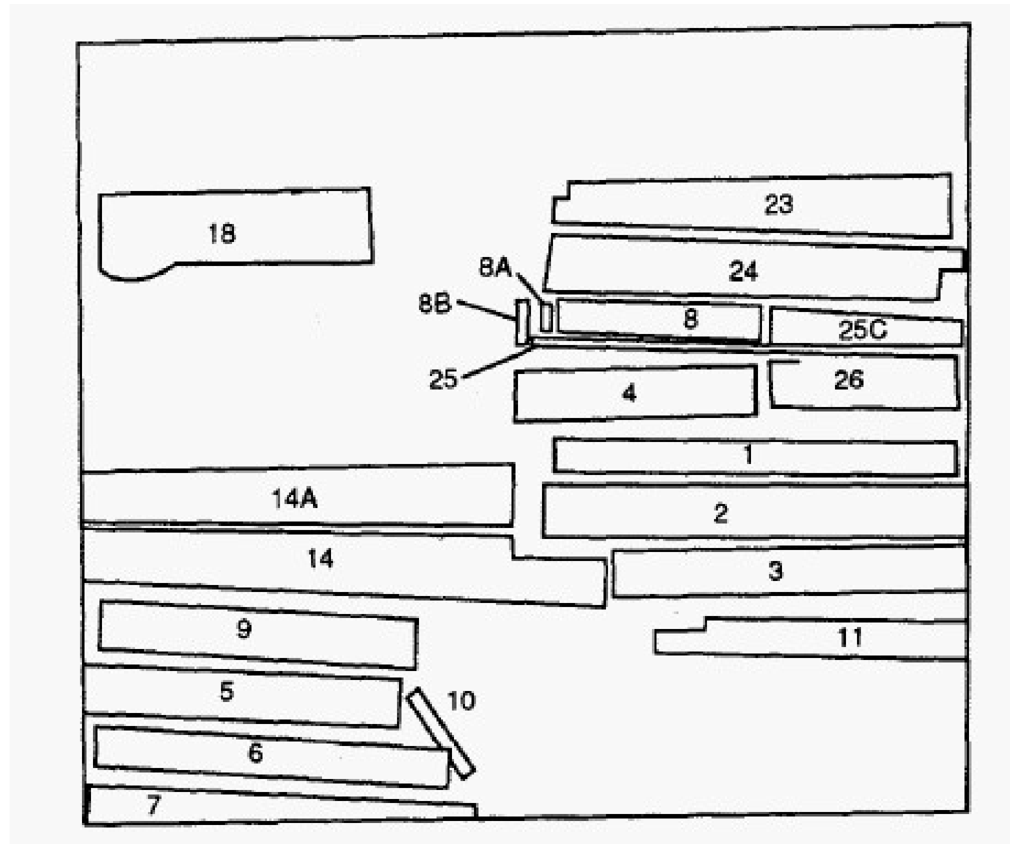


EXPLANATION

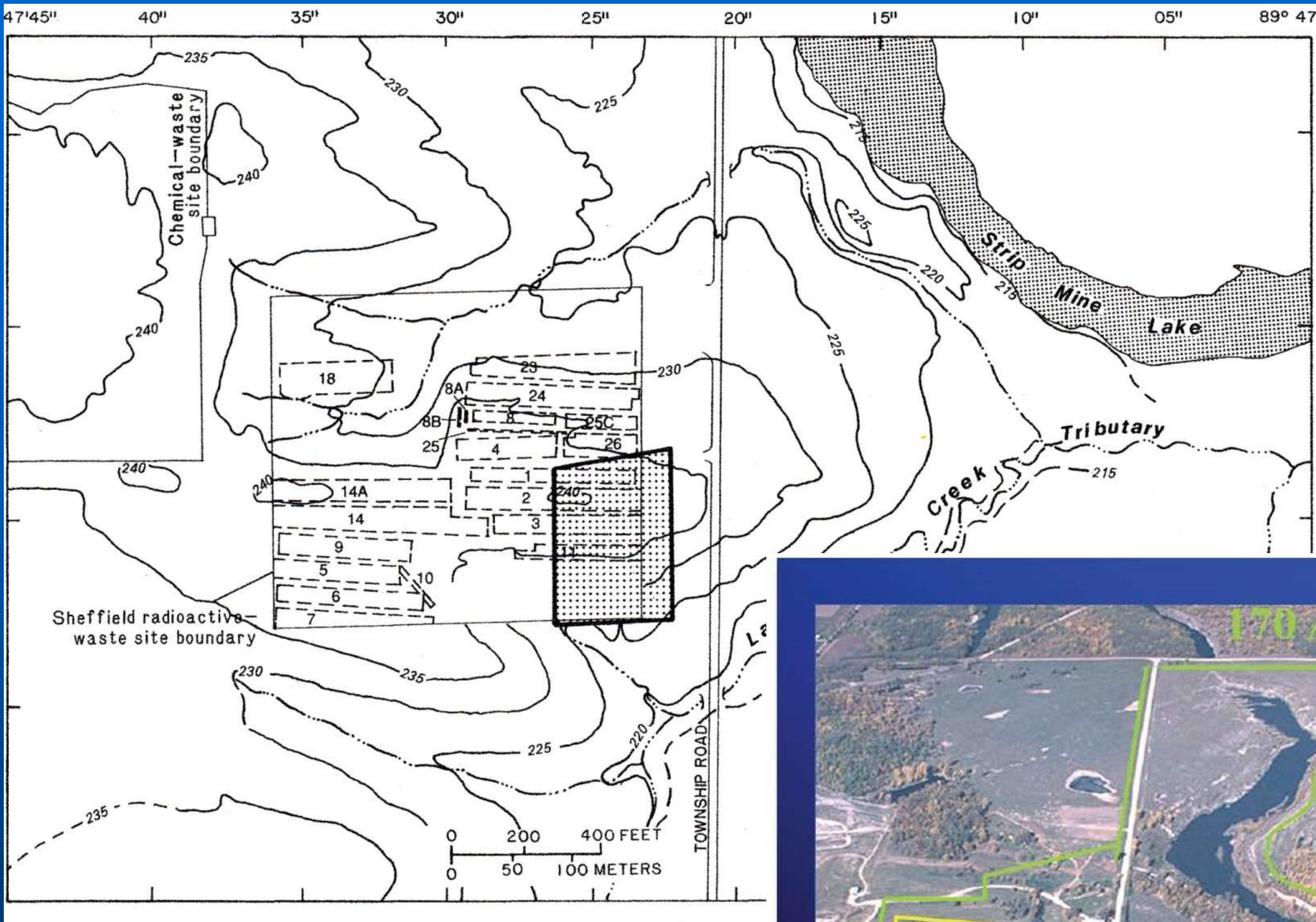
NATIONAL WEATHER SERVICE STATION



0
100
200
300
400
500
Depth (ft)
Soil, sand
Silt
Pebbly Sand
Shale



18
23
24
8A
8B
8
25C
25
4
26
1
14A
2
14
3
9
11
5
10
6
7



ocation of the study area (modified from Garklavs and Healy, 1986, fig. 3).

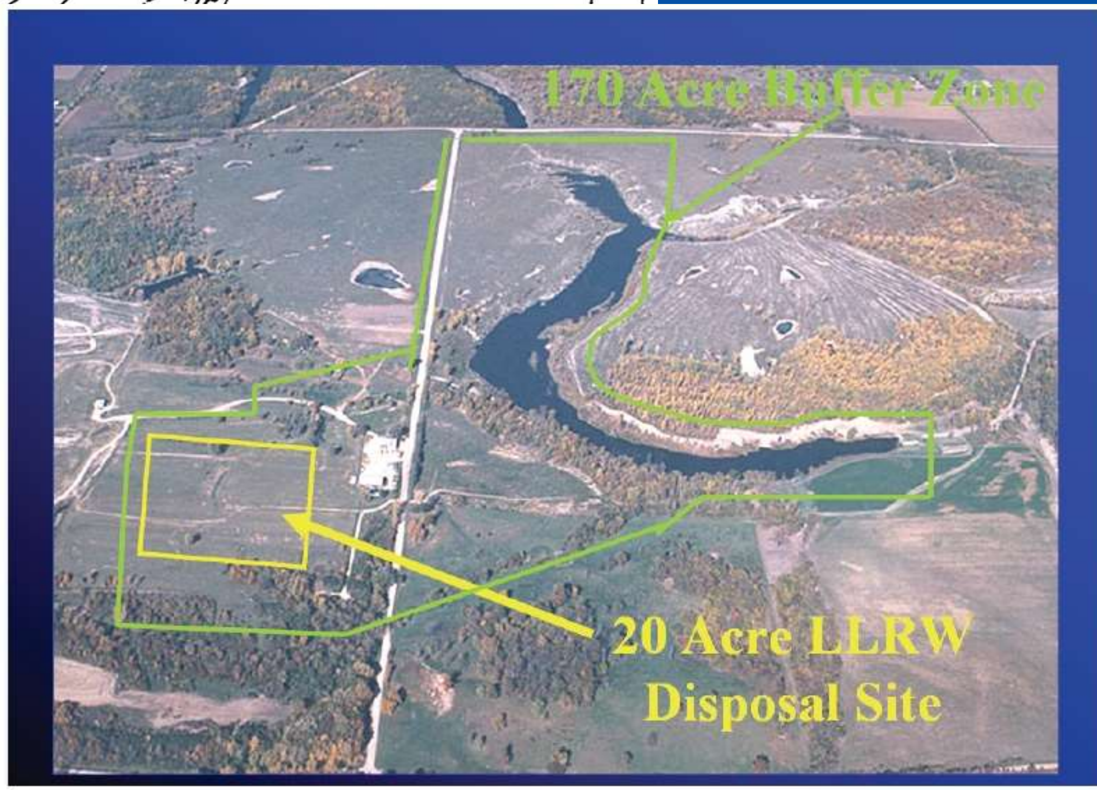


Photo 1 - Aerial view of the Sheffield LLRW Disposal Facility with feature overlays (IEMA, 1999)

Sheffield

The site consists of 20 acres (8.1 ha) of 21 unlined trenches 20 to 25 feet (6.1 to 7.6 m) deep. During its operation, about 3.2 million ft^3 (90,600 m^3) of LLRW were buried which was about 60,000 Ci (2,220 TBq) of activity. Also 126 pounds (57.2 kg) of Special Nuclear Material.

Table 1 – Maximum Values Estimated in the Sheffield Inventory

Important Radionuclides with half-lives greater than five years, as estimated by three studies		
Radionuclide	**Curies**	**Half-life (Years)**
H-3 (Tritium)	5,990	12.35
C-14 (Carbon)	450	5,730
I-129 (Iodine)	0.01	15,700,000
Sr-90 (Strontium)	3,690	29.12
Cs-137 (Cesium)	15,500	30
Co-60 (Cobalt)	20,000	5.27
Pu-238 (Plutonium)	7.5	87.74
Pu-239, Pu-240, Pu-241	4,870	24,065; 6,550; 14.4
Am-241 (Americium)	137.5	43.2

(IEMA, 2009)

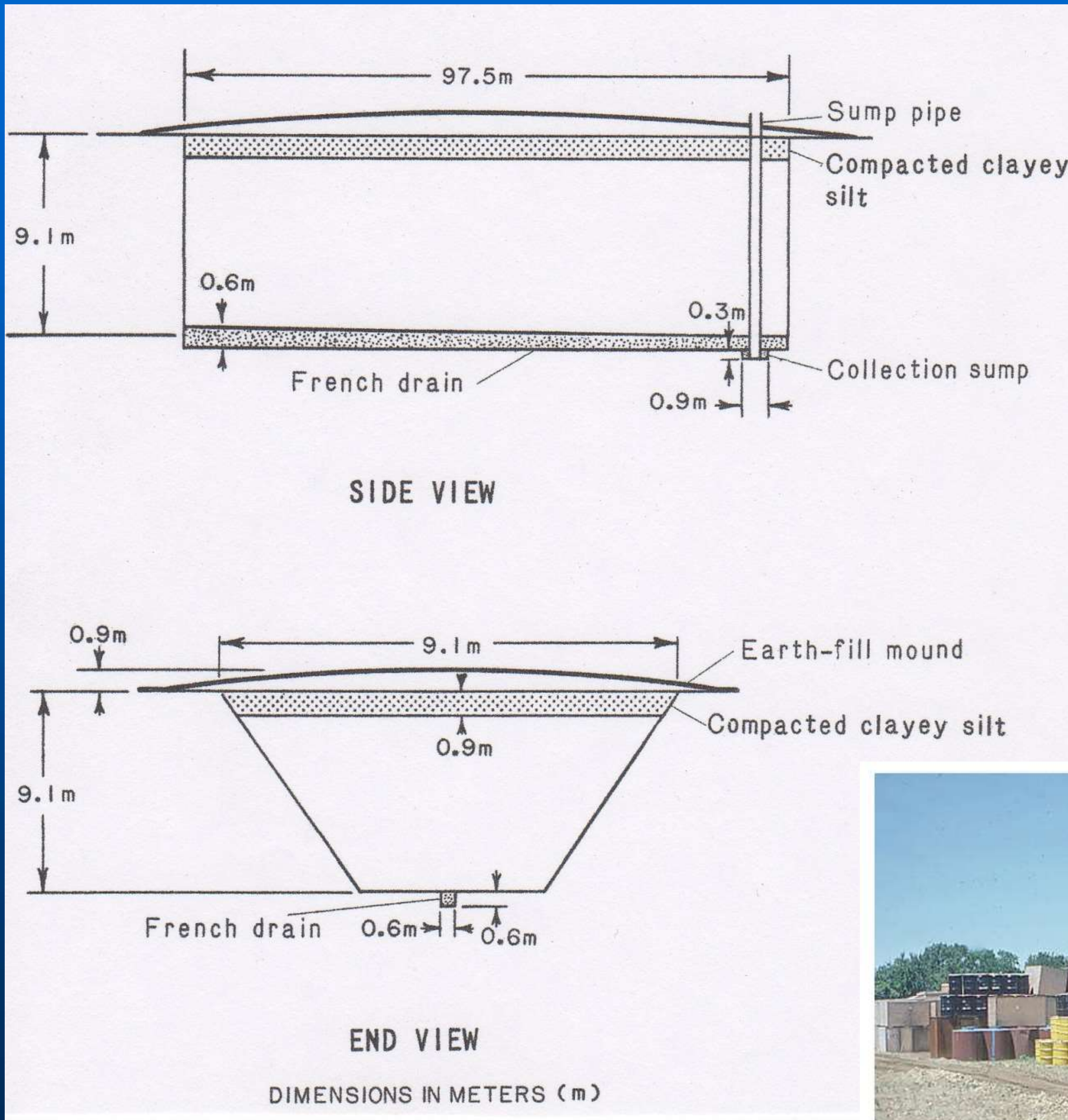


Photo 2 - Low-level radioactive waste awaits disposal at the Sheffield site (IEMA, 1970s)

Burial of nuclear waste at the Sheffield Waste Site.

Trouble at Sheffield

The growth of nuclear power in the early 70s increased the demand for LLRW disposal space. 1970—9,000 ft^3 (255 m^3).

1977---57,000 ft^3 (1,614 m^3).

California Nuclear, Inc. went to Nuclear Engineering Company (now U.S. Ecology)

In the mid 70s, NECO sought to amend their permit to build new trenches.

However, in 1977 tritium was detected in on-site monitoring wells.

Trouble at Sheffield

Tritium was migrating from Trench 11 and at rate faster than that predicted based on previous (low budget?) site characterization.

Additional soil cores drilled by the USGS revealed that there were water-permeable sand layers that were more extensive across the area than indicated in the study.

Sand layer in glacial till

Trouble at Sheffield

The sand layers allowed trench leachate to spread more than initially predicted.

The trench covers collapsed as the wastes packages settled.

The openings allowed precipitation to enter the trenches. More leachate, more movement of tritium.



Things get worse

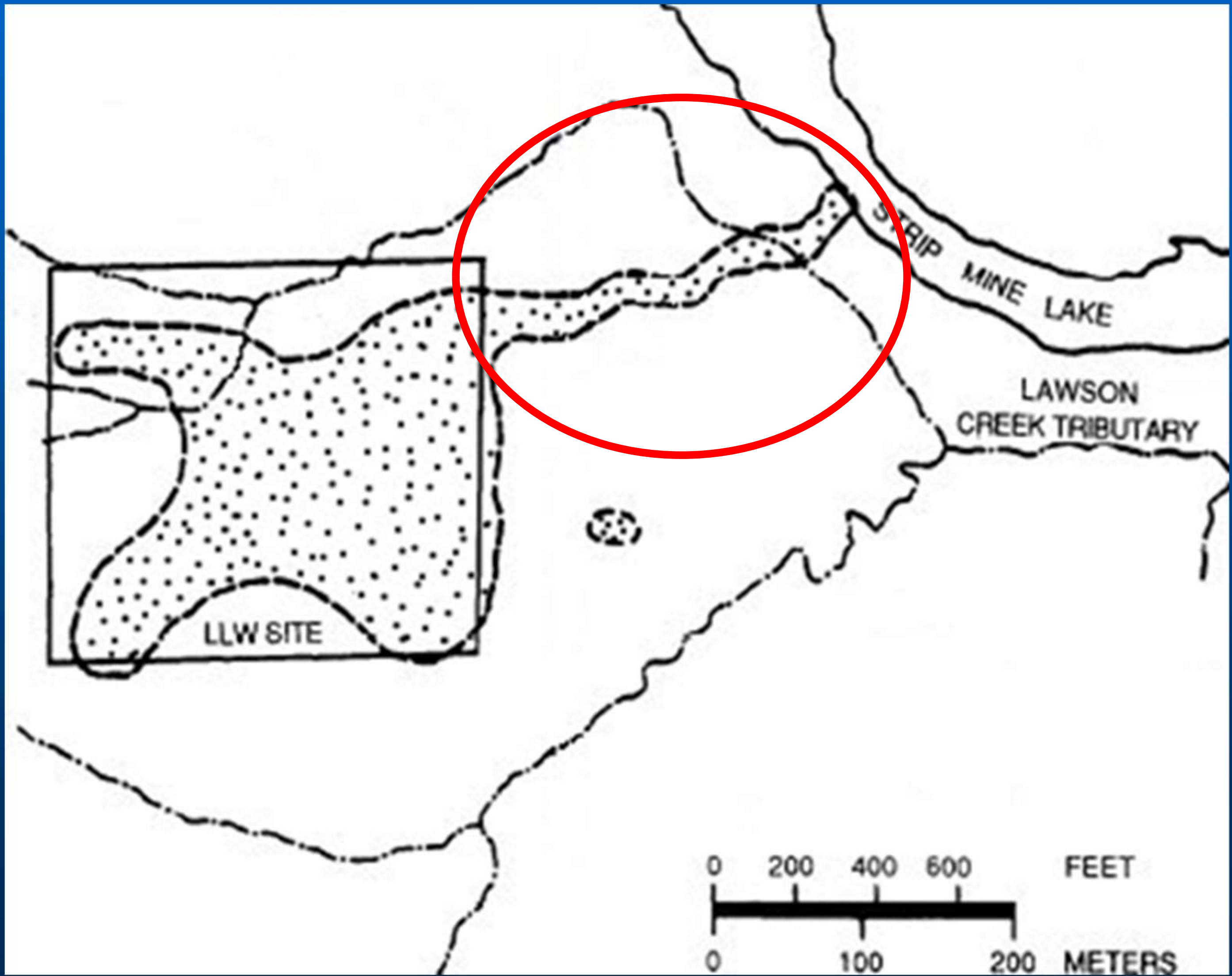
On-site wells contained as much as 1,300,000 pCi/L tritium (1.3 μCi/L) (48.1 kBq/L).

In 1978, the NRC ruled that Trench 15 could not be used for waste disposal. Sheffield was, by default, "full."

1981. Tritium detected in monitoring wells off-site.

1982. Tritium migrating off-site to nearby lake.

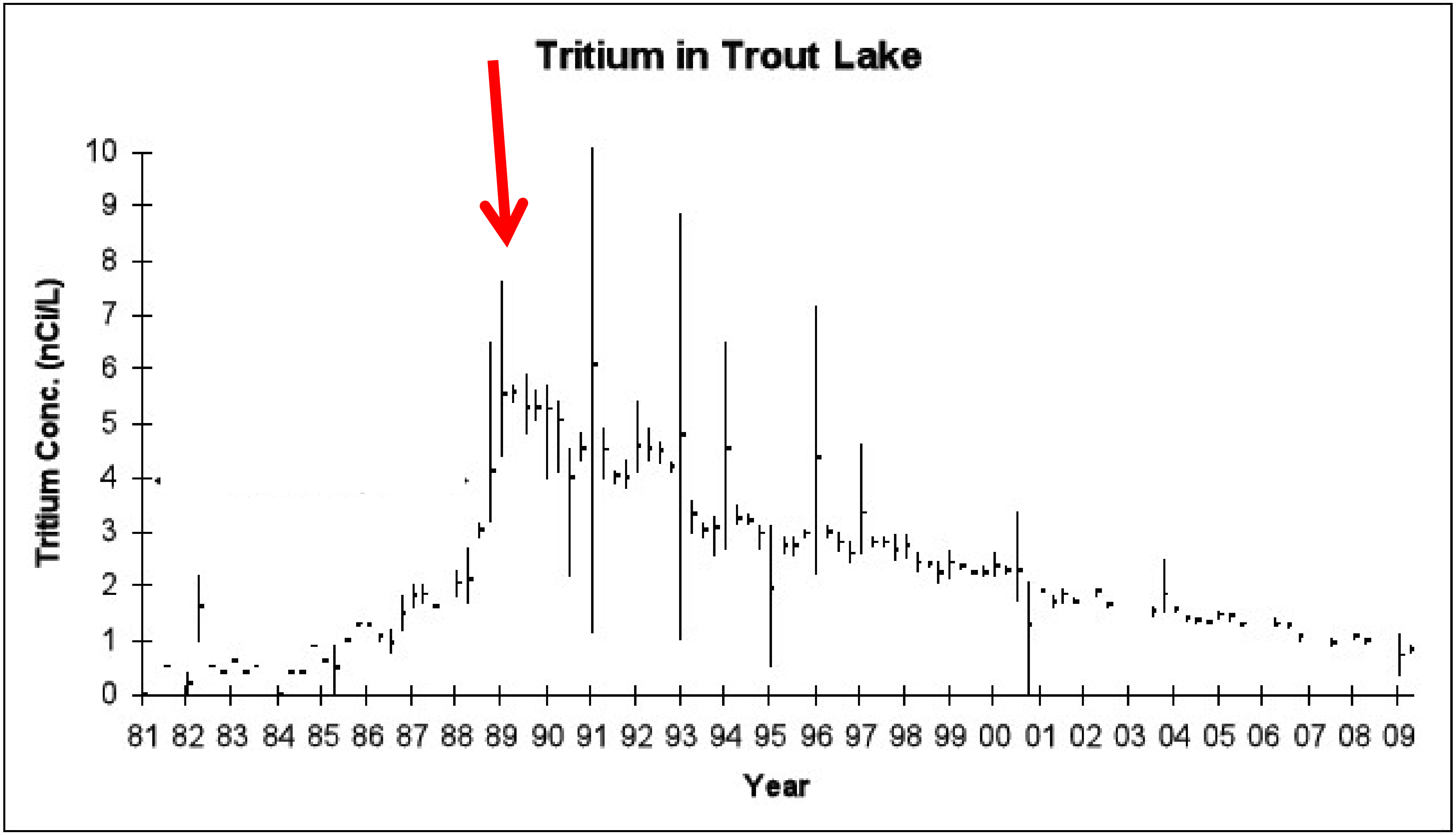
Tritium moved off-site



Remediation of Sheffield

1987 to 1989. A new clay cover was placed over the trenches (the LLRW were not removed).

Illinois Emergency Management Agency (IEMA) monitors gamma exposure, surface water, off-site public and private wells, and groundwater wells.



Graph 3 – Tritium in Trout Lake water samples (IEMA, 2009).

"The . . . movement of tritium in itself does not constitute a threat to the people or mean that the site has failed."

Barnwell, South Carolina

The Barnwell Waste Management Facility opened in 1971, and is operated by Chem-Nuclear Systems, Inc. Still open!
Site geology: layers of sand and gravel to a depth of 500+ feet (152+ m).
Humid climate: mean annual precipitation of 47 inches (119 cm). Water table between 30 and 60 feet (9.1 to 18.3 m).
Occupies 235 acres (95.1 ha).

Barnwell

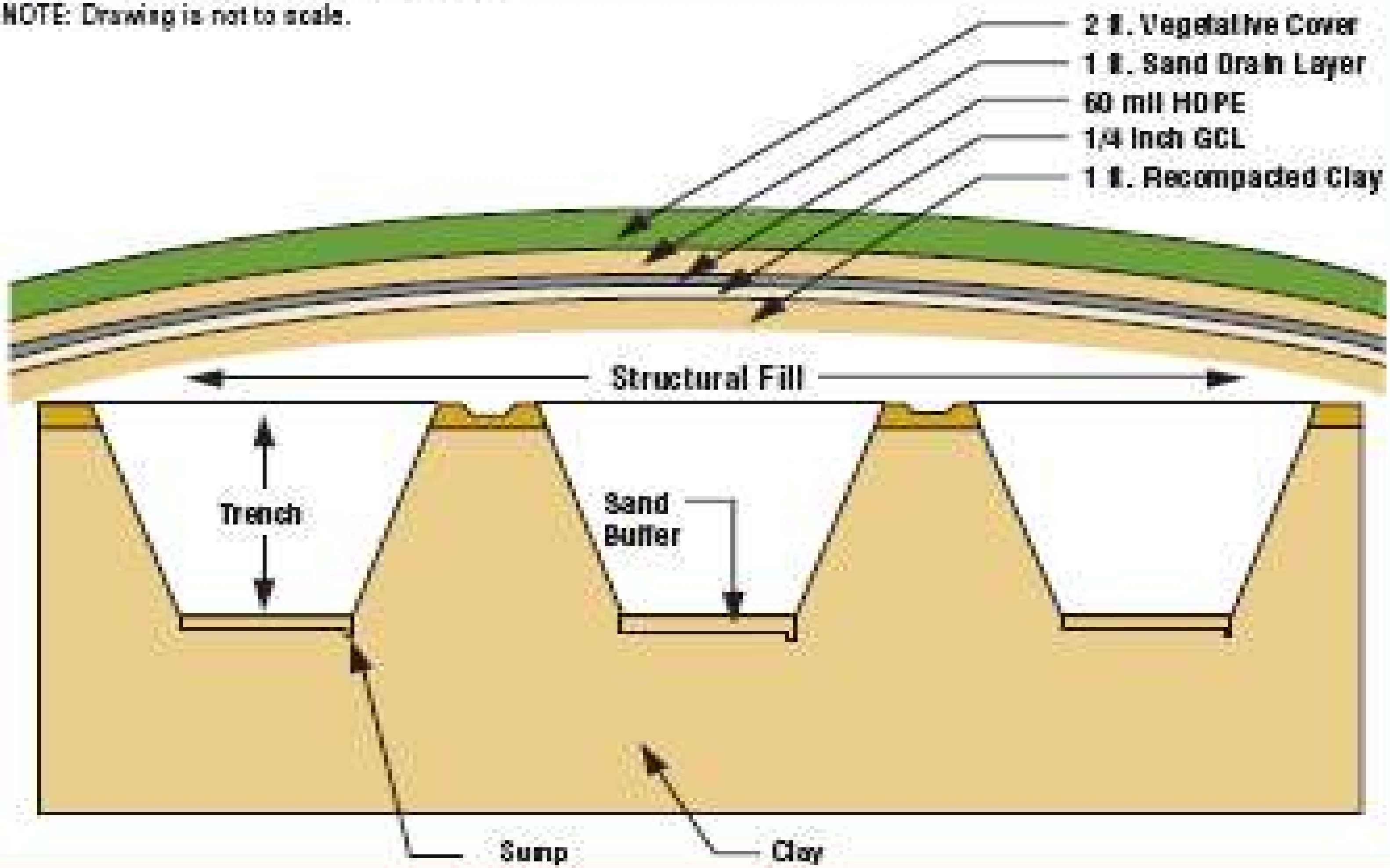
Barnwell can accept Class A, B, and C wastes for shallow land burial, *but* only from the Atlantic Compact (Connecticut, New Jersey, and South Carolina).

Prior to 2008, Barnwell could accept all waste classes from non-Compact States. Access was terminated by S.C. State Government which impacted 36 states including Illinois.

Barnwell, South Carolina

Barnwell, trench and cover design

FIGURE 7
Enhanced Cover Construction Details
NOTE: Drawing is not to scale.



Waste containers

Cylindrical B/C Trench disposal vaults in an active trench. Vaults are immediately backfilled to fill void spaces and reduce radiation exposure.

High Integrity Container of Class A LLRW
a cylindrical disposal vault.

Low activity commercial reactor steam generators placed among disposal vaults for burial.

Clive, Utah

The Energy*Solutions* Clive Facility is the largest (600 acre) [242 ha] commercial disposal site in the U.S.

Located in Utah's west desert.

Climate: arid, annual precipitation of 8 inches (20.3 cm) per year.

Site geology: layers of silt, gravel, and sand (Pleistocene Lake Bonneville).

Located in the West Desert Hazardous Industry Area.

Clive

The facility has two hazardous wastes incinerators, and a hazardous waste landfill.

The site was initially used to dispose of uranium mill tailings in Denver.

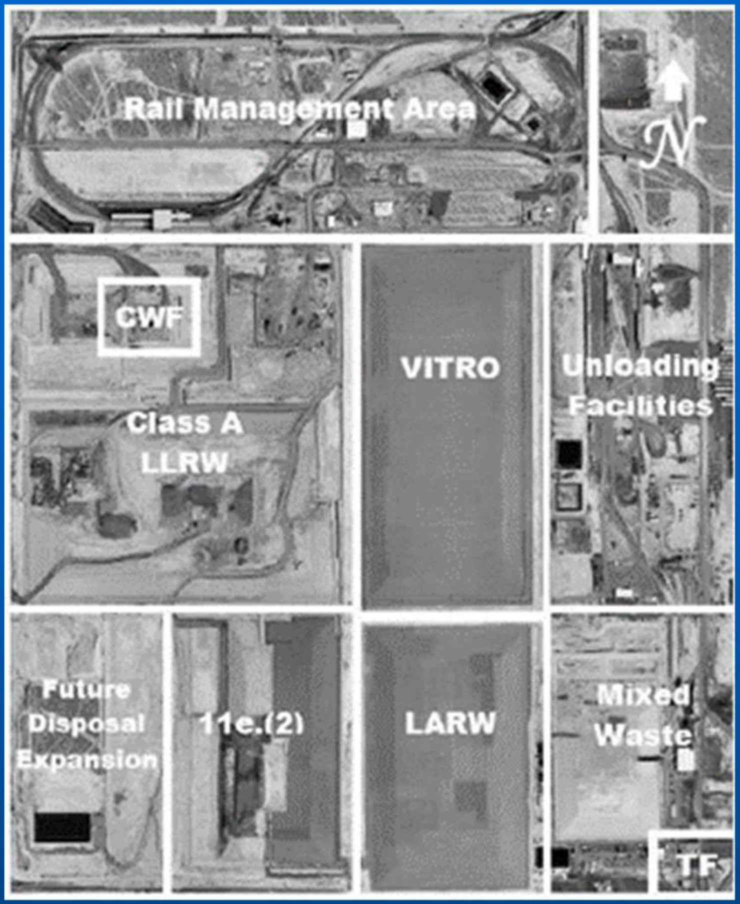
Now licensed to accept.

Class A LLRW, 11e. (2) material (U milling waste), NORM, and MLLA (mixed hazardous-low level waste).

Clive, UT

http://www.energysolutions.com/

Aerial and side view of the cell at the Clive, Utah, low-level radioactive waste site.



The Energy*Solutions* Clive Facility. In addition to showing the location of the disposal area of Class A LLRW, there are areas for uranium mill tailings from Salt Lake City Vitro Chemical, Byproduct Material (11e.(2)), Low Activity Radioactive Waste (LARW), and Class A-Mixed LLRW. CWF refers to Containerized Waste Facility.

LLRW from University of Illinois go to Clive

All LLRW wastes processed by Division of Research Safety are Class A wastes. "There are no Class B and C wastes."

Chase Environmental Group, Inc. transports the waste drums, then turns them over to Energy*Solutions* to transport to Utah.

Where will LLRW go in the future?

Barnwell has 2.7 million ft^3 (76,500 m^3) remaining capacity, but all of it is allocated to the Atlantic compact until 2050.

Clive, Utah. Energy*Solutions* say that they the capacity until 2038, but they can accept only class A wastes–at present.

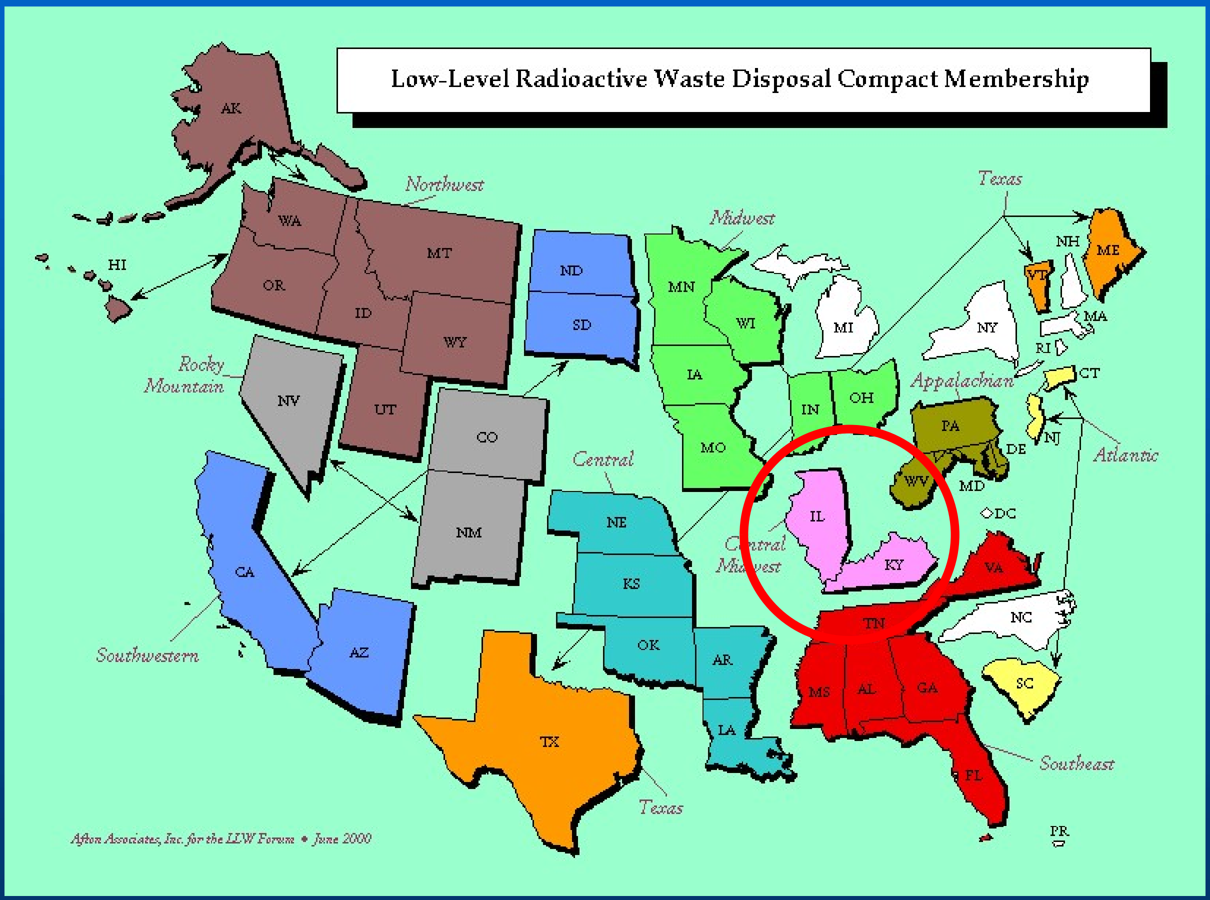
Richland has 21 million ft^3 (595,000 m^3) capacity remaining and can accept LLRW from 11 states. Expected to close in 2056.

A new LLRW facility!

In 2011, the Texas Compact Disposal Facility opened! Located in northwest Texas. First new facility since passage of the Low-Level Radioactive Waste Policy Act of 1980 (amended in 1985) to promote the siting and construction of new regional LLRW disposal facilities.

Most States joined together to form organizations called Compacts.

The LLRW Compacts



Illinois and Kentucky joined together in 1984 to form the Central Midwest Interstate Low-Level Radioactive Waste Compact.

http://www.cmcompact.org/

The LLRW Compacts

The formation of the ten LLRW compacts yielded no new LLRW facilities for many years.

Central Midwest Compact tried to locate a new site near Martinsville, Illinois in 1990s.

(more about this site later)

Southwest Compact tried locate a new facility in Ward Valley, CA (blocked by State government)

Central Compact, Nebraska (blocked by State Government)

Most Compacts are currently dormant.

The Texas Compact Disposal Facility

Operated by Waste Control Specialists.

Located in an arid climate.

Site geology: 200 feet (61 m) of red clay with layers of sand and siltstone.

Licensed to accept Class A, B, and C wastes!

The Texas House of Representatives voted to allow the facility to accept LLRW from 36 States that were not part of the Texas Compact---which includes Illinois!

No options for Class B and C until Texas

Prior to this event, Illinois had no options for Class B and C wastes.

For example, The Clinton Nuclear Power Station had been storing Class B wastes on-site in a room within the power-plant complex.

They thought that they had a 20-year capacity to store Class B wastes on-site (circa 2008).

The Texas Compact Disposal Facility

LLRW are placed in 10-foot (3.0 m) tall, 1 foot- (30.5 cm)-thick concrete canisters and buried 30 to 100 feet (9.1 to 30.5 m) below ground surface in disposal cells.

As the cells are filled, they covered with 300 feet (91.4 m) of clay.

http://www.wcstexas.com/

Waste Control Specialists Site

Greater than Class C

GTCC wastes are by default treated like spent fuel. They are "homeless."

Considered by the NRC as not acceptable for shallow-land disposal, and must be disposed in a geological repository or an alternative proposed by DOE and approved by the NRC.

Greater than Class C

There is no disposal site currently available for GTCC LLRW. Many CTCC wastes are currently stored at or near the site where they were generated.

Estimated volume of CTCC LLRW in storage is 1,100 m^3.

CTCC LLRW

The proposed disposal methods are a deep, geological repository, deep boreholes, near-surface trenches, and above-ground vaults.

No decision has been made public yet.

U.S. DOE management of LLRW

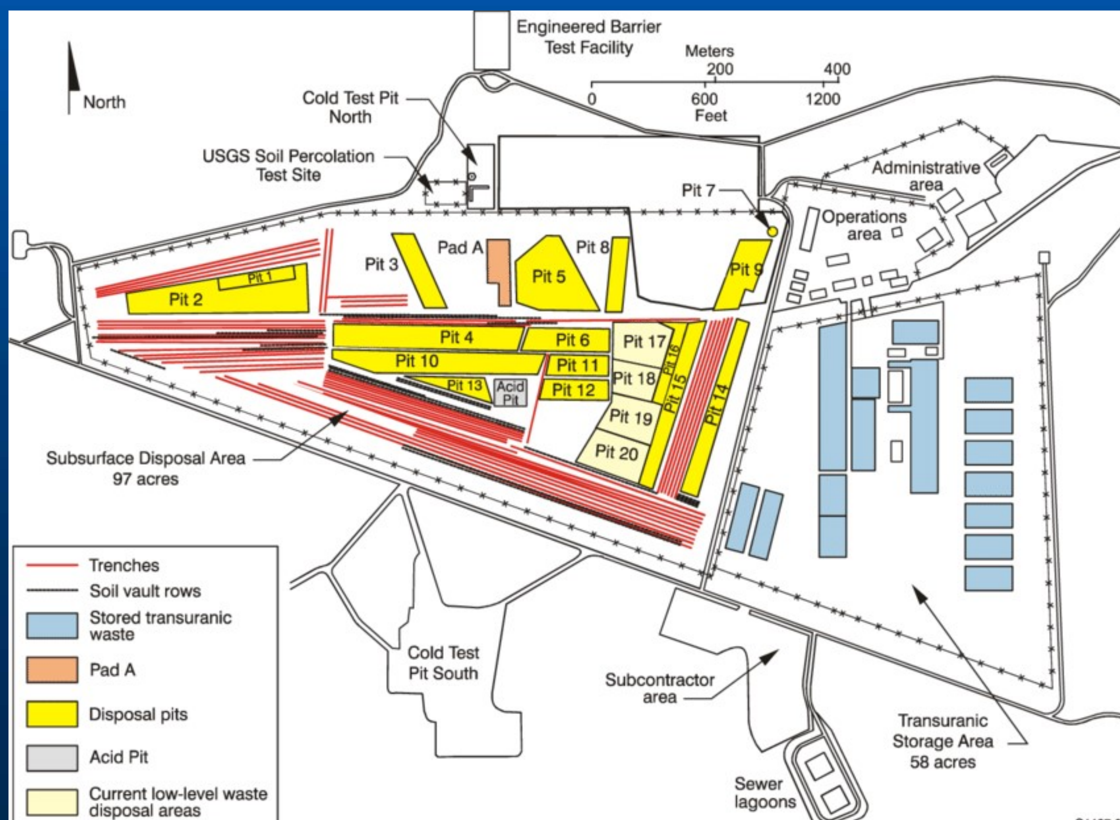
U.S. DOE also uses shallow land disposal of waste containers.

DOE has more disposal sites than what is available for commercial LLRW. There is “sufficient capacity” to at least 2070. DOE is also sending LLRW to commercial facilities.

U.S. DOE management of LLRW/TRU wastes

Location	Name of current disposal area
Hanford Site	Low-Level Burial Grounds (200 West and East Area)
Savanna River Site	E-Area Low-level Radioactive Waste Disposal Facility
Nevada National Security Site (formerly the Test Site)	Area 5 Radioactive Waste Management Site
Los Alamos National Laboratory	Area G of Technical Area 54, Materials Disposal Area
Idaho National Laboratory	Radioactive Waste Management Complex
Oak Ridge Reservation	Environmental Management Waste Management Facility

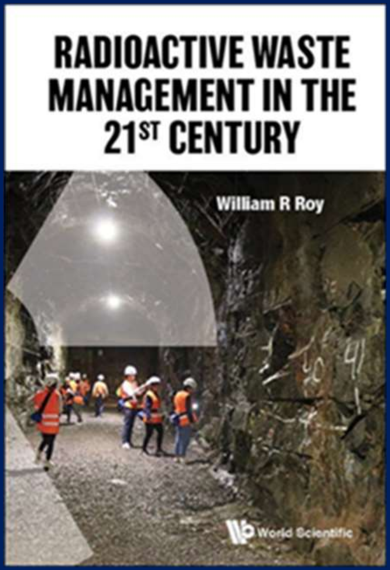

Idaho
Radioactive Waste Management Complex


Engineered Barrier Test Facility
Meters
0
200
400
600
1200
Feet
North
Cold Test Pit North
USGS Soil Percolation Test Site
Administrative area
Pit 7
Operations area
Pad A
Pit 8
Pit 3
Pit 5
Pit 9
Pit 1
Pit 2
Pit 4
Pit 6
Pit 17
Pit 10
Pit 11
Pit 16
Pit 18
Pit 13
Acid Pit
Pit 12
Pit 15
Pit 14
Pit 19
Pit 20
Subsurface Disposal Area
97 acres
Trenches
Soil vault rows
Stored transuranic waste
Pad A
Disposal pits
Acid Pit
Current low-level waste disposal areas
Cold Test Pit South
Subcontractor area
Transuranic Storage Area
58 acres
Sewer lagoons
G1137-01

Nevada National Security Site

Class Assignment 5

Read Chapter 4.
Answer Review Questions 5, 8 and 9.
Rubric:
This assignment is worth 20 points.
Question 5 is worth 10 points.
Question 8 is worth 5 points.
Question 9 is worth 5 points.



Questions?