Chapter 6

Disposal Technologies

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OVERVIEW

Most low-level radioactive waste (LLW) generated in the United States over the last 40 years has been disposed of by shallow-land burial. Unfortunately, at three of the Nation's six commercial disposal facilities, water infiltrated into the shallow trenches and in some cases caused radioactive contaminants to migrate into the surrounding environment. **Preventing water infiltration into disposal units is the key to safe disposal of LLW and mixed LLW.**

Disposal facilities that are well-designed, well-constructed, and well-maintained should be able to safely isolate LLW and/or mixed LLW for a few hundred years, and even longer if they are well-maintained throughout the operating period and post-closure care period. The disposal industry's ability to construct water-tight disposal facilities will certainly improve with experience, primarily from budding new facilities and monitoring their long-term performance. Since the integrity of these facilities **will degrade over time, long-term monitoring may be advisable for as long as the waste remains harmful.**[1]

Gently sloping covers to the facilities, called caps, can be made of a variety of natural materials (e.g., clay) and man-made materials (e.g., synthetic membranes). In humid areas, these caps are generally composed of multiple layers of these various materials so that precipitation is kept from entering disposal units. If the cap leaks, below-grade facilities buried in impermeable clay may fill with water, unless they are pumped, thereby creating a "bathtub" effect. Water infiltrating into above-grade tumuli and earth-covered vaults can be drained (via gravity) into external collection basins and then monitored.

Unit disposal costs for most Class A LLW in 1989 average just over $40 per cubic foot. These costs will probably rise in 1990 when the surcharge to these States, allowed under the Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA)[2], increases from $20 to $40 per cubic foot. Unit disposal costs at new disposal sites will undoubtedly be higher than today's costs for several reasons: 1) the presence of more small-scale disposal facilities with higher per unit disposal costs, 2) the use of more expensive technologies for waste packaging and disposal, 3) host community compensation packages, and 4) extended long-term care periods.

The development of better combinations of soil layers and synthetic membranes in multilayered caps could improve the long-term performance of disposal facilities. In-cap monitoring systems also could be more widely used so that leaks in the cap can be located and the cap repaired quickly.

INTRODUCTION

The goal of disposal is to isolate LLW and mixed LLW during the the time it poses an undue risk to humans and the environment. Since the toxicity and longevity of risk associated with different waste constituents varies, the required level and time period of containment depend on the concentration of the particular waste constituents. The Nuclear Regulatory Commission (NRC) requires that Class A LLW be contained for up to 100 years, Class B for 200 to 300 years, and Class C for up to **500 years. These** requirements are based on the half-life of the radionuclides in the waste, the types of radiation emitted, and potential pathways to humans. These containment periods and the structural stability requirements of the waste are designed to ensure that an inadvertent intruder would not be exposed to radiation that poses an undue health risk to the individual. The Environmental Protection Agency (EPA) does not set similar containment periods for hazardous waste. It does, however, require that no migration occur during the post-closure care period—a period that lasts 30 years unless monitoring data support that this period be shortened or lengthened. However, unlike LLW, the toxicity of some hazardous waste (e.g., heavy metals and some synthetic organic chemicals) does not significantly decrease with time.

Disposal technologies for LLW and mixed LLW generally involve burial of the waste beneath the Earth's surface. Disposal technologies typically

[1] Determining the harmful period will depend on the long-term toxicity of the radioactive and hazardous, as defined under the Resource Conservation and Recovery Act, constituents in the waste.

[2] Public Law 99-240, Jan. 15, 1986.

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provide waste isolation in two different ways. First, shielding of the radioactive material is provided by concrete and/or layers of earth. Second, disposal facilities are designed to minimize the infiltration of water into the waste and any subsequent migration of dissolved waste constituents into the surrounding environment. **Infiltration can be minimized in three ways: by locating the disposal site in a relatively dry environment; by designing the disposal facility so that any precipitation quickly runs off the site, rather than percolating into the facility; and/or by surrounding the waste with water-resistant material, such as concrete coated with a waterproofing material.**

Mixed LLW was included with other LLW and disposed of at commercial LLW disposal sites until November 1985. Since that time, mixed LLW is required to be disposed of at facilities designed to meet both NRC regulations for LLW and EPA regulations for hazardous waste. However, no such disposal facilities yet exist. Since waste disposal facilities for mixed LLW will probably require at least another few years to construct and license, most mixed LLW will have to remain in storage until the States and compacts develop mixed LLW disposal facilities. If it is assumed that 3 to 10 percent[3] of the LLW volume generated a year is mixed LLW and that all of this waste is stored,[4] about 130,000 to 430,000 cubic feet of mixed LLW will be in storage by the end of 1992.

After a brief history on LLW disposal, various waste isolation technologies will be described with emphasis on the near-surface, underground disposal techniques now being developed for both LLW and mixed LLW. Much of this material addresses the suitability of different disposal facility designs for different regions of the United States, particularly the humid regions in the East and the arid regions in the West. The last section of this chapter addresses disposal costs.

HISTORICAL BACKGROUND

Early Experience

Between the mid-1940s and the late 1970s, the majority of commercial LLW (as well as defense LLW) was stacked in shallow trenches and subsequently covered with several feet of soil. This disposal technique, which is illustrated in figure 6-1, is commonly called **shallow-land burial** (SLB). In the 1950s, the Atomic Energy Commission (AEC) established interim-disposal sites for commercial LLW at unlicensed, federally owned defense facilities near Oak Ridge, TN, and Idaho Falls, ID, until commercial facilities could be sited. By the early 1960s, there were three commercial disposal facilities operating at Beatty, NV; West Valley, NY; and Maxey Flats, KY. Within the next 10 years, three more facilities were opened at Richland, WA; Sheffield, IL; and Barnwell, SC.[5] See table 6-1 for the volumes of LLW disposed of at each of these facilities.

The late 1970s **saw the closing of three commercial SLB sites, two due to radionuclides leaking from burial trenches.** At West Valley, NY, some trench caps failed and the trenches filled with water to the point that water spread over the ground surface. The site was shut down in 1975. The earthen caps covering some of the burial trenches at Maxey Flats, KY, also failed, and water filling the trenches eventually spread as surface run-off. The trench water was pumped out and treated, and the site was closed in 1977. The Sheffield, IL, site was closed in 1978 when it reached its licensed capacity. Tritium migration has since been detected at Sheffield, but no health and safety hazard was or is deemed to exist (17). Remedial action, such as maintaining trench caps and pumping water from the trenches, is now occurring at all three sites.[6] **To date, monitoring efforts have not found significant amounts of radionuclide migration beyond the boundaries of these three inactive disposal sites (17).**

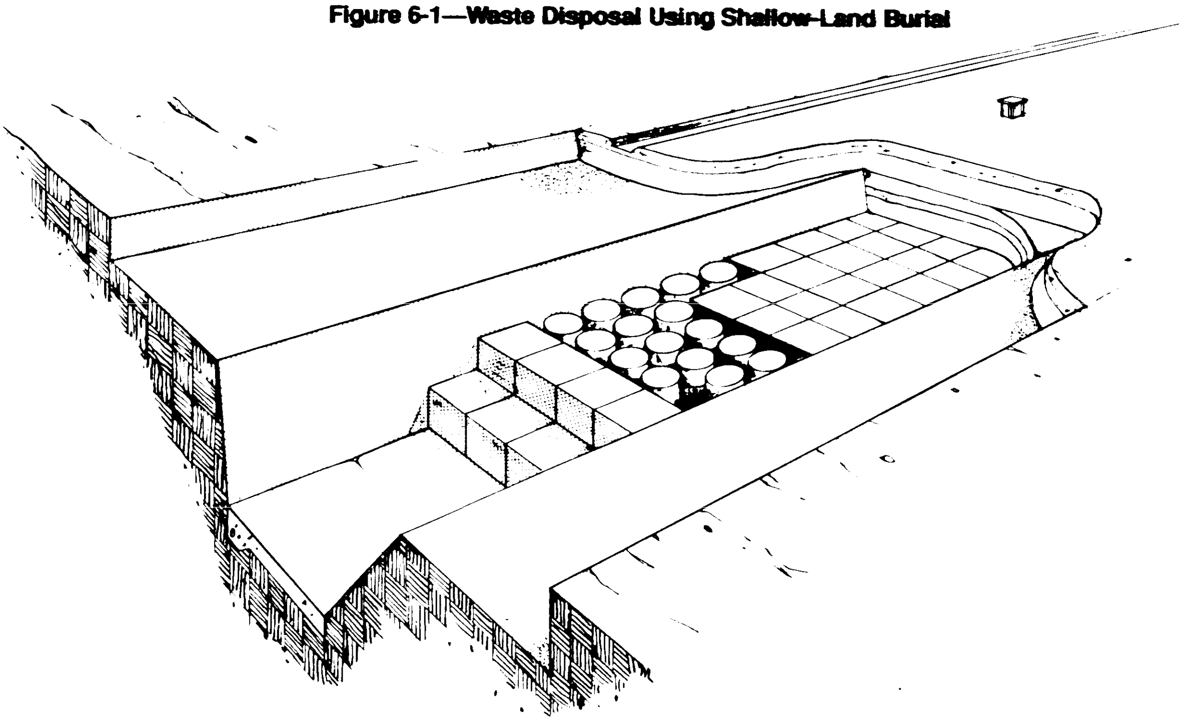
[3] As no national survey has been conducted, 3 to 10 percent is an estimate based on ad hoc surveys. If waste oil is listed by EPA as hazardous waste, this estimate would rise dramatically.

[4] Ad hoc State surveys and industry surveys indicate that the cumulative volumes of mixed LLW in general are holding steady and not increasing as would be expected since no disposal capacity has been available since November 1985. Some mixed LLW may be slipping through brokers and waste processors and entering LLW disposal sites undetected.

[5] Of all LLW so far disposed of by the United States, less than one-tenth of one percent (89,472 drums) was dumped into the ocean. All drums were deposited within 220 miles of our coastline during the 1946-70 time period when ocean dumping was practiced. Few records of these activities were kept, but sporadic monitoring of the few known sites has detected no adverse ecological impacts from these activities (8). Ocean dumping of LLW is not a politically viable option; it would require that an ocean dumping permit be approved of by EPA and both Houses of Congress within 90 days after receipt of an application.

[6] Both Maxey Flats and West Valley continue to ''receive' wastes generated by onsite cleanup and water treatment operations.

Figure 6-1—Waste Disposal Using Shallow-Land Burial



SOURCE: U.S. Department of Energy, "Conceptual Design Report Alternative Concepts Of LOW-Level Radioactive Waste Disposal," prepared by Rogers and Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987.

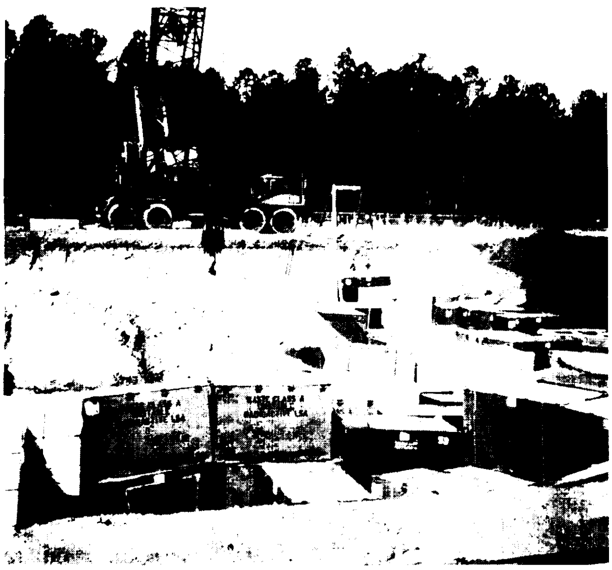


Photo credit: Gretchen McCabe

These two photographs illustrate the difference in disposal practices used at the humid site in Barnwell, SC (above) and at the and site in Richland, WA (right), Both technologies are shallow-land burial for Class A waste, but the low precipitation in Washington does not necessitate stacking of Class A waste containers to minimize radionuclide migration.

Table 6-1—Amounts of Commercial LLW Disposed of Through 1988

Disposal site	Years in operation	Cumuklative amounts in 10^6 cubic feet	Approximate percent
Barnwell, SC	1971-present	20.6	45
Richland, WA	1965-present	10.8	24
Maxey Flats, KY	1963-1977	4.8	10
Beatty, NV	1962-present	4.0	9
Sheffield, IL	1967-1978	3.1	7
West Valley, NY	1963-1975	2.5	5
Total		45.8	100

SOURCE: U.S. Department of Energy, Draft, *Integrated Data Base for 1989: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics*, DOE/RW-0006, Rev. 5, August 1989.

Significance of Past Problems

Radioactive waste at land-based disposal sites can pose a human health hazard in firer ways. First, radionuclides can be leached out of the waste by infiltrating water thereby contaminating groundwater and/or surface water supplies. Second, radionuclides may be released in gaseous form into surrounding soils and ultimately to the atmosphere. Third, workers can be exposed to radiation from the waste during waste emplacement. Finally, humans may inadvertently uncover waste from a disposal facility at some time in the future The relative importance of these release modes, which are discussed in more detail in ch. 4, vary considerably from one disposal facility to another.

Past environmental problems at the disposal facilities in Illinois, New York, and Kentucky can be traced to one or more of the following:[7]

- inadequate disposal facility designs;
- inadequate waste compaction prior to disposal;
- inadequate packaging of LLW containing liquids and highly mobile radionuclides, such as tritium;
- haphazard stacking of waste packages in disposal trenches;
- poor cap construction and/or maintenance;
- poor drainage of surface runoff; and
- an inability to monitor, detect, and remove infiltrating water from disposal trenches.

NRC's regulations for disposal sites (10 CFR Part 61) are aimed at minimizing water infiltration by avoiding these mistakes.

Many engineers familiar with past and present disposal practices believe that a well-designed and well-constructed disposal facility for LLW and/or mixed LLW can safely contain the waste for a few hundred years and probably longer. Disposal facilities at Richland, WA, and Beatty, NV, have both operated since the mid-1960s without any significant radionuclide migration. The disposal facility at Barnwell, SC, has operated successfully since 1971 despite its wet climate. Therefore, **past problems with the disposal of LLW should not be interpreted to mean that LLW cannot be safely disposed of in near-surface facilities.**

The performance of any LLW disposal facility will naturally reflect the disposal site characteristics, as well as the facility's design, construction, and management. Unfortunately, it is not possible to accurately predict how long a particular disposal facility will perform at an acceptable level for two reasons. First, the longevity of hazard associated with LLW and mixed LLW can range from several decades to a few hundred years and even longer for some wastes. These time periods extend well beyond the few decades of disposal site developers' experience. Second, many of the materials (e.g., impervious plastic membranes) and current facility designs have only been developed over the last several years and have yet to be subjected to long-term testing.

Given the Nation's limited experience with the design of LLW and mixed LLW disposal facilities relative to the length of risk from the waste, **it is important to recognize that uncertainties about the long-term performance of disposal facilities can be significant.** Disposal sites may contain minor undetected flaws. Facility designs may not behave exactly as predicted. Climate patterns may change. Institutional problems and mismanagement in the construction, operation, and maintenance of disposal facilities may occur and are often difficult

[7] Similar problems with water infiltration and radionuclide migration have also occurred at several Department of Energy (DOE) defense sites in the United States, as well as at SLB facilities in Canada and in the United Kingdom (3).

to detect. These uncertainties generally increase with time. Long-term monitoring programs **supported with long-term care funds can compensate for these uncertainties.**

GENERIC DISPOSAL TECHNOLOGIES

Four generic disposal technologies are described below based on their location relative to the Earth's surface, Several recent reports have compared these technologies in great detail using about two dozen different factors, including the level of technology development, degree of waste isolation, long-term stability and maintenance, worker safety, cost, ease of monitoring, and waste removal in the event of unacceptable contaminant migration, licensability, etc. (19, 9, 5).

All four generic disposal technologies, if properly implemented, could probably provide acceptable levels of waste isolation. Although no single disposal technology can be unequivocally judged "best" for all situations, most States and/or compacts have chosen some type of near-surface, underground disposal technology as the most appropriate **for isolating LLW and mixed LLW.** For ease of explanation, near-surface, underground disposal will be used as a baseline for evaluating the other three generic technologies.

Above-Ground Disposal in Concrete Vaults

With this technology, isolation is provided by a reinforced-concrete building constructed on the Earth's surface. As shown in figure 6-2, the building would not be covered with earth, but instead would simply have a flat or gently sloping concrete roof. Walls and the roof would probably range in thickness from 2 to 3 feet. The waste in the building would be isolated from humans and the environment as long as the integrity of the building is maintained. Some Canadian utilities presently use similar above--ground vaults for **storing** low-level and higher-level radioactive wastes for later disposal.

Although above-ground vaults can be easily sited and monitored, they have several disadvantages relative to near-surface, underground disposal facilities discussed below. First, above-ground facilities lack the protection of an earthen cover, thus leaving them exposed to degradation by wind, rain, and freeze-thaw cycles throughout most of the United States; long-term maintenance could be a problem. Second, since these facilities would be located above ground, there would be no surrounding soil to mitigate releases of radioactive material when the structure ultimately deteriorates. Third, inadvertent human intrusion is more likely; therefore, institutional control measures must be stronger.

Near-Surface Underground Disposal Facilities

Near-surface underground disposal technologies have been used for most LLW and mixed LLW so far generated in the United States. With most of these technologies, waste packages are disposed of within a few tens of feet of the Earth's surface and are capped with about 5 to 20 feet of soil, as illustrated in figure 6-1. To minimize cap subsidence and the subsequent infiltration of water, waste can be compacted and/or packaged in a stabilized form prior to disposal.

Well-designed and well-constructed near-surface disposal facilities can provide adequate levels of waste isolation if the waste can be kept dry. Ideally, a facility should be sited in an area away from surface water (including flash floods) and where travel time of any infiltrating precipitation to the groundwater table would be long and the travel of groundwater slow.[8] In areas where the groundwater time-of-travel is not long, concrete vaults can be used to increase the level of isolation and the stability of the disposal facility. Vaults also minimize the possibility of water infiltrating the waste.

The most commonly discussed near-surface disposal concepts include: trenches and below-grade vaults; above-grade tumuli and earth-covered vaults; and earth-mounded concrete bunkers, a combination of tumuli on top of below-grade vaults. These technologies will be discussed in more detail in the next section on near-surface disposal technologies.

[8] EPA uses the term "groundwater time-of-travel to judge the vulnerability of groundwater. It depends on precipitation rates, soil composition. orientation of sediment and rock layers, and depth to groundwater. EPA requires that the time for infiltrating water to reach the groundwater table and move 100 feet in any direction be greater than 100 years. Areas with a shorter groundwater time-of-travel are defined as having vulnerable hydrogeology and should be given special attention in designing a site (15).

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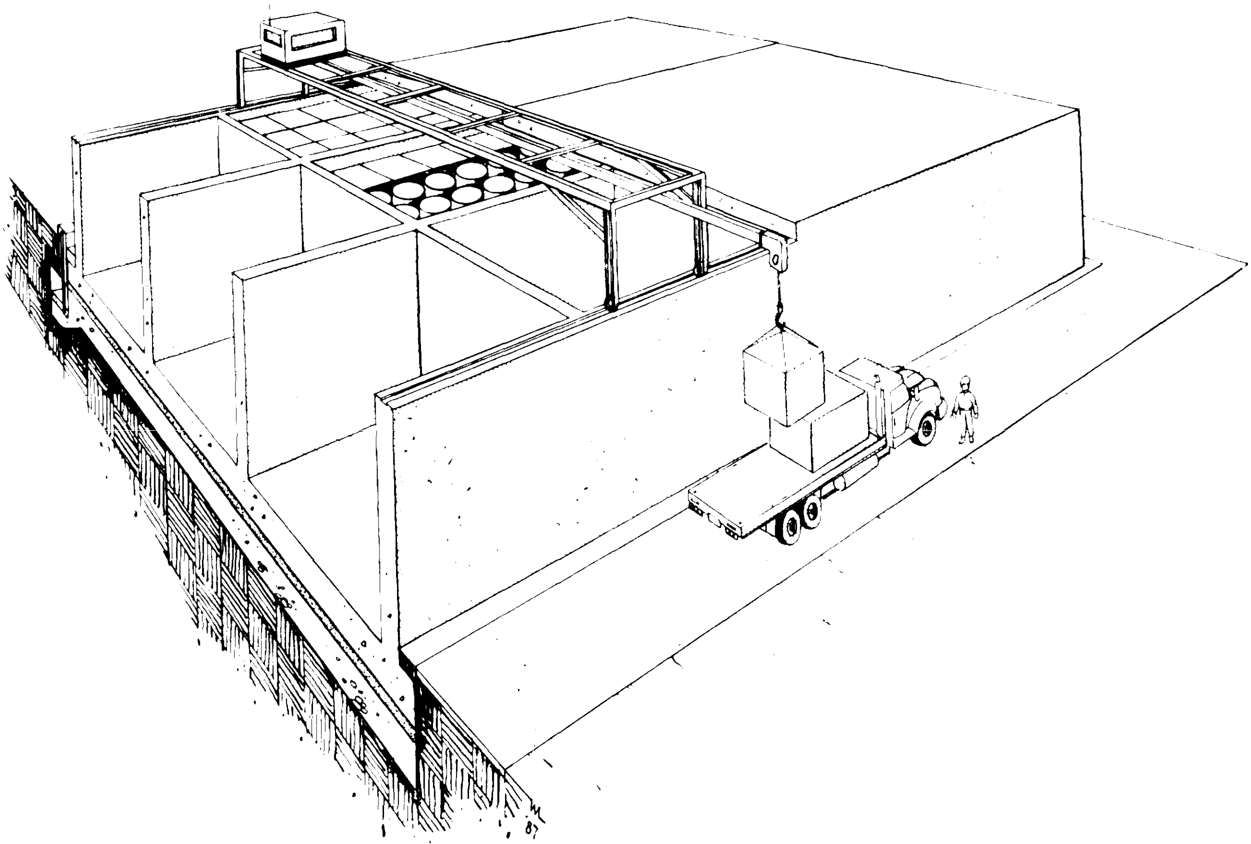
Figure 6-2-Above-Ground Disposal in Concrete Vaults



SOURCE: U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts of Low-Level Radioactive Waste Disposal," prepared by Rogers and Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987,

Photo credit: Chem-Nuclear Systems, Inc.

Photo credit: US Ecology, Inc.

The above two photographs illustrate the **disposal** site layout at a humid site (left) and at an arid site (right). Two-thirds of the site (in the foreground) at the arid site is for hazardous waste.

Intermediate-Depth Disposal in Augered Holes

LLW could be buried at intermediate depths of several tens of feet below the Earth's surface using augered holes. As shown in figure 6-3, this technology typically involves boring holes—measuring 8 or more feet in diameter—into the ground and possibly lining these holes with concrete or cement grout, typically measuring about 1 foot thick, After the hole has been filled with waste to within about 10 feet of ground level, grout is poured around the waste to form a solid cement-waste matrix inside the hole. A concrete cap is then placed on top of the waste, and the hole is backfilled with soil (2).

Over the last several years, augered holes with typical depths of 20 to 50 feet have been used on an experimental basis for the disposal of LLW and transuranic wastes at the Department of Energy's (DOE's) Savannah River National Laboratory, Nevada Test Site, and Oak Ridge National Laboratory. To maximize waste isolation, augered holes are normally located well above the water table.[9]

Augered holes would probably be acceptable for commercial LLW disposal; however, this option is not optimal for three primary reasons relative to near-surface disposal. First, the additional protection gained by disposing of the waste at depths of more than a few tens of feet below the Earth's surface is not necessary. Second, suitable sites may be difficult to find in some regions of the United States due to the presence of groundwater. Third, monitoring and possible removal of emplaced waste in the event of unacceptable levels of contaminant migration generally becomes more difficult as burial depths increase.

The use of augered holes is being phased out at the Savannah River National Laboratory in favor of buried concrete vaults, which are easier to operate and result in less worker exposure.

Deep Disposal in Geologic Repositories

Deep geologic repositories, located at depths from a few hundred to a few thousand feet below the Earth's surface, are generally favored most by the scientific community worldwide for disposing of high-level and transuranic radioactive waste. The geologic formations surrounding a repository provide natural barriers to the migration of radionuclides by groundwater over the long-term. Engineered barriers, such as the waste form and waste package, enhance the isolation of the waste during the first few thousand years (13). After the excavated rooms in a repository are filled with waste, all shafts and tunnels are backfilled and sealed. A schematic view of a repository is shown in figure 6-4.

Several European countries plan to use geologic repositories for the disposal of low-level and intermediate-level waste. Sweden has developed a repository about 200 feet under the Baltic Sea. Finland plans to dispose of similar waste from its nuclear power plants in repositories about 300 feet beneath each plant. The United Kingdom is proposing to dispose of its low-level and intermediate-level waste in a repository 1,000 feet underground. West Germany disposed of some LLW in the Asse Salt Mine between 1967 and 1978. In the United States, DOE is presently planning to use deep geologic repositories constructed at depths of a few thousand feet for the disposal of commercial spent fuel and high-level and transuranic wastes generated from defense activities.

Geologic repositories for the disposal of LLW and mixed LLW is not optimal relative to near-surface technologies for several reasons. First, the additional protection gained by disposing of the waste at such depths below the Earth's surface is not necessary. Second, suitable repository sites may be very difficult to find in many regions of the United States, especially in the East where the time-of-travel of groundwater is short. Third, developing repositories of the small size required by most States or compacts would be prohibitively expensive. Finally, monitoring and waste removal from a backfilled repository (in the event of leaking waste or other problems) would be very difficult.

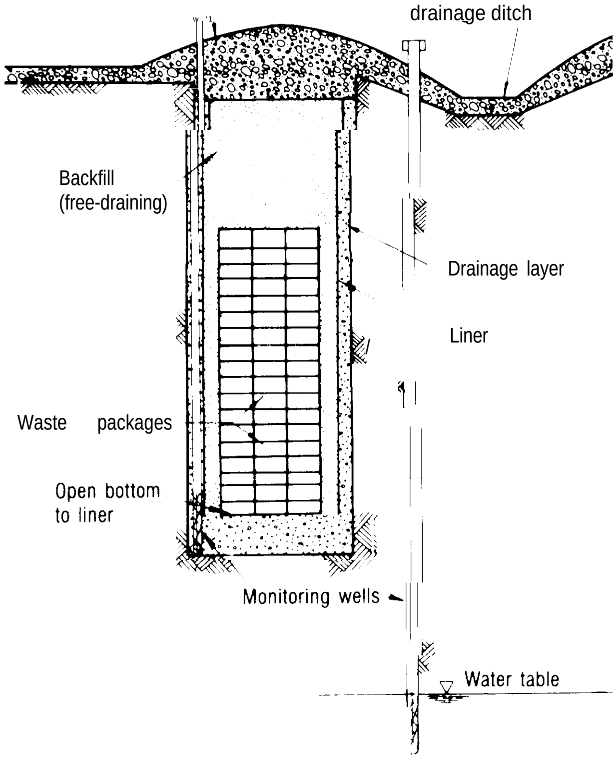
NEAR-SURFACE DISPOSAL TECHNOLOGIES

Near-surface technologies involve disposing of waste packages within a few tens of feet of the Earth's surface and capping the waste with 5 to 20 feet of soil. As shown in figure 6-5. disposal sites encompass: the actual waste disposal facilities, such as trenches or tumuli; any facilities for waste storage

[9]Mike O'Rear, U.S. Department of Energy, Savannah River National Laboratory; Robert Sleemen, U.S. Department of Energy, Oak Ridge National Laboratory; and Robert Dodge, Reynolds Electric Engineering Corp., separate personal communications, June 1988.

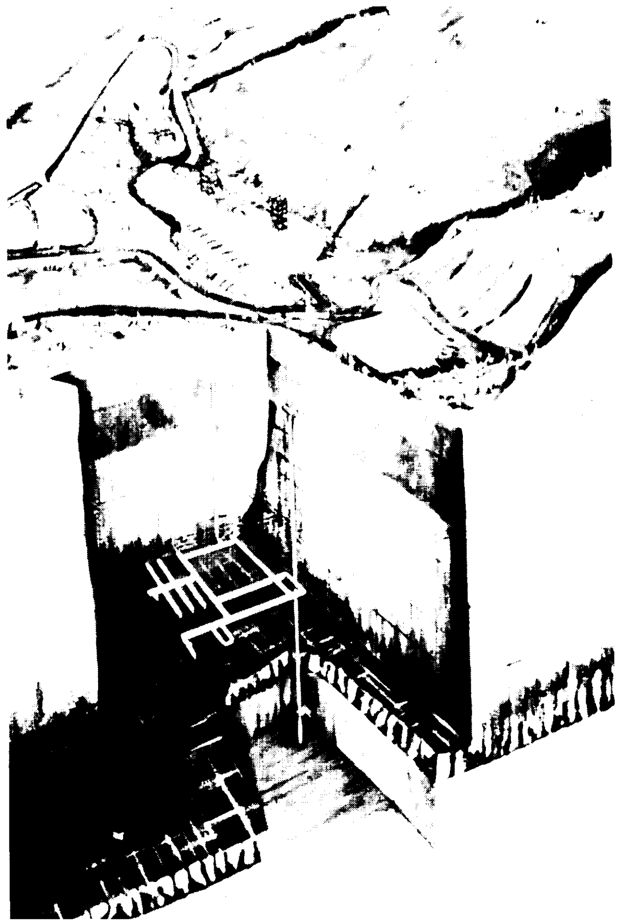
[10]Mike O'Rear, U.S. Department of Energy, Savannah River National Laboratory, personal communication, June 16, 1988.

Figure 6-3-intermediate-Depth Disposal in Augered Holes



SOURCE: U.S. Nuclear Regulatory Commission, "Alternate Methods for Disposal of Low-Level Radioactive Wastes: Technical Requirements for Shaft Disposal of Low-Level Radioactive Waste," contractor report prepared by the U.S. Army Corps of Engineers, Waterways Experiment Station, NUREG/CR-3774, vol. 5, October 1985, p.22.

Figure 6-4-Schematic of Deep-Geologic Repository Design



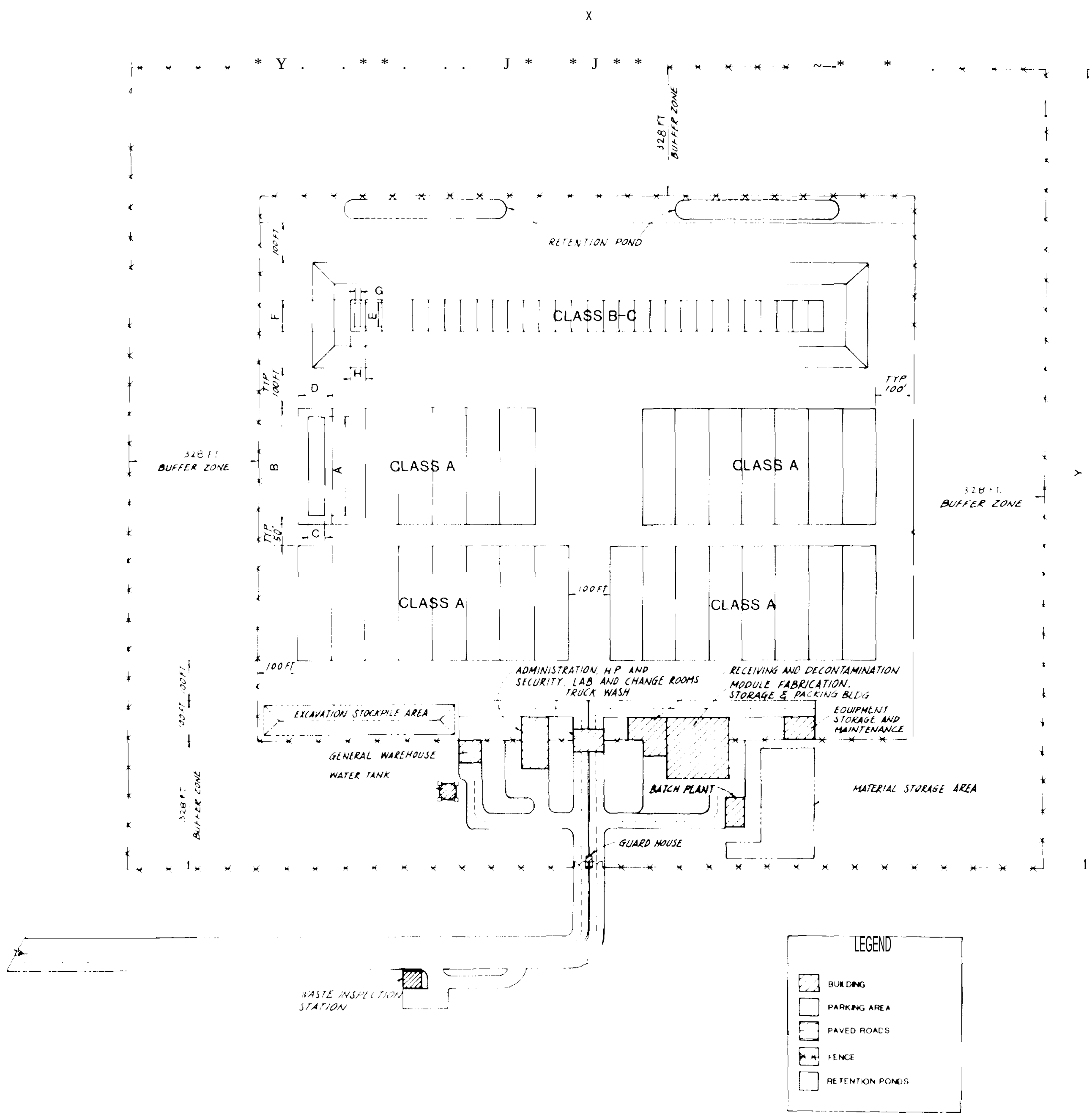
SOURCE Courtesy of U S Department of Energy.

and/or treatment; catchment basins for drainage water from the site; and unused buffer zones around and under the disposal units for monitoring and naturally dispersing any releases of waste constituents from the disposal units. Private firms will most likely operate these facilities; however, State governments will retain title to the land. During the two-to-four decades of site operation, disposal activities will be conducted in accordance with the general conditions of a facility license issued by NRC or an Agreement State.

On the one hand, there may be advantages to disposing of Class A, B, C, and mixed LLW in separate disposal facilities (at the same site). First, the disposal requirements for different types of waste are often quite different. Second, disposal units containing Class A waste will probably require monitoring for about 100 years; disposal units containing Class B, C, and mixed LLW may require monitoring well beyond that timeframe. Third, if different types of waste are separated, problems with one type of waste can be handled without the involvement of other waste types. On the other hand, there may be advantages to disposing of different types of wastes in the same facility. For example, Class B and C waste can be emplaced in the bottom of disposal trenches and covered with stabilized Class Awaste.[11] This arrangement minimizes worker exposure to Class B and C waste and is less expensive than disposal in separate units.

[11] NRC does not allow unstabilized Class A waste to be disposed of in the same unit with Class B or Class C (10 CFR Part 61.7(b)(2)).

Figure 6-5-Layout of a Typical Disposal Site



SOURCE: U.S. Department of Energy, "Conceptual Design Report:Alternate Concepts of Low-Level Radioactive Waste Disposal," prepared by Rogers and Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987

Facility Siting-Natural Site Characteristics

Selecting an appropriate site for a waste disposal facility involves a general regional screening of many sites, eliminating unacceptable sites, and examining in more detail a few potentially good sites. In selecting a disposal site, NRC regulations (10 CFR Part 61 .50) require that:

1. Primary emphasis be placed on site suitability in isolating the waste.
2. The site be capable of being characterized, modeled, analyzed, and monitored.
3. The projected population growth and future development shall not affect site performance.
4. Areas of known natural resources must be avoided if their exploitation would damage the site performance.
5. The site must be well-drained, free of ponding, above the 100-year flood plain, and away from coastal high-hazard areas or wetlands.
6. Upstream drainage areas must be minimized to decrease the amount of run-off that could erode a disposal unit.
7. The site must provide sufficient depth to the water table so that groundwater does not intrude waste packages.
8. Groundwater shall not be discharged to the surface within the disposal site.
9. Areas of active tectonic processes (e.g., faulting, folding, seismic activity, or volcanism) shall be avoided.
10. Areas of active surface geologic processes (e.g., erosion and slumping) shall be avoided.
11. The site shall not be located where nearby facilities or activities would damage performance of the site.

EPA has very similar siting criteria that they call location standards (14). Although these standards have not been finalized, NRC and EPA developed joint siting guidelines for commercial mixed LLW disposal. In addition to siting criteria listed above, the joint guidelines stipulate (22):

1. The site should provide a stable foundation for engineered containment structures. 12
2. Areas of highly vulnerable hydrology should be given special attention. Disposal sites located in such areas may require extensive, site-specific investigations that could restrict or modify a facility's design or operating practices. However, finding a site located in an area of vulnerable hydrogeology alone is not considered sufficient reason to prohibit siting.

Waste Form and Packaging

In the past, water infiltration into waste disposal trenches has been caused or aggravated by the compaction and settling of physically unstable waste after disposal and by the consequent collapse of the overlying cap into disposal trenches. **Compacting the volume of all LLW and mixed LLW to the maximum extent practical prior to disposal will prevent many of these problems. (See** ch. ***5*** for waste minimization and treatment techniques.) NRC regulations require that Class B and C waste remain physically stable for at least 300 years. Some States and compacts may require that Class A waste be stabilized too.

High-integrity containers (HICs) and concrete "overPacks' containing several waste canisters are used to provide added structural stability, water resistance, and shielding for the waste (see figure 6-6). These containers also simplify the loading of waste into a disposal facility and the removal of waste from a facility should removal ever become necessary or desirable. These containers have wall thicknesses ranging from several inches to 2 feet, depending on shielding requirements. Structural stability of the waste is less important if the waste is either encased in grout after emplacement or placed in a concrete vault.

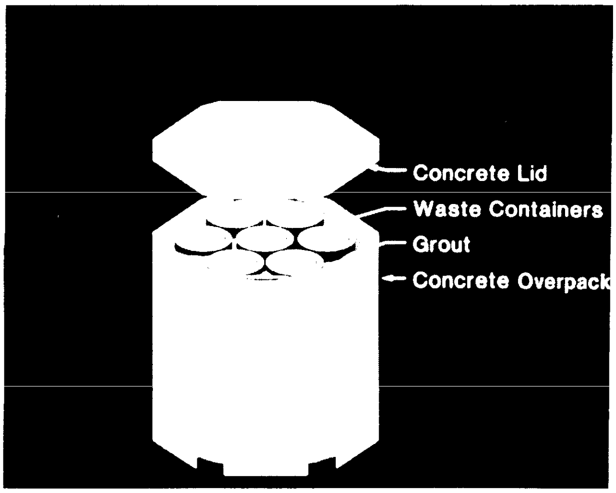
Engineered Features

Disposal Unit

After volume reduction and waste preparation, the waste is transferred to a disposal unit, which may have a dirt floor, a concrete loading pad, or an enclosed containment vault located in a trench (i. e., below-grade) or at ground level (i.e., at-grade). The loading surface of disposal units is typically sloped gently toward one or more sumps, which collect any infiltrating water. The loading surface may be underlain by a layer of gravel and an impermeable

12 Certain soils and geologic settings (e.g., karst) may be prone to subsidence or shifting when soil moisture or groundwater conditions change. It is not clear what types of soil are most desirable for a disposal facility. In permeable soils, infiltrating water can become contaminated and slowly percolate downward into groundwater aquifers. In impermeable soils, infiltrating water can fill disposal facilities like a bathtub and overflow into adjacent surface water supplies. EPA modeling studies indicate, however, that LLW disposal facilities situated in soils with low permeabilities may be safer than comparable facilities situated in well-draining, high-permeability soils (1).

Figure 6-6--Low-Level Radioactive Waste Overpack



SOURCE Courtesy of Westinghouse Electric Corp.

barrier that slopes toward additional water collection sumps.

Disposal units generally cover an area of several hundred to 1,000 square feet, with waste stacked a few tens of feet high, For small volume disposal facilities, disposal units may be sized to hold a year's supply of waste. Adequate space between disposal units may ease monitoring and waste removal should it become necessary. After a disposal unit is filled with waste, the unit can be surrounded by a layer of gravel to promote drainage of infiltrating water to collection sumps.

If concrete vaults are not used, soil, sand, or gravel can be used to fill the space between the waste packages. This type of fill material allows water to rapidly drain through the waste but helps to stabilize the waste packages in the disposal unit, Added stability could be important over the long-term as the waste packages degrade and the cap settles. These fill materials also allow easy removal of the waste, if such action ever became necessary after disposal.

Another alternative for stabilizing waste in a trench or tumulus involves injecting cement grout into and around the waste packages. On the one hand, grouting increases the stability of the stacked waste packages over the short- and long-term and helps prevent any infiltrating water from percolating around or through the waste (at least over the short-term), On the other hand, grouting makes it much more difficult to remove the waste from the

Photo credit: US Ecology, Inc.

LLW packages being transferred onto the dirt floor of a shallow-land burial trench,

disposal unit should such action ever become necessary.

Concrete containment vaults add structural stability to the disposal unit, help to prevent any infiltrating water from coming in contact with the waste. and provide an intrusion barrier around the waste. Walls are typically 2 to 3 feet thick; ceilings may range from 3 to 6 feet thick. Waste containers may be loaded into a vault through an open side or top, which is sealed after the vault has been filled. Vaults are designed to support their own weight. as well as the weight of the enclosed waste and overlying soil cover.

To evaluate the suitability of concrete for such vaults, DOE's Brookhaven National Laboratory

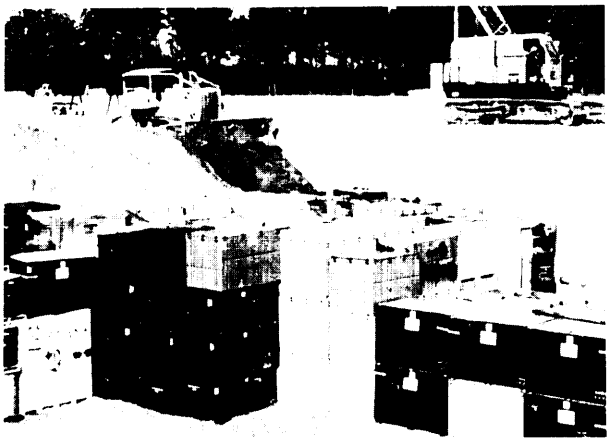


Photo credit: Chem-Nuclear Systems, Inc.

Stacked fill material being moved over waste containers in a shallow-land burial trench.

conducted an in-depth analysis of both ancient and contemporary concretes used throughout the world (6). The study found that some ancient concretes have performed adequately for 2,000 years or more. Although modem concretes have not been in use for much more than a century, there are many examples of these concretes performing adequately for periods spanning several decades and a few for periods of about 100 years (6).

Considering the harsh conditions that ancient concretes have withstood and the relatively benign conditions expected at most near-surface disposal facilities, it should be possible to make **concrete durable enough to last for a few hundred years and perhaps longer (6). Some predictive models even indicate that concrete will last longer than 1,000 years; however, beyond about 500 years, the uncertainty of such predictions increases.**[13]

After waste is emplaced in a vault, the space between the waste packages can be left open or filled with soil, sand, gravel, or cement grout if added stability is needed.[14] Added stability could be important over the long-term as the vault degrades and the cap settles. Emplacing fill material between waste packages is quite easy for top loading vaults, but somewhat more difficult for side loading vaults where working space is needed between the uppermost layer of waste and the vault ceiling.

Cap

After a disposal unit is filled with waste packages, it is covered with a gently sloping, single- or multi-layered cap. **The cap is the barrier with the most potential for diverting the greatest amount of precipitation away from disposal units. In addition, it is the feature of the disposal facility that is easiest and cheapest to repair, replace, or to cover over if infiltration does occur.** The long-term integrity of a cap is dependent on the cap design as well as the stability of the material underneath the cap, including the waste, the disposal unit, and the backfilled material around the disposal unit.

As shown in figure 6-7, caps maybe composed of multiple layers of different soil types and one or more interspersed impermeable synthetic membranes. These membranes can provide an excellent barrier against infiltrating water for the lifetime of the membranes, which typically spans a few decades. During this time, layers of compacted clay (e.g., bentonite) within the cap will naturally consolidate, thereby providing a long-term and hopefully permanent barrier against infiltrating water. Layers of gravel overlying the clay allow for drainage and lateral transport of water to surface drainage ditches adjacent to each disposal facility. A layer of cobblestones within the cap can provide a barrier to intrusion by burrowing animals. All these layers would probably be protected with a 2- to 3-foot surface layer of native soil.

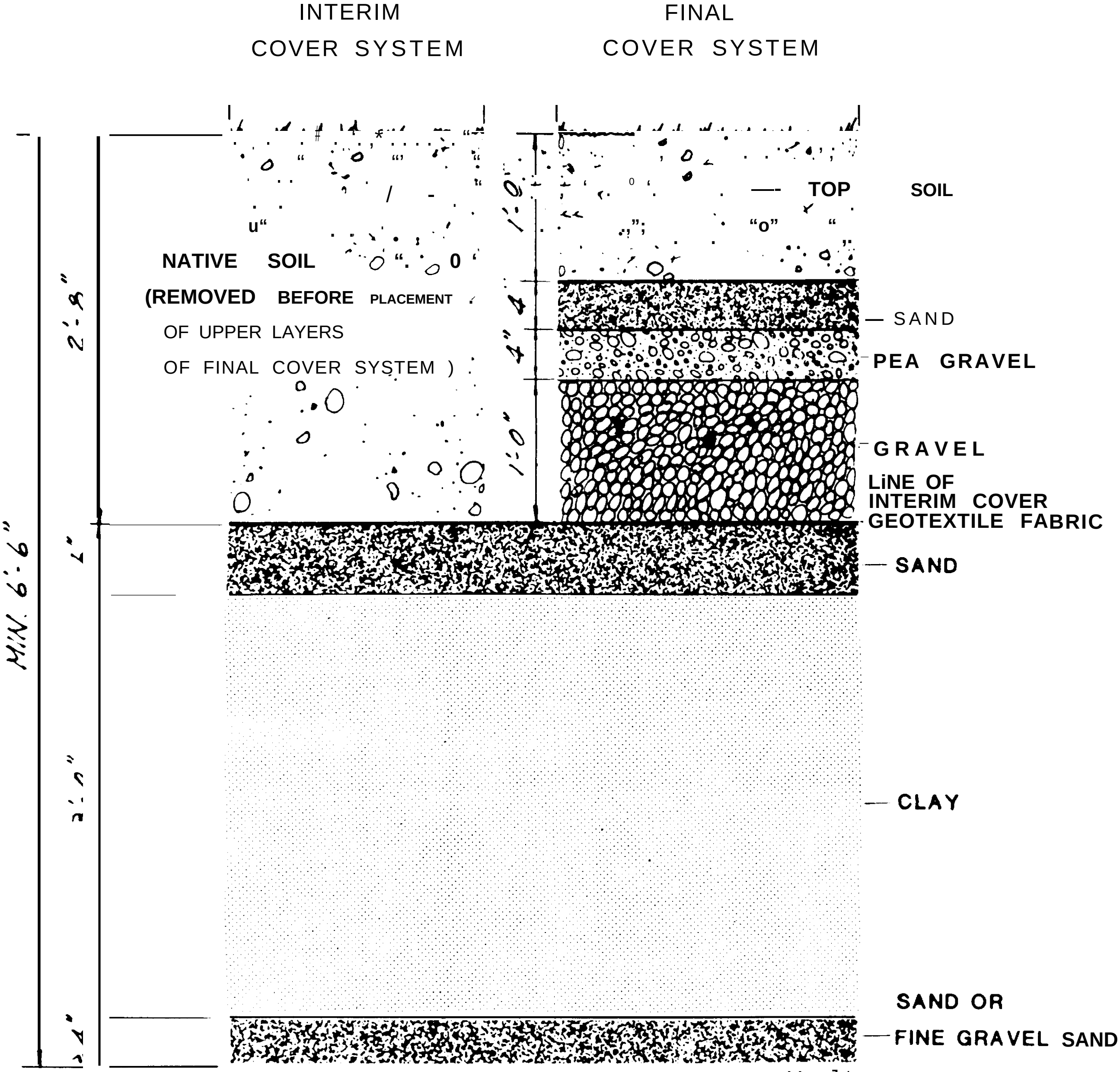
The thickness of the cap may range from 3 to 6 feet for Class A and B waste. A cap thickness of at least 16 feet is required over disposal units containing Class C waste. Alternatively, a thinner cap can be used if the Class C waste is covered by an intrusion barrier (e.g., concrete slab) with a lifetime of at least 500 years. Due to the adverse effect of freezing on clay minerals, layers of clay have to be buried a few feet below the lowest level of frost penetration, which ranges from less than a foot in the mild climates of some southern States to 4 or 5 feet in some northern States. As the thickness of the cap increases, the required strength of a vault and the height and breadth of the cap have to be increased.

[13] OTA workshop on disposal technologies, Salt Lake City, Utah, Mar. 6, 1989.

[14] Grouting, however, will make waste removal very difficult if such action ever becomes necessary.

[15] In arid regions, all of these layers would likely be unnecessary.

Figure 6-7—Typical Multilayered Cap



SOURCE U S Department of Energy, "Prototype License Application: Safety Analysis Report Belowground Vault, Vol. II: Appendices AH, " app. B, prepared by Rogers & Associates Engineerig Corp.for the Nuclear Energy Low-Level Waste Management program, DOE/LLW-72T October 1988

Most caps have surface slopes ranging from a few degrees on top of the disposal unit to a maximum of about 15 degrees along its sides.[16] Gently sloping cap surfaces may be planted with shallow-rooted vegetation, In arid regions it may be difficult to support vegetation on the cap. Rip rap (medium-size gravel) may be used to prevent erosion from infrequent flash flooding. The cap itself usually extends laterally a few tens of feet beyond the disposal unit and terminates at impervious lateral

[16] EPA technical guidance calls for a more gradual slope—one that ranges between 3 and 5 percent and the erosion rate is less than 2 tons per acre per year (16).

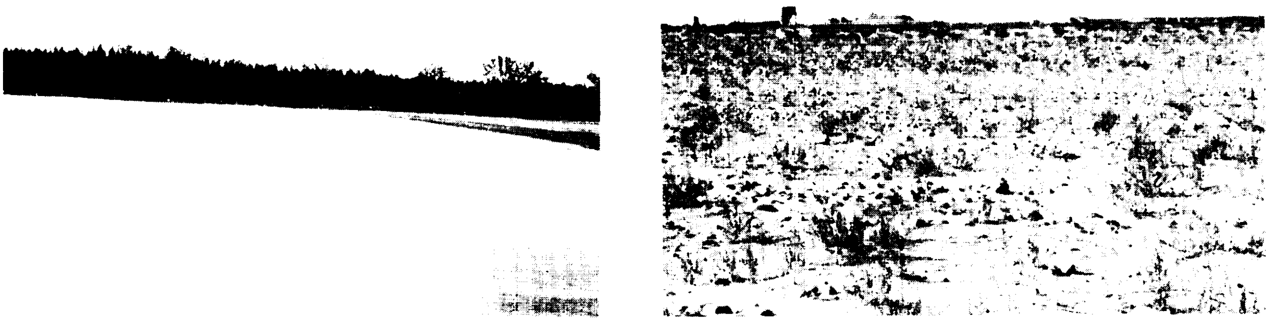


Photo credit: Gretchen McCabe

A contrast of the cap used over shallow-land burial trenches in humid regions (left) versus that used over arid regions (right). The cap on the left is at the Barnwell, SC and the cap on the right is at the Richland, WA site. The clay cap in Barnwell is monitored for subsidence for a few months and then covered with topsoil and planted with vegetation.

drainage ditches that carry surface runoff either offsite or to onsite retention ponds for monitoring, possible treatment, and subsequent offsite discharge.

Monitoring System

Past problems with radionuclide migration highlight the need for long-term monitoring of disposal facilities and sites. NRC or the respective Agreement State can independently monitor sites at its own discretion to ensure the accuracy of measurements taken by site operators. At a minimum, the site operator or custodial agency must continue periodic monitoring during the 100-year institutional period following site closure.

A monitoring program during site operation may include monthly or quarterly measurements of radiation levels in open and filled disposal units and periodic measurements of radionuclides in surrounding soil, vegetation, wildlife, air, surface water, and groundwater. The number of monitoring stations at a site and the sampling frequency may depend in part on the amount of annual precipitation and the past performance of the facility—the lower the rainfall and the better the performance, the less frequent the monitoring needs to be.

The best means for tracking the potential migration of waste constituents is to monitor the movement of precipitation over, around, and perhaps (in worst cases) through disposal facilities. As facilities are currently designed, the vast majority of precipitation falling on a disposal site is diverted away from the buried waste by the cap covering each disposal unit. Any migration of contaminants from the waste would be associated with small amounts of water that might infiltrate through the caps; if there is no leakage through the cap, there should be no migration of contaminants (assuming the disposal site is far removed from groundwater).[17]

Three primary locations for collecting and monitoring infiltrating water are often included in new disposal facility designs in humid regions. Sumps in the loading pads or vault floors collect water moving downward through the disposal units. Sumps in the gravel layers under the loading pads or vault floors collect water moving through the backfilled material surrounding the disposal units. Monitoring wells are also typically located around the perimeter of disposal sites. However, disposal facility designs have yet to incorporate a monitoring system into the lower layers of a cap so that leaks in the cap can be quickly detected and repaired before much water enters a disposal unit.

To minimize the migration of contaminants away from disposal units, any infiltrating water must *not* be allowed to accumulate in the disposal units and to saturate the waste. Infiltration can be prevented by pumping accumulated water out of disposal units or passively draining water (via gravity) to collection basins for monitoring, possible treatment, and offsite discharge. Most disposal site engineers believe that passive drainage that minimizes the dependence on human or mechanical

[17] NRC regulations prohibit the disposal of wastes with greater than 1 percent of free liquids; all liquids must be evaporated, solidified, or retained in absorbent material prior to disposal. Some States may also restrict the use of absorbent material and require the stabilization of all wastes.

measures is preferred. In some facility designs, the internal drainage collection pipes all run into a 6-foot-diameter concrete monitoring gallery under the site with a monitoring port for each drainage collection pipe. The more sumps there are, the easier it is to pinpoint the source of any leaks. However, it may be more difficult to maintain a more complex drainage and monitoring system.

Other Engineered Features

Many other engineered features can be incorporated into disposal facility designs to minimize the infiltration of surface water and to keep the waste as dry as possible. For example, the outside of concrete vaults can be covered with synthetic membranes, epoxy resins, bentonite panels, etc., to increase their resistance to water. The insides of vaults and concrete containers can be coated with epoxy resins, asphalt, synthetic liners, or other waterproofing materials. Open disposal units can be covered with some sort of mobile roof during filling to shelter the waste from precipitation.

General Designs of Near-Surface Disposal Facilities[18]

Most engineers who are familiar with the disposal of LLW and hazardous wastes believe that **acceptable near-surface disposal facilities for LLW *and* mixed LLW can be developed anywhere in the country using readily available materials and widely applied construction techniques.** Furthermore, they believe that **significant breakthroughs in technology are not necessary, imminent, or worth waiting for. The probability is high that disposal facilities that are well-designed, well-constructed, and well-maintained can safely isolate LLW and/or mixed LLW for a few hundred years and perhaps even longer.** Incremental improvements will come from construction experience and the long-term monitoring of facility performance.

Disposal facility designs now being developed by States and compacts often incorporate many of the natural site characteristics and engineered features described above. **The use of these features to prevent water infiltration, especially at sites located in humid regions, tends to increase the level of public confidence in the long-term performance of disposal facilities.** However, facilities that do not incorporate these features, especially those facilities in arid regions, should not necessarily be considered unacceptable.

Although disposal facility designs have improved over the last decade, **States must create an institutional process to ensure the proper siting, design, construction, and management of disposal facilities.** Using a more sophisticated and/or expensive facility design will not necessarily improve the long-term containment of the waste if the facility is not properly developed and managed. The consequence of inadequate design and shoddy construction and/or management may not be evident for many decades after a disposal facility has been closed. Moreover, adapting a good general design to fit the natural characteristics of a specific disposal site can be as or more important than choosing the general design itself.

Below-Grade Facilities

With below-grade facilities, the elevation of adjacent surface drainage channels is above the highest level of buried waste. (See figure **6-8.)**

All commercial LLW disposal facilities in the United States have used ***trenches,*** a disposal technology commonly referred to as **shallow-land burial** (SLB) (see figure 6-1). Typical trenches may be 20 to 60 feet wide, 20 to 40 feet high, and several hundred feet long. Trench floors are usually sloped a few degrees toward pumpable sumps located along the sides and at the ends of the trenches and are covered with a uniform layer of gravel for internal drainage. Once a portion of the trench has been filled with waste, it is normally covered with 3 to 10 feet of compacted soil from a newly excavated portion of the same trench or another. In many cases, a multilayered cap may be constructed over this fill material. Depending on the site characteristics, trenches may be spaced as close as 15 feet apart.

In light of the inadequate performance of SLB facilities in New York, Illinois, and Kentucky, nearly 80 percent of States and compacts have banned or restricted the use of SLB for isolating LLW (20). **"Improved" SLB is now practiced at**

[18]This discussion is based primarily on reformation from the U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal, prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987; and from the New York State Energy Research and Development Authority, "Handbook of Disposal Technologies for Low-Level Radioactive Waste," June 1987.

the three existing commercial disposal facilities in South Carolina, Washington, and Nevada. The primary improvements mandated by NRC's 10 CFR Part 61 regulations involve segregating Class A, B, and C waste, stabilizing Class B and C waste, and using an intruder barrier or deeper burial for Class C waste. To date, **there has been no offsite migration of radionuclides at any of these three facilities.**

Due to past problems with SLB, some States and compacts have expressed much interest in using ***below-ground vaults.*** As shown in figure **6-8, below-ground concrete vaults are underlain with a layer of gravel, and typically have sumps and a pump-out capability for removing infiltrating water. After the vaults have been filled with waste and sealed, the trenches are backfilled and typically covered with a multilayered cap.**

Below-ground vaults measuring 100 feet long, 50 feet wide, and 20 feet high have been used at DOE's Savannah River National Laboratory for the disposal of defense LLW, which is comparable to commercial Class B and C waste.[19] Below-ground vaults have also been used for the retrievable **storage** of transuranic and other LLW at the Oak Ridge National Laboratory, in Canada, and in other foreign countries.

Above-Grade Facilities

With above-grade facilities, the elevation of adjacent surface drainage channels is below the lowest level of buried waste. (See figure 6-9.)

An above-grade ***tumulus is*** now being used on a demonstration basis for the disposal of Class A waste at the Oak Ridge National Laboratory. A concrete pad measuring 100 feet by 65 feet was first poured at ground level on top of a layer of gravel. Compacted waste is being placed into reinforced concrete containers measuring about 5 feet by 6 feet by 7 feet. These containers are then placed in two layers on the concrete pad. The stacked containers will be covered with layers of clay, an impermeable membrane, and soil to form a low-gradient mound with a relief of about 20 feet. Vegetation will be used to prevent cap erosion.[20]

A tumulus has also been proposed (see figure 6-9) for the disposal of Class B and C waste generated by the cleanup of a now-defunct spent fuel reprocessing operation located at the West Valley, New York, facility. According to present plans, the final dimensions of the tumulus over the vault will measure about 30 feet high, about 250 feet across at the base, and about 500 feet long. Slopes on top of the tumulus will be a few degrees; slopes along the sides of the mound will be about 15 degrees.[21]

In cases where additional long-term stability is required, the waste can be disposed of in ***earth-covered, above-ground vaults.*** With this type of facility, the waste is placed inside a concrete vault constructed at ground level. Once the vault is covered with a cap, the facility will have the contour of a gently sloped tumulus. Such facilities have been proposed for waste disposal in humid regions of the United States, especially for Class B, C, and mixed LLW.

Earth-Mounded Concrete Bunkers

Earth-mounded concrete bunkers (EMCBs) have been developed and successfully used in France over the last two decades. Trenches are first filled to ground level with Class B and C waste, which is encased in concrete. Reinforced concrete is poured over the uppermost layer of waste, thereby forming large monoliths. Metal drums and/or concrete containers of Class A waste are then stacked on top of the concrete monoliths and covered with soil, giving the facility its tumulus shape. (See figure 6-10.)

There are two potential problems with this disposal scheme. First, EMCBs may have to be monitored and maintained for the 500-year lifetime of the Class C waste in the trenches even though Class A and B waste will have decayed within 100 years and 300 years, respectively. Second, dealing with potential problems with Class B and C waste might necessitate removal of the overlying Class A waste.

DEVELOPING SITE-SPECIFIC DISPOSAL FACILITIES

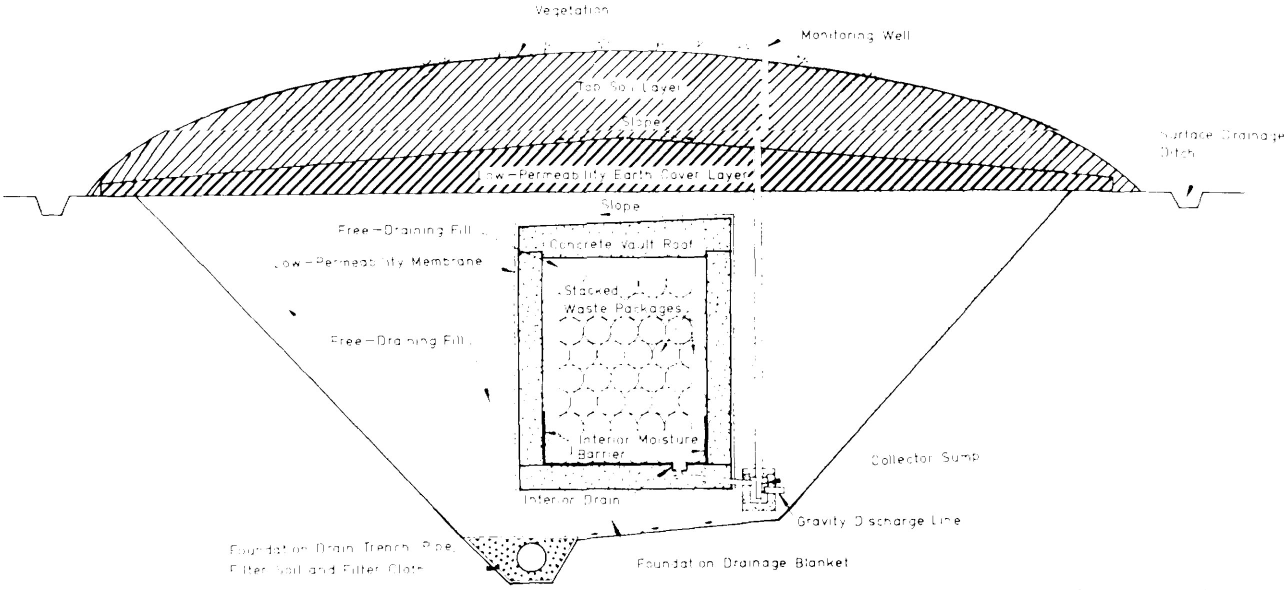
There are probably many acceptable ways in which different features can be incorporated into site-specific disposal facility designs. **Due to differences in site characteristics, especially annual**

[19] O'Rear, Op. cit., footnote 10.

[20] Robert Sleemen, us. Department of Energy, Oak Ridge National Laboratory, personal communication, June 16,1988.

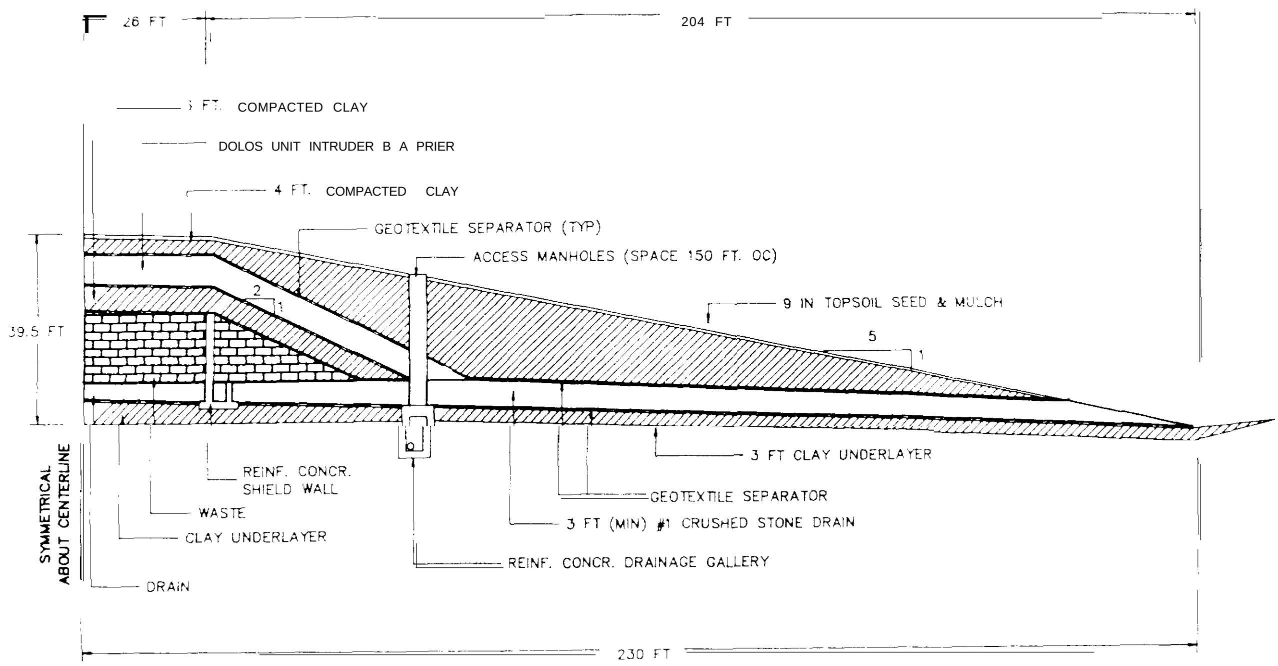
[21] Henry Wal_te r, U.S. Department of Energy, personal communication on Sept. 28, 1989.

Figure 6-8-Below-Ground Vault Cross Section



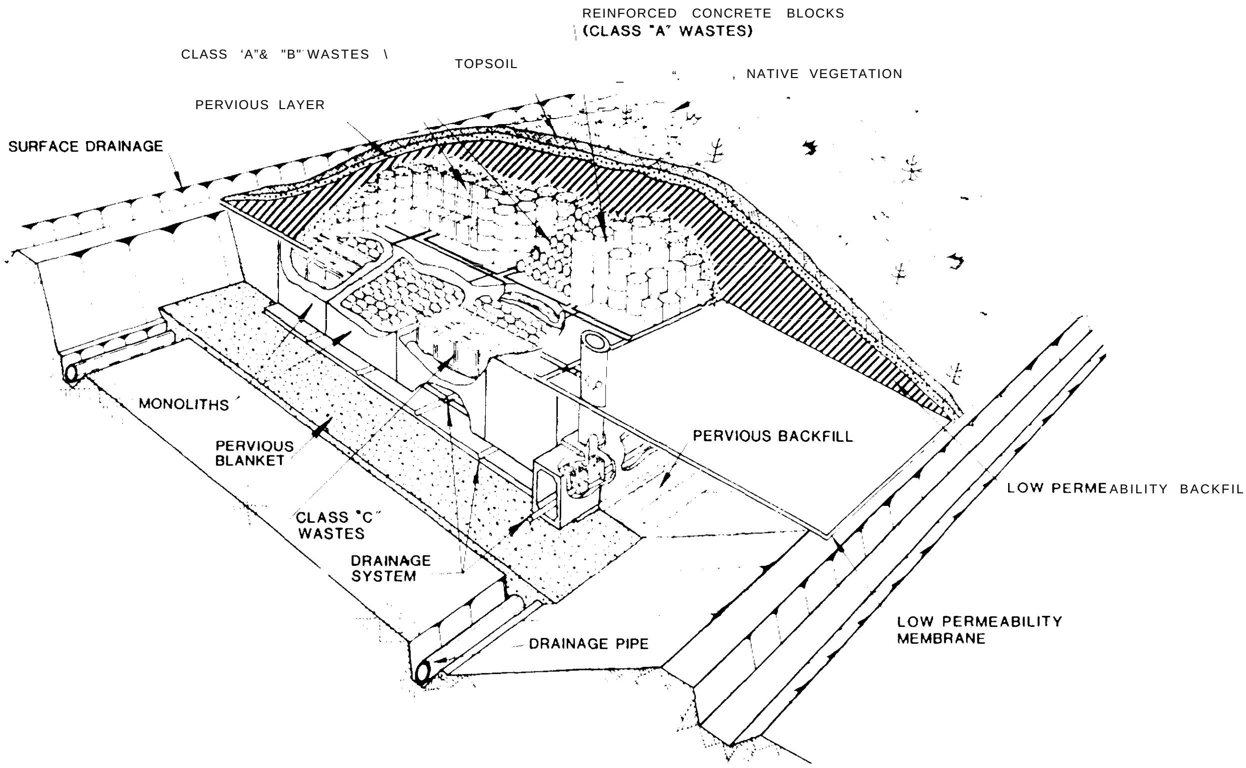
SOURCE: R.D. Bennett, "Waste Covers, Filters, and Drains," *Proceedings from The U.S. Department of Energy Ninth Annual Conference on Low-Level Radioactive Waste,* Denver CO, Aug. 25-27, 1987.

Figure 6-9—Above-Grade Tumulus Cross Section



SOURCE: R.R. Blickwedehl, and Maestas, E., "West Valley Demonstration Project Above-Grade Low-Level Waste Disposal Concept," paper given at Workshop on Disposal Technology Selection—"A Critical Path," Boston MA, June 28-July 1, 1987.

Figure 6-10--Perspective View of an Earth Mounded Concrete Bunker



A perspective view of the Earth Mounded Concrete Bunker depicts the approximate locations of wastes which are separated according to level of activity Class "C" wastes are embedded in concrete monoliths belowground while Class 'B' wastes and stabilized Class 'A' wastes are stored above-ground in earthen mounds over the concrete monoliths. A drainage network is provided within and around the structure to prevent the contact of water with the wastes and to provide collection and monitoring capabilities

SOURCE. U.S Nuclear Regulatory Commission, "Alternative Methods for Disposal of Low-Level Radioactive Wastes Technical Requirements for an Earth Mounded Concrete Bunker," contractor report prepared by the U.S. Army Corps of Engineers, Waterways Experiment station. NUREG/CR-3774, Vol. 4, Oct. 1965, p.6.

precipitation and time-of-travel of groundwater, there is no one disposal facility design that is optimum for all regions of the country. For example, a facility design that might be suitable for a site in an arid region might be inappropriate for a site in a humid region, and visa versa.[22] With increasing experience and long-term monitoring, some disposal facility **designs will undoubtedly prove superior to others.**

Selecting an Appropriate Facility Design for LLW

Both below-grade and above-grade facility designs have advantages and disadvantages when used in regions of the country with high or low precipitation. Regardless of the design chosen, it is of utmost importance to keep LLW and mixed LLW dry.[23]

22 Wind erosion and intense periods of rainfall are concerns in arid environments, An above-grade structure may require more active maintenance In arid climates than a below-ground structure. Furthermore, a clay cap used in humid regions may dry out and crack m arid regions.

23 Many other parameters can be Used to evaluate the desirability of disposal facility designs, These parameters include: protection Of the genera] population, protection of inadvertent intruders, worker protection, land requirements, costs, long-term stability, development time, previous operating experience, monitorability, licensability, ability to remove the waste after disposal, etc. More detailed comparisons of disposal facility designs arc provided in U.S. Department of Energy, "Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal," prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987; New York State Energy Research and Development Authority, "Handbook of Disposal Technologies for Low-Level Radioactive Waste," June 1987; and Illinois Department of Nuclear Safety, "Technical Considerations for Low-Level Radioactive Waste Disposal in Illinois," draft summary, November 1987.

Regions With High Precipitation

As engineered features decrease the potential for water infiltration, many of these features will likely see extensive use in humid regions of the United States, principally the East. In fact, the level of public confidence in the long-term performance of a waste disposal facility may depend on incorporating more of these design features, Design engineers generally agree that **"passive" features, such as natural down slope drainage, are generally more reliable over the long-term than "active" features, such as pumps.**[24]

If a disposal site is located in an area with a long groundwater time-of-travel and far from flood-prone areas, **infiltration of precipitation will be the most likely cause of buried waste coming into contact with water. Therefore, a well-designed and well-maintained** cap is used to prevent this scenario. If the cap is 100 percent effective, there should be no post-disposal migration of waste constituents from either below-grade or above-grade facilities. However, if infiltration occurs, the facility design will likely affect the rate at which water accumulates inside the facility, the rate at which contaminants leach from the waste, and the subsequent migration of contaminated water from the waste disposal facility.

Precipitation leaking into **below-grade trenches** tends to accumulate in sumps located at the ends or sides of the trenches. If water accumulating in the sumps is not pumped out, the trenches **can fill with water like a "bathtub."** Water in the trenches will eventually saturate the waste and will leach contaminants from it, Contaminated water will then percolate through the floor and walls of the trench into the groundwater and/or overflow at ground level. The same sequence of events can occur with below-grade vaults, but perhaps to a lesser degree. Any water pumped from trenches or below-ground vaults can be monitored and treated for contaminants and subsequently discharged offsite.

The "bathtub" effect is not a problem with above-grade tumuli or earth-covered, above--ground vaults. Instead. any water infiltrating through the cap is usually collected above an impermeable barrier (e.g., concrete loading pad, or a synthetic liner/clay layer below the disposal unit) that prevents downward migration of water below the lowest level of waste. Rather than accumulating inside the facility and saturating the waste, this collected water is typically channeled passively (via gravity) through buried pipes to external collection ponds, where it can be monitored, treated if necessary, and subsequently discharged offsite.

The ability to account for any water that infiltrates through the cap and into the disposal facility also varies between below-grade and above-grade facilities. With above-grade facilities, precipitation will either run off the cap, drain through the facility and into external collection basins, or remain inside the facility. With below-grade facilities, infiltrating water might also leak laterally through the vault or trench walls or downward through the vault or trench floor, if it is not immediately pumped out. Only monitoring wells around the disposal site perimeter would be able to detect any such leakage. Lining trenches and vaults with impervious natural or synthetic material will probably help contain infiltrating water inside below-grade facilities. but liners may also aggravate the bathtub effect and increase the likelihood that the waste will become saturated with water.

As shown in table **6-2,** certainty about the performance of a disposal facility is high if the cap sheds all precipitation from the facility. However, if the cap is less than 100 percent effective, **the potential for accurately determining the fate of infiltrating precipitation is high for above-grade facilities with a good monitoring system, moderate for below-grade facilities with a good monitoring system, and low for any facility with a poor monitoring system. In addition, in-cap monitoring systems would significantly improve engineers' ability to evaluate both the effectiveness of caps and the overall performance of above-grade and below-grade facilities.**

Since the bathtub effect is an unlikely problem for above-grade facilities, they probably have a greater potential for keeping buried waste dry if the cap leaks. Given comparable monitoring systems, **above-grade facilities also provide a higher level of certainty about disposal facility performance than do below-grade facilities.** However, above-grade facilities do have disadvantages rela-

[24] Some disposal experts believe that including too many engineered features into a facility design simply adds to its complexity and cost without necessarily improving its long-term performance. However, given the limited experience with different facility designs, engineers do not know at what point a facility may be considered overdesigned.

Table 6-2—Lsvels of Certainty About Disposal Facility Performance in Regions of *High* Precipitation

Good monitoring	Poor monitoring
Facility performance good Disposal facility design not critical High certainty about facility performance	**Facility performance good** Disposal facility design not critical Low certainty about facility performance
Facility performance poor *Above-grade facilities:* High certainty about facility performance and the need to treat infiltrating water	**Facility performance poor** *Above-grade facilities:* Low certainty about facility performance and the need to treat infiltrating water
Below-grade facilities: Moderate certainty about the nature of surface *and/or* groundwater contamination	*Below-grade facilities:* Low certainty about the nature of surface *and/or* groundwater contamination

SOURCE: Office of Technology Assessment, 1989

tive to below-grade facilities. First, disposal sites with above-grade facilities occupy about 70 percent more land area than sites with below-grade facilities (10), as shown by the wider cap in figure **6-9.** Due to increased land requirements for above-grade facilities, unit disposal costs are higher. Second, the broader surface area and steeper side slopes for tumuli could be more prone to erosion. Third, eventual unrestricted use of the disposal site may be limited by the ridge-swale topography.

Regions With Low Precipitation

Where there is no precipitation, there will be no infiltration of precipitation and no migration of waste constituents from either an above- or below-grade facility. In regions of the country where annual precipitation is very low today and will probably remain so over the next few centuries, principally in the **West,** there seem to be no technical reasons for **using the more elaborate above-grade facilities to dispose of LLW; below-grade facilities are adequate and likely preferable[25] in most arid regions.**

Selecting an Appropriate Facility Design for Mixed LLW

As described in chapter 3, NRC's 10 CFR Part 61 regulations emphasize physically stabilizing LLW to minimize cap subsidence and the subsequent infiltration of water. However, NRC-licensed facilities are ***not*** expected to contain all the waste (i.e., ''zero release' for any period of time. Instead, the hydrogeologic environment surrounding the disposal facility is expected to dilute, disperse, and adsorb any leaking contaminants to acceptable levels during facility operation and after facility closure. NRC requires an institutional care period of up to 100 years following site closure (10 CFR Part 61.59). This period is to ensure that no undue risk is posed to public health and safety from the disposal site.

EPA controls the disposal of hazardous wastes in landfills through its regulations found in 40 CFR Part 264. The goal of EPA's regulations is to totally contain hazardous wastes. To do this, the bottom and sides of EPA-licensed facilities are lined with layers of clay and double synthetic material, forming a double-lined bathtub. Leachate collection systems are situated between the double liners to prevent any leaking contaminants from escaping into the surrounding environment. If leaks develop in both liners during operation or pose-closure, pumping and treating contaminated water from remediation wells surrounding the site can hopefully be used to control the migration of waste constituents. In such a case, EPA would likely require extension of the standard 30-year post-closure care period (40 CFR Part 264. 117).

Over the last few years NRC and EPA have developed joint guidelines and joint guidance for siting and designing mixed LLW disposal facilities (22, 23), **These guidelines propose an above-grade facility as an acceptable design.** A multilayered cap forms an ''umbrella' over the waste, rather than a bathtub under the waste. EPA's double liners and leachate collection systems are located beneath the waste where they can intercept infiltrating water and channel it via gravity to collection basins for monitoring, possible treatment, and offsite discharge.[26]

A few humid eastern States are planning to use earth-covered, above-ground vaults for mixed LLW disposal, since these facilities appear to be more reliable for isolating waste in humid areas than below-grade facilities..

[25] The greatest environmental risk to an arid site may be from wind erosion and intense periods of rainfall; therefore, an above-grade structure would more likely be damaged than a below-ground facility.

[26] State and compact progress in developing mixed LLW disposal units is generally well behind their progress in developing disposal units for their nonmixed LLW. There are several technical and political factors causing this delay,

Arid States seem to prefer less elaborate, below-grade facilities rather than above-grade facilities. If precipitation is not a problem, there seems to be no technical reasons for using above-grade facilities rather than below-grade facilities, **or for using double liners and leachate collection systems beneath the waste, as** required by EPA's regulations. In fact, an above-grade facility could be inappropriate in arid regions due to wind erosion and/or water erosion from periods of intense rainfall that could damage it much more than a below-ground facility .27

Development Schedules

Designs for nonmixed LLW facilities must be approved by NRC or by Agreement States; designs for mixed LLW facilities must be approved by NRC or by Agreement States, *and* by EPA, or by a State with mixed waste authorization. Most host States are planning to obtain licensing/permitting authority from NRC and EPA for both LLW and mixed LLW facilities, since this approach appears to be the most expeditious. An optimistic schedule for developing a waste disposal facility, *barring nontechnical obstacles, is* shown in table 6-3. [U]

Regardless of the general disposal facility design chosen, there **are no *technical obstacles* preventing all States and/or compact regions from finding acceptable sites within their borders and designing, constructing, and licensing waste disposal facilities for LLW and mixed LLW. There are, however, institutional and political obstacles hindering facility development. This is particularly true for mixed LLW facility development.** Potential regulatory conflicts and inconsistencies and regulatory overlap and duplication between NRC and EPA have hindered mixed LLW disposal facility development (see chs. 1 and 3). Lawsuits have and likely will further delay development of both nonmixed and mixed LLW disposal units.

Phased Facility Development in Humid Regions

Multilayered caps have the greatest potential for diverting the vast majority of precipitation away from waste disposal facilities. However, caps must be compatible with site-specific facility designs and climatic conditions. For example, shallow-rooted surface vegetation must have an appropriate amount of precipitation and/or soil moisture for survival and growth.[29] Layers of clay within the cap also have to be buried a few feet below the lowest level of frost penetration to maintain the cohesiveness of the clay minerals.

It should be possible to develop a multilayered cap that is 100 percent effective in diverting precipitation away from a disposal facility for many decades or even centuries. However, developing such a cap may require experimenting with different combinations and arrangements of natural soils and synthetic membranes. The results of generic research could be applied nationwide. However, subjecting prospective cap designs to several years of testing under actual conditions would have to be conducted at or near actual disposal sites. In fact, it may require a decade or so to find the most appropriate cap designs for a particular humid region of the country.

Development of waste disposal facilities in humid regions need not be delayed while the performance of caps is tested in site-specific, long-term demonstration projects. Waste disposal units can be covered with a cap that could be replaced or covered over later if an alternative cap design proves more durable. If vaults are used, it may be possible to leave them uncovered until a cap that has performed well in a demonstration project is constructed. When effective caps are constructed and their performance verified *over a few decades,* it may be possible to eliminate some engineered features from later disposal units, thereby reducing future disposal costs.

[27] EPA believes that double liners and leachate collection systems are necessary in arid regions because of few, but intense periods of rainfall (written comments from Glen Galen, U.S. Environmental Protection Agency, Sept. 13, 1989). In contrast, arid site developers believe that these features will unnaturally trap water and increase contaminant migration (comments from Tom Baer, US Ecology, Inc., OTA Review Panel, Washington, D. C., Aug. 18, 1989).

[28] It should be noted that lawsuits will likely impede this schedule significantly.

[29] Riprap may have t. be used instead of vegetation on steeper, highly erosive slopes or in places where precipitation is insufficient to support vegetation.

Table 6-3-Optimistic Schedule for Developing a Disposal Facility[a]

Development activity	Year 0	1	2	3	4	5	6	7
Screen State and select numerous sites for evacuation	0- – – –	o						
Select most appropriate site		0						
Characterize site		o- – – –	– :– –	– –o				
Develop conceptual designs			o--D					
Develop operating plans			o—-o					
Perform safety analysis		o-	- – – –o					
Develop detailed designs			o- – –	- o				
Prepare license application and environmental report			o-— – –	7-o				
Submit license application				o-— --	o			
NRC/EPA/State reviews license					o– – – –	; — - – –	-o	
Preliminary licensing decision						0		
License granted							o	
Prepare site			:	:	:	: o– -	—-. 0	
Construct facility							o-– – –	-4
Begin operations								0

[a]It is likely that lawsuits will be filed and that this optimistic schedule will be significantly delayed

SOURCE: U S. Department of Energy, “Conceptual Design Report Alternate Concepts for Low-Level Radioactive Waste Disposal,’ prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987

REMEDIATING LEAKING DISPOSAL FACILITIES

Preventive Measures

Waste constituents that leak from disposal sites into the environment are often very difficult and expensive to cleanup. Under certain contamination scenarios, the waste may have to be removed from the facility, treated, and “redisposed” in a new facility. To prevent waste migration and costly redisposal operations, it will likely prove cost effective to invest in any one of the following, sequential activities:

1. **Careful facility development:** Waste disposal facilities will perform best if they are properly sited, designed, and/or constructed in accordance with widely accepted engineering practices. Whenever possible, ‘‘passive’ features (e.g., downslope drainage) should be used instead of “active’ features (e.g., pumping). If a disposal facility has not been properly developed, correcting some problems with available engineering techniques may be possible (18); otherwise, a facility may never function as intended.
2. **Monitoring and improving the cap:** Monitoring operations that quickly detect any leaks in a cap can avoid costly redisposal operations. Since a cap is only a small percentage of the cost of an entire disposal facility, a cap can be improved or replaced at a fraction of the cost of removing the waste from an inadequate facility and redisposing the waste elsewhere. **Repairing, replacing, or recapping leaking caps (or sections of caps) is probably the best route to long-term remediation.**
3. **Water removal and treatment: If the bathtub effect saturates below-grade trenches, it may be necessary to periodically pump the water out and treat any contaminated water with available water treatment techniques** prior to offsite discharge.

The likelihood that a facility will need remediation increases where the annual precipitation is higher and when waste remains harmful longer. Although longer-lived radioactive wastes and mixed LLWs with environmentally persistent hazardous constituents account for only a small percent of all LLW, it **may be prudent to build into the disposal fees the costs of potential remediation.**

Removing Waste From Disposal Units

The public’s acceptance of a waste disposal operation will generally increase if the waste can be removed from a disposal facility at a later date if necessary, Waste packed in high-integrity containers or concrete overpacks would make removal easier. However, the more isolated the waste is after disposal, the more difficult and expensive removal becomes. Overall, the ease and cost of waste removal depends largely on the design and size of the disposal units and the timing of the removal .[30] In general, **the removal of waste from a capped disposal facility should be considered only as a last resort.**

Disposal Units Without Concrete Vaults

Waste containers are easily removed from a trench or tumulus prior to the emplacement of a permanent soil cap. After this time, the ease with which the waste can be removed depends largely on the integrity of the containers holding the waste. High-integrity containers and/or concrete overpacks will generally make waste removal easier for the first few decades after disposal; much later, however, waste removal will be increasingly difficult as the waste containers or overpacks gradually degrade.

Cement grout can be poured or injected into and around all the waste packages or overpacks emplaced in a trench or tumulus. Although grouting will increase the stability of the waste packages and help prevent any infiltrating water from percolating around or through the wrote, grouting makes it very difficult to remove waste from a disposal unit.

Disposal Units With Concrete Vaults

It is usually quite easy to remove ungrouted waste from a concrete vault **before vault closure.** If the vault is designed to be loaded through an open side, the waste can be removed in the same manner in which it was emplaced. However, removing a specific container of waste from inside the vault may require first removing many containers around it. For top-loaded vaults, a stack of waste containers can usually be easily removed before the roof is emplaced.[31]

Removing ungrouted waste from a vault **after closure may be relatively easy or very difficult. For top-loaded vaults with roof segments that can be lifted off (he vault with a crane, waste removal may be quite easy.** For most other vault designs without removable roofs, waste removal would involve breaking through a 2 to 3 foot thick concrete roof or vault wall. Waste removal would also involve stripping away all or part of the permanent cap.

For vaults where the space between waste packages or overpacks is grouted, waste removal would be extremely difficult. Grouting, however, probably would not be necessary because of the high level of stability provided by the vault itself.

Long-Term Monitoring

NRC regulations require up to 100 years of institutional control of disposal sites after closure to ensure that the disposal facilities are performing as designed and to provide some protection against inadvertent intrusion (10 CFR Part 61.59). At the end of this post-closure period, the license will be terminated and the site released for restricted or unrestricted use, depending on the nature of the disposed LLW and past performance of the site. According to EPA regulations, land disposal facilities for hazardous wastes must be monitored and maintained for 30 years after facility closure. Depending on the performance of the site, this period can be shortened or extended by EPA.

The level of public confidence in the long-term performance of waste disposal facilities can be increased by long-term monitoring. Since Class B, C, and **some mixed LLW will remain harmful well beyond 100 years, some States plan to monitor the disposal facilities containing these wastes for as long as the waste remains harmful.**

Disposal facilities, especially those in humid regions, may perform well over the short-term but may deteriorate after a few decades. The frequency of monitoring disposal facilities may have to be increased with time as the concrete and other structural components used in the overpacks and vaults degrade with age. It may be prudent to incorporate any assumptions about the necessity for long-term monitoring into the disposal costs for these long-lived wastes.

POTENTIAL AREAS FOR TECHNOLOGY IMPROVEMENT

Due to the low cost of caps and their accessibility (compared to other components of a waste disposal

[30] *The term* ***retrieval*** commonly refers t. the removal of waste from a disposal unit **prior to** the installation of a permanent, multilayered cap **During this time, wrote containers** or overpacks would probably remain intact. Easy retrievability provides the option of removing the waste from a disposal unit if the waste needs to be moved for some reason. **Recovery** commonly refers to the removal of waste from a disposal unit at some time **after** a permanent, multilayered cap has been emplaced and usually well after closure of the disposal facility. Depending on the timing of recovery, waste containers or overpacks may or may not be totally intact,

[31] Since vaults will probably provide all the stability necessary for a disposal facility, the usc of high-rn[cgrit! containers for waste packages may be unnecessary. However, high-mtcgrlt) containers may make it somewhat easier [o load or unload the waste.

facility), it is relatively inexpensive to repair, recap, or replace a leaking cap. However, to begin with, cap designs should be tailored to regional climate conditions. Developing better combinations of soil layers and synthetic membranes, particularly **for humid regions, probably holds the greatest potential for improving the performance of past and future near-surface disposal facilities. These** development efforts as well as long-term, onsite demonstrations may also benefit from advances in containment systems for hazardous waste landfills.

Additional studies **could also focus on improved monitoring systems that can be located inside the lower portion of a multilayered cap so that leaks in the cap can be identified and repaired as quickly as possible.** In addition, if settling of a facility was significant, the integrity of any drainage pipes that run under disposal units to monitoring ports could be damaged or completely crimped so that they are rendered useless. If this problem occurred, any water migrating from a disposal facility without an in-cap monitoring system would not be discovered until it reached the monitoring stations surrounding the facility.

Small-scale or prototype disposal units at each disposal site offer an opportunity for long-term, onsite demonstrations. In addition, closely monitored test facilities may be useful to better evaluate the overall and long-term performance of all disposal units within a site.

DISPOSAL COSTS[32]

The average cost per cubic foot of waste, or unit **disposal cost,** has increased significantly for all LLW over the last two decades, For example, unit disposal costs for most Class A LLW steadily increased from about $1 per cubic foot in 1975 to about $15 per cubic foot in 1980; disposal costs tripled between 1980 and 1986 (1 1). These cost increases stem primarily from two causes. First, compliance with NRC and State regulatory requirements developed in the early 1980s added to disposal costs. Second, the LLRWPAA created an optional schedule of increasingly higher surcharges for waste originating outside a disposal site's compact. As shown in table 6-4, there are additional penalties for generators if their respective compacts do not meet the milestones established in the LLRWPAA.

At the beginning of 1988, the minimum fees (including surcharges) charged by the three different LLW sites ranged from about $38 to $46 per cubic foot for dry Class A LLW (see table 6-5).[33] **Disposal costs will likely increase substantially in 1990 when the surcharge increases from $20 to $40 per cubic foot.**

Unit disposal costs are especially sensitive to the facility design, the annual waste capacity of the disposal facility, and the mode of financing used for facility development. As shown in table 6-6, more **elaborate facility designs can cost almost twice as much as shallow-land burial** now used at all three commercial sites. Table 6-6 also indicates that **unit disposal costs increase significantly as the capacity of the facility decreases.** For example, unit disposal costs increase by a factor of two as facility capacities decrease from 350,000 to 150,000 cubic feet per year. Moreover, as shown in figure 6-11, unit disposal costs increase by a factor of four as facility capacities decrease from 60,000 to 10,000 cubic feet per year. Finally, private financing will increase disposal costs about 10 to 31 percent over public financing, depending on the design and capacity of the facility (see table 6-7).

Unit disposal costs for LLW will undoubtedly increase over the next few years for four reasons. First, as shown in table 6-4, the surcharges on waste disposal will increase before States and compacts develop new disposal facilities. Second, as LLW volumes decrease, unit disposal costs at disposal sites will increase to cover fixed operating costs. Third, unit disposal costs at new disposal facilities may be higher, especially if: 1) more expensive disposal technologies are used, 2) new disposal facilities are smaller, and/or 3) waste packaging requirements are more stringent. Fourth, disposal costs for Class B, C, and mixed LLW may increase due to a recognized need for long-term monitoring and potential remediation.

Unit disposal costs will probably vary significantly from one State or compact to another for three reasons. First, the volumes of LLW generated

32Overall disposal costs cover the following items: disposal facility construction and operation; any surcharges (table 6-4); and extended custodial care, monitoring, possible remedial action, and administrative costs, The LLRWPA and its 1985 amendments do not set legal limits on fees that a disposal site may charge.

33These fees rise dramatically with increased radioactivity in the waste.

Table 6-4-Surcharges for LLW Disposal (dollars per cubic foot)

	States achieving milestones		States failing milestones	
Milestone	Year	Normal surcharge	Year	Revised surcharge
7/06 ... , ...	1986-1987	$10/ft^3^	1/86 to 7/86	$10/ft^3^
			7/86 to 1/87	$20/ft^3^
			l/87—site access may be denied	
1/88	1988-1989	$20/ft^3^	1/88 to 7/88	$40/ft^3^
			7/88 to 1/89	$80/ft^3^
			l/89-site access may be denied	
1/90	1990-1992	$40/ft^3^		
1/92		$80/ft^3^		$120/ft^3^
1/93		Site **access** denied	States take title to LLW or refund to generators 25% of surcharges paid during previous 3 years.	
1/96			States take title to LLW.	

NOTE: See also table 2-1
SOURCE” Office of Technology Assessment, 1989

Table 6-5-Approximate 1968 Disposal Costs for Class A LLW (dollars par cubic foot)

Site location	Volume disposed (ft^3 for 1988)	Disposal charge	Surcharge	Total cost
Richland, WA , ...	403,303	$18	$20	$38.00
Barnwell, SC	931,602	26	20	46.00
Beatty, NV	100,852	24	20	44.00
Total	1,435,757		Average	$42.67

SOURCE Lawrence P Matheis, Nevada State Health Division, letter to Leonard Slosky, Rocky Mountain Low-Level Radioactive Waste Board, Feb. 29, 1988 U S Department of Energy, Draft, “Integrated Data Base for 1988: Spent Fuel and Radioactive Waste Inventories, Projections, and Characteristics,” DOE/RW-0006, Rev 5, August 1989 p. 157.

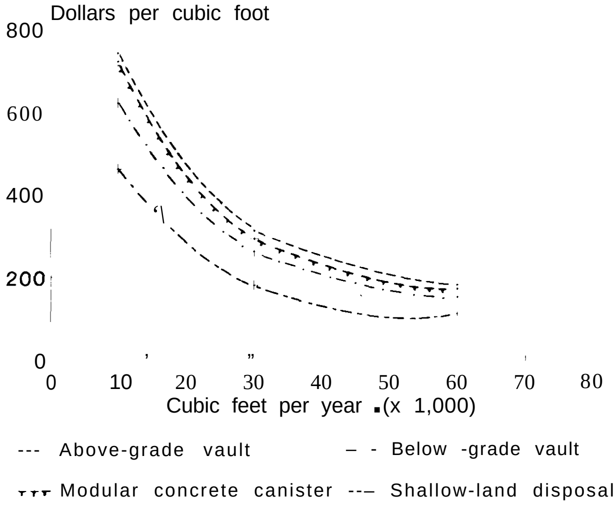
Table 6-6-Approximate Unit Disposal Costs Without Surcharges (dollars per cubic foot)[a]

	Facility capacity in thousands of cubic feet/year				
Disposal facility	10	60	50	230	350
Below-grade facilities					
Shallow-land burial	$460	$110	$55	$40	$30
Concrete containers . . . . Concrete vaults	$590	$140	$80	$55	$40
Above-grade, earth-covered facilities					
Concrete containers . . . . , .					
Concrete vaults	$670	$160	$90	$65	$50
Above-ground vaults (no earthen cover)					
Earth-mounded concrete bunkers	$780	$180	$105	$75	$55

[a]Costs assume public financing of the disposal facility.

SOURCE” U S Department of Energy, “Conceptual Design Report: Alternative Concepts for Low-Level Radioactive Waste Disposal,” prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-60T, June 1987, pp. 12-24, p. 25, U.S Department of Energy, “1 987 Annual Report on Low-Level Radioactive Waste Management Program,” August 1988, pp 17-19; EG&G Idaho, “Facility Life Cycle Cost and Average User Fee Projections for Small-Volume Low-Level Radioactive Waste Disposal Facilities,” DOE Contract No DE-ACO7-76IDO1570, February 1989; Rogers & Associates Engineering Corp , “Conceptual Designs and Preliminary Economic Analyses of Four Low-Level Radioactive Waste Disposal Facilities,” October 1987; US Ecology, Inc., “Proposal for Development and Operation of the Appalachian States Low-Level Radioactive Waste Compact Regional Disposal Facility,” prepared for the Commonwealth of Pennsylvania, Vol. II: Executive Summary, p. 18, and Vol III” Technical Presentation, October 1988; Julie Conner, EG&G Idaho, personal communication, May 1989,

Figure 6-1 l—Effects of Waste Volume on Unit Disposal Costs



SOURCE: EG&G Idaho, Inc., "Facility Life Cycle Cost and Average User Fee Projections for Smell-Volume Low-Level Radioactive Waste Disposal Facilities," prepared under DOE Contract No. DE-AC07-76D01570, **February** 1969.

by different States and compacts vary considerably. As shown in appendix A, the Southeast Compact generates about 500,000 cubic feet per year, whereas the Rocky Mountain Compact generates about 4,000 cubic feet per year. Second, disposal facilities located in humid regions will probably be more expensive than facilities in arid regions of the country due to the added design features required to minimize the infiltration of precipitation. Third, disposal facility costs vary according to local economic conditions, such as land values and labor and material costs, and according to State and local regulations .34

Table 6-7-Effect of Financing on Unit Disposal Costs for Shallow-Land Burial and Below-Grade Vaults (dollars per cubic foot)

	Facility capacity in thousands of cubic feet/year		
Financing	10	60	230
Shallow-land burial:			
Public	$360	$ 9 0	$33
Private	$460	$110	$40
Incremental cost of private financing ... , . .	28°7"	22%	18%
Below-grade vaults:			
Public	$450	$110	$50
Private	$590	$140	$55
Incremental cost of private financing	31 "/0	27%	10%

SOURCE. U.S. Department of Energv, "Conceptual Design Report Alternative Concepts for Low-Level Radioactive Waste "Disposal, " prepared by Rogers & Associates Engineering Corp. for the National Low-Level Waste Management Program, DOE/LLW-6OT, June 1987, pp. 12-24, p 25; EG&G Idaho, "Facility Life Cycle Cost and Average User Fee Projections for Small-Volume Low-Level Radioactive Waste Disposal Facilities," DOE Contract No. DE-ACO7-76IDO157, February 1989.

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34It is important to recognize that unit disposal costs are influenced by assumptions about specific characteristics of sites and facility designs, cost of capital, inflation, liability insurance, tax rates, operating lifetime of the facility, and many other factors incorporated into various cost models. Duc to the variation among disposal facility development costs, **each State or compact will need to obtain site-specific cost estimates for its respective site using updated and realistic financial assumptions.**

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