Low-Level Radioactive Waste Management

Part 1

“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 four approaches:

Acceptable Knowledge/Process

Knowledge

Dose-to-Curie methods

Non-destructive analysis

Direct sampling and analysis
Acceptable Knowledge/Process Knowledge

The history of waste site or waste-generating process is known. Example: wastes created from an controlled 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, 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. Most 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.
Early LLRW Disposal

Late 1940s to 1970

The Atomic Energy Commission placed both commercial and Federal LLRW 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 LLRW Disposal

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


The AEC endorsed the concept of shallow land disposal for commercial LLRW. Land disposal had been used since the 1950s.
Early LLRW Disposal

In the 1950s, shallow land burial was conducted, but at times careless and undocumented.

LLRW from the "National Reactor Testing Station" in Idaho, c. 1950.
Early LLRW Disposal

Cardboard boxes and open drums in unlined ditches.

LLRW from Hanford, c. 1950
Desirable characteristics for shallow land burial

True for municipal wastes, coal ash, incinerator ash and 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. For both the liner (bottom) and the cover above the wastes to minimized infiltration.
Desirable characteristics for land burial

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

3. Local geology is well known; subsurface layers of material and their hydrogeologic properties are documented and understood; a site assessment.

4. Stable area (no earthquakes, soil erosion, landslides)–flat; a risk assessment has been conducted.
Beatty, the first LLRW facility

1962: Beatty (bay-dee), Nevada. First commercial LLRW facility. Licensed by the AEC. Climate: arid (annual precipitation of 2.5 to 5 inches [6.4 to 12.7 cm]).
Site geology: river sand over silt, clay and gravel to a depth of 600 feet (183 m).
Water table at 260 to 330 feet (79 to 101) (depth).
22 trenches, 6 to 50 feet deep (1.8 to 15.2 m). Mounded trench covers when full.
Figure 3. Beatty, Nevada, disposal facility map.
Beatty received 4.7 million ft$^3$ (133,000 m$^3$) of LLRW which was 640,000 Ci (23,680 TBq). 80% waste came from commercial nuclear power plants. Liquid wastes were also buried. Tritium was detected in well water samples off-site.
Demise of Beatty

In 1976, employees removed a cement mixer, tools, and building material which were brought to the site as radioactive waste, and used them in local construction projects.

From 1976 to 1979, a series of events involving improper handling and packaging of LLRW resulted in the closing of the site for intervals because the operator’s license was temporarily suspended.

Closed in 1992 because of bad public relations.
Maxey Flats, Kentucky

In 1963, the Maxey Flats LLRW disposal site opened under a lease between the State of Kentucky and Nuclear Energy Company (now US 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

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 US.
Figure 5. Maxey Flats, Kentucky, disposal facility map.
Cross-section of Maxey Flats
Maxey Flats

As was the practice at the time, there was no:

* waste minimization
* volume reduction
* waste compaction
* waste de-watering,

* packing of waste containers to avoid void spaces.

Waste packages included cardboard and fiberboard boxes which degraded quickly.
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 earth 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 affect.”
“Bathtub effect” at Maxey Flats and West Valley
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 US EPA.

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

During remediation, trench leachate was collected.
A 45-mil geomembrane cover was placed over the trench area to prevent infiltration of more water into the trenches.
The LLRW were not exhumed.
The site will have to be monitored and maintained in perpetuity.
Environmental monitoring
West Valley, New York

The West Valley disposal site opened as a commercial facility in 1963 by Nuclear Fuel Services.

14 parallel trenches that were about 20 feet (6.1 m) deep. 22 acres (8.9 ha) in size.

Site geology: 10 to 20 feet (3.0 to 6.1 m) of weathered glacial till over 150 to 300 feet (45.7 to 91.4 m) of unweathered till (layers of sand, gravel, silt, and clay. Bedrock: shale.
Figure 7. West Valley, New York, disposal facility map.

This map is an artist's rendering from limited input and is therefore not accurate as to measurements and distance.

Sand, gravel, and boulders
Sand and gravel
Gravel and silt
Layered clay
Gravel, sand, and silt
Fine sand and silt
Interbedded silt
Shale
During its operation period, 2.5 million ft$^3$ (70,800 m$^3$) of LLRW were buried: about 1.3 million Ci (48,100 TBq) of activity. When a section of a trench was filled, covered with 4 to 8 feet (1.2 to 2.4 m) of soil. Like Maxey Flats, West Valley was plagued by the “bathtub effect.” Two trenches filled with leachate and it seeped through the covers in 1975. Operations were “suspended” because the major activity was reprocessing spent nuclear fuel (more about this later).
Closure of West Valley

Leachate was collected and pumped into above-ground tanks.

Soil covers were re-compacted.

Sheet of plastic were installed over the trenches.

Because the LLRW is located in the middle of the Nuclear Services Center, difficult to assess impacts.

Future of LLRW site linked to the West Valley Demonstration Project.
Richland, Washington

The US 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).

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

Water table at about 245 feet (75 m).
Soil, sand, gravel, and boulders

Unconsolidated interbedded granular material

Chemical trench

Resin tanks

Special materials

Reactor head trench

1
2
3
4B
4A
4
5
6
7
8
9
10
11B
11A
16
14
13
Richland

In 1994, the site consisted 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.
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.

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).
Location of the study area (modified from Garlaw and Healy, 1986, fig. 3).

Photo 1 - Aerial view of the Sheffield LLRW Disposal Facility with feature overlays (IEA, 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>
<thead>
<tr>
<th>Radionuclide</th>
<th>Curies</th>
<th>Half-life (Years)</th>
</tr>
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<tbody>
<tr>
<td>H-3 (Tritium)</td>
<td>5,990</td>
<td>12.35</td>
</tr>
<tr>
<td>C-14 (Carbon)</td>
<td>450</td>
<td>5,730</td>
</tr>
<tr>
<td>I-129 (Iodine)</td>
<td>0.01</td>
<td>15,700,000</td>
</tr>
<tr>
<td>Sr-90 (Strontium)</td>
<td>3,690</td>
<td>29.12</td>
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<tr>
<td>Cs-137 (Cesium)</td>
<td>15,500</td>
<td>30</td>
</tr>
<tr>
<td>Co-60 (Cobalt)</td>
<td>20,000</td>
<td>5.27</td>
</tr>
<tr>
<td>Pu-238 (Plutonium)</td>
<td>7.5</td>
<td>87.74</td>
</tr>
<tr>
<td>Pu-239, Pu-240, Pu-241</td>
<td>4,870</td>
<td>24,065; 6,650; 14.4</td>
</tr>
<tr>
<td>Am-241 (Americium)</td>
<td>137.5</td>
<td>43.2</td>
</tr>
</tbody>
</table>

(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 ft³ (255 m³). 1977—57,000 ft³ (1,614 m³).

California Nuclear, Inc. went to Nuclear Engineering Company (now US 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 a 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. The sand layers allowed trench leachate to spread. Also, the trench covers collapsed as the wastes packages settled.
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 rules 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.
Map 2 - Areas where tritium was found at and near the Sheffield LLRW Disposal Facility site (USGS, 1986).
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.

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).
183.73 acres - total burial space inside buffer zone
71.5 acres - used for burial space as of Nov. '89
112.23 acres - remaining for burial space

This map is an artist’s rendering from inexact input and is therefore not accurate as to measurements and distance.
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 June 30th, 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

Class A trenches are 100 feet long (30.5 m), 300 feet wide (91.4 m), and 30 feet (9.1 m) deep. Class B and C trenches are 600 feet (183 m) long, 50 feet (15 m) wide (to reduce occupational exposure), and 20 feet (6 m) deep. Slit trenches are used for higher-end Class C. Regardless of waste class, they are placed in concrete overpacks.
Barnwell, trench and cover design

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

- 2 ft. Vegetative Cover
- 1 ft. Sand Drain Layer
- 60 mll HDPE
- 1/4 Inch GCL
- 1 ft. Recompacted Clay

Structural Fill

- Trench
- Sand Buffer
- Sump
- Clay
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.