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Study of Engineering and Water Management Practices that will Minimize the Infiltration of Precipitation into Trenches Containing Radioactive Waste

EPA REVIEW NOTICE

PREFACE

The Office of Radiation Programs of the U.S. Environmental Protection Agency carries out a national program designed to evaluate population exposure to ionizing and non-ionizing radiation, and promote the development of controls necessary to protect the public health and safety.

This report was prepared to summarize current engineering and water management practices that could minimize water infiltration from precipitation into trenches containing buried radioactive waste.

Problems have occurred at existing commercial radioactive burial sites located in humid zones due to the formation of leachates containing radioactive nuclides from the waste materials. The leachates in turn provide a source, and in some cases, a driving mechanism for the migration of radioactive materials from the trenches into the burial site environs.

The present study examines methods by which burial site containment could be improved through the application of improved trench cover designs to existing and future burial sites. The work is based primarily upon a review of existing engineering practices as reported in the literature. The study has reviewed a number of materials and methods that could be considered for application at radioactive waste burial sites.

Readers of this report are encouraged to inform the Office of Radiation Programs - Las Vegas Facility of any omissions or errors. Comments or requests for further information are also invited.

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Final Report

STUDY OF ENGINEERING AND WATER MANAGEMENT PRACTICES THAT WILL MINIMIZE THE INFILTRATION OF PRECIPITATION INTO TRENCHES CONTAINING RADIOACTIVE WASTE

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CHAPTER 1
SUMMARY AND RECOMMENDATIONS

SUMMARY

Low-level radioactive solid wastes (radwastes) are generated by virtually every facet of the nuclear industry and are conventionally buried in shallow trenches at several land disposal sites. Burial practices are straightforward, involving placement of wastes into the trench, backfilling with soil, some compacting, and mounding of the surface soil to minimize ponding.

Disposal of low-level radwastes by these procedures has generally been effective. Escape from disposal sites of low-level radioactive material that could cause environmental damage is rare. However, the few problems that have developed at several disposal sites have spawned investigations into methods for improving the safety of low-level radwaste disposal practices. For example, water has infiltrated through soil covers and trench walls and filled trenches at several sites, and trenches have overflowed and leaked into underlying bedrock formations thus contaminating local ground and surface water with measurable radioactive material. So far, levels of contamination from such incidents have not exceeded safe limits, but suggest potentially more significant emissions.

Conventional low-level radwaste disposal practices can be improved. In some instances, improper sites have been selected, and operations have been inadequate. Disposal trenches are not always water secure, and infiltration and leakage have occurred. However, problem situations may be avoided in the future and are largely correctable at existing sites.

The purpose of this project is to identify methods by which infiltration of water into disposal trenches can be controlled or eliminated. Table 1 summarizes a variety of practices and concepts based on experience and research into the prevention of water movement at sanitary landfills and other waste disposal facilities on land, reservoirs, canals, dams, and other situations where water infiltration control is necessary:

- Barriers to minimize or eliminate infiltration of precipitation into radwaste disposal trenches;
- Methods to stabilize the surface at disposal sites; and
- Procedures to minimize perpetual site care requirements.

TABLE 1. SUMMARY OF CONCEPTS FOR CONTROL OF WATER INFILTRATION INTO RADWASTE DISPOSAL TRENCHES

Concept Description	Expected Longevity[a]	Approximate Cost/Trench Installed[b]	Reference No.	Comments
<u>Trench and Site Construction Alternatives</u>				
Situate disposal site on a slope	NA[c]	NA	42	Applicable for new trenches only
Situate disposal site on level ground	NA	NA	42	Applicable for new trenches only
Construct system of berms/ drainage ditches on the site	Indefinite with regular maintenance	$10/linear meter of berm or ditch		Should be implemented in all cases
Construct trenches with level bottoms	NA	NA	42	Applicable for new trenches only
Construct trenches with sloped bottoms	NA	NA	42	Applicable for new trenches only
Line trench bottom with permeable soil or other material	NA	$500-1,000	42	Applicable for new trenches only
Construct narrow gravel-filled diversion trenches around the entire site and/or individual disposal trenches	Indefinite with regular maintenance	$100/linear meter of diversion trench	36	Applicable for new trenches or as a remedial measure

TABLE 1 (Continued)

Concept Description	Expected Longevity[a]	Approximate Cost/Trench Installed[b]	Reference No.	Comments
Trench and Site Construction Alternatives				
Trench liners	Varies with material and exposure conditions; at least 5 to 40 years	$40,000 to 275,000, depending on liner material	28, 39, 75	Applicable for new trenches only.
Grout curtains around entire site and/or trench periphery	Variable; grout curtains for dams and buildings have expected lives of at least 10 to 50 years	Up to $70,000 depending on the grout material used	2, 7, 8	Applicable for new trenches or as a remedial measure.
Injection of a slurry of impermeable material into each trench to fill void spaces	5 to 50 years, depending on the filler material	$140,000 to 700,000 depending on the material	--	Applicable for new trenches or as a remedial measure.

TABLE 1 (Continued)

Concept Description	Expected Longevity[a]	Approximate Cost/Trench Installed[b]	Reference No.	Comments
Trench Caps and Covers				
Concrete caps (in general)	at least 40 years	see below	36, 52, 80, 28	Applicable for new trenches or as a remedial measure
-thin layer cap (10 cm)		$ 16,000		
-thick concrete mound cap (100 cm)		$140,000		
-concrete encapsulation and cover		$500,000		
Asphaltics	at least 15 years	see below	28, 37, 39, 55	Applicable for new trenches or as a remedial measure
-normal asphalt concrete (10 cm)		$3,600-5,400		
-hydraulic asphalt		$5,400-7,600		
-soil asphalt		$2,300		
-catalytically blown bituminous seal		$2,700-3,600[d]		
Soil cement	at least 25 years	see below	5, 39, 74	Applicable for new trenches or as a remedial measure.
-15 to 20 cm layer with a bituminous seal coal		$2,300		
-carbonate bonding (15 cm)		$2,400		

TABLE 1 (Continued)

Concept Description	Expected Longevity[a]	Approximate Cost/Trench Installed[b]	Reference No.	Comments
Trench Caps and Covers				
Synthetic polymer membranes				Applicable for new trenches or as a remedial measure.
-butyl rubber	at least 20 years	$5,000-$8,000[d]	39	
-polyethylene	at least 5-10 years	$1,800-$3,500[d]	28, 39, 40	
-polyvinyl chloride	at least 5-10 years	$2,300-$4,500[d]	28, 39	
-ethylene-propylene diene	at least 5-10 years	$5,000-$7,500[d]	28	
-chlorinated polyethylene	at least 5-10 years	$4,300-$6,500[d]	28	
-hypalon	at least 10 years	$4,300-$6,500[d]	28	
Clay	1,000 + years in absence of mechanical damage	$1,300 (37)-$10,000 (35)	1, 3, 5, 36, 39, 69, 82	Applicable for new trenches or as a remedial measure.

TABLE 1 (Continued)

Concept Description	Expected Longevity	Approximate Cost/Trench Installed	Reference No.	Comments
Trench Caps and Covers				
Soil sealants	at least 5 years	$1,000 and up, depending on the sealant material	33, 35, 86, 87	Applicable for new trenches or as a remedial measure.

a Expected longevity is the estimated time for the conceptual method to remain intact with minimum maintenance. A minimum of 40 years is considered essential.

b Costs approximate for a "typical" trench 100 m long by 15 m wide by 6 m deep. Costs include materials and installation. The costs do not include normal trench excavation and filling or maintenance. Maintenance costs can vary widely depending on what type of trench cap cover is used (soil, gravel, grass).

c NA - not applicable.

d Includes a 15 to 30 cm soil cover.

In general, these concepts have not been applied at radwaste disposal sites, although they have been proven elsewhere.

Surface infiltration can be controlled with a multilayer cover:

1. A compacted soil cover over the wastes, mounded;

2. An impervious cap of clay, concrete, asphalt, plastic, or similar material;

3. A protecting layer of soil; and

4. A layer of gravel.

Covers of this type would protect the wastes from surface infiltration and are themselves protected from exposure to environmental extremes and root damage from vegetative growth.

Infiltration of precipitation through the surface soil between trenches and thence horizontally into the trenches can be minimized through the use of berms and drainage ditches to divert surface runoff; construction of impermeable curtains or other barriers could be used to inhibit horizontal water flow.

A series of moisture cells placed in the trench bottom and below the soil cover can detect the presence of water in the trenches. Any water that has entered a disposal trench can be accumulated in a sump and removed by pumping via an access pipe before it saturates deposited wastes or flows offsite. If water is allowed to remain in contact with the wastes for more than a few days, it can become contaminated and thus require further treatment. Frequent monitoring and pumping can avoid water contamination problems. Pumping will be necessary until any danger of radioactive contamination has passed.

A properly located, designed, and operated low-level radwaste disposal site can be essentially water secure for several decades, if not centuries. Such security will require more effort and care than has been committed toward low-level radwaste disposal management in the past, and it will not be free. But, considering the potential damage from inadequate practices, control of water infiltration is neither infeasible nor prohibitively expensive.

RECOMMENDATIONS

The following recommendations apply to low-level radwaste disposal in general. A specific recommendation may not be applicable at all sites, but universal application is not the intent, nor is it expected that any one site would benefit from implementation of all of the recommendations. Finally, it should be noted that these recommendations are not intended to be requirements.

The recommendations are divided into three groups -- remedial steps that could be taken at existing sites and ongoing burial operations, new or improved practices that could be implemented during the design and operation of future sites, and post-closure practices.

Remedial Steps

- Where not already available, access wells should be placed at the low end of each trench and any standing water removed.

- Trench covers should be leveled, the cover soil recompacted, a new soil mound placed, and an impermeable cap and cover added.

- Moisture probes should be placed in each trench and monitored regularly.

- A series of berms and drainage ditches should be constructed and regularly maintained to handle surface runoff and prevent site flooding.

- At sites where trenches are leaking or leaking is suspected, or that are underlain by fractured bedrock, grouting should be considered as a means to prevent offsite movement of radioactive material.

- Consideration should be given to injection of an impermeable material into trenches where water contact or waste settlement has been or is now a problem.

New or Improved Practices

- Greater emphasis should be given to the site selection aspects of disposal activities. Over a span of several hundred years, leaks are possible at virtually any site; thus burial activities should be situated to minimize the impacts of such leaks on the local and areal environment. The newer low-level radwaste burial sites, which were selected after relatively extensive site surveys and hydrogeological investigations, are generally more secure than the older sites.

- Radwastes should never be placed in a trench containing standing water nor should they be dumped during a rainstorm. The trench should be drained ahead of time or a separate wet-weather trench with covers for contingency use provided.
- Temporary berms should be constructed around each open trench to prevent entrance of surface runoff.
- Wastes should be compacted as much as possible and, to minimize settlement as the organic waste fraction decomposes, void spaces filled with granular or other suitable material.
- Covers should be placed as noted in Remedial Steps, above.
- Moisture cells should be placed both immediately under the mounded cover and in the trench bottom. Any water detected in the trenches should be removed immediately. Immediate removal may avoid further treatment and disposal problems for the infiltrate.

Post-Closure Practices

- Vegetative growth over closed trenches should be carefully controlled or eliminated to prevent disruption of the cover's integrity by root propagation.
- Ground and surface water should be monitored regularly; soil and vegetation samples from the area should be analyzed for possible contaminants.
- Site inspections should be conducted regularly, especially following any major climatic or geological event.

CHAPTER 2

INTRODUCTION

BACKGROUND

In the early days of the Manhattan Project, little thought was given to radioactive waste disposal; it was secondary to the main task at hand. Solid wastes were usually buried in the most accessible and convenient vacant place without much thought for long-term consequences. Initially, this presented no problem because of the small waste quantities involved and the isolated nature of the research facilities. However, with the passing of time, nuclear research and production expanded and wastes accumulated. The commercialization of nuclear power and isotope technology led to commercial waste generation and the establishment of two types of waste burial facilities - federal (Atomic Energy Commission (AEC) or Energy, Research and Development Administration (ERDA)) for wastes generated by government research and production, and commercial, for wastes generated by industrial and private use of radioisotopes. The commercial sites were limited to low-level (<1 microcurie (μCi)/ ft^3 or gal.) radwastes. The federal government segregated high- and low-level wastes; most of their attention focused on the disposal problems of the more dangerous high-level wastes. Low-level waste land burial was not considered particularly hazardous.

THE PROBLEM

In November 1973, a group of researchers for the State of Kentucky identified radioactive tritium (hydrogen -3), cobalt -60, strontium -89 and -90, cesium -134 and -137, and plutonium -238 and -239 in the soils and surface waters below the Maxey Flats low-level radwaste burial site. A December 1974 report concluded that the disposal site was responsible for the unusual offsite radioactivity (46). At the West Valley, New York low-level radwaste burial site, water has been seeping out of two trenches and running off of the site into some nearby streams. The runoff contains elevated tritium levels (Richard Cunningham, 57). The levels of radioactivity in a Clinch River, Tennessee, tributary creek periodically exceed the maximum permissible EPA limits (See 10 CFR 20 and 40 CFR 158 for drinking water regulations). The radioactive materials are leaching out of several Holifield National Laboratory, Oak Ridge radioactive waste burial trenches which are flooded by a rising water table several months each year (46).

These and similar problems at the other low-level radwaste burial sites are among the formidable obstacles facing continued nuclear reactor development. Safe waste burial a necessity. If the leaching of wastes cannot be prevented, then an alternate disposal method must be developed; if there are none, waste generation, and consequently, nuclear technology development must cease.

The problems are not insurmountable, however. Radwaste burial is similar in principle to many hazardous waste control situations. The disposal technique must be such as to prevent any possibility of the hazardous material coming in contact with any part of the environment which could affect man. Traditionally, burial, or more generally land disposal, has been considered the best method for achieving this end. But, as the recent experiences at Maxey Flats, West Valley, and Holifield indicate, environmental contamination is still a possibility.

A basic problem with land burial is water: rainwater, surface runoff, groundwater. Water, leaking into or percolating through a burial site, can dissolve certain constituents of the waste. As the water percolates out of the site, it carries some of these constituents with it. If the contaminated water flows into a groundwater aquifer or surface water, it will contaminate parts of the environment directly affecting man.

When water attacks radwastes, the resulting leachate can contain not only dissolved organics and heavy metals, but also radioactive material. This radioactive leachate, because of its potential carcinogenic and mutagenic properties, is much more insidious in its effects than other hazardous leachates. Although such radioactive leachates are in one sense less hazardous than other toxic leachates because the radioactivity will eventually decay, the immediate health effects can be much more devastating. It should be noted at this point that none of the radioactively contaminated leachates thus far identified has had serious environmental or public health effects; the leachates have been low level discharges further diluted in the environment (Richard Cunningham, 57). The potential for serious damage in the future is nonetheless real.

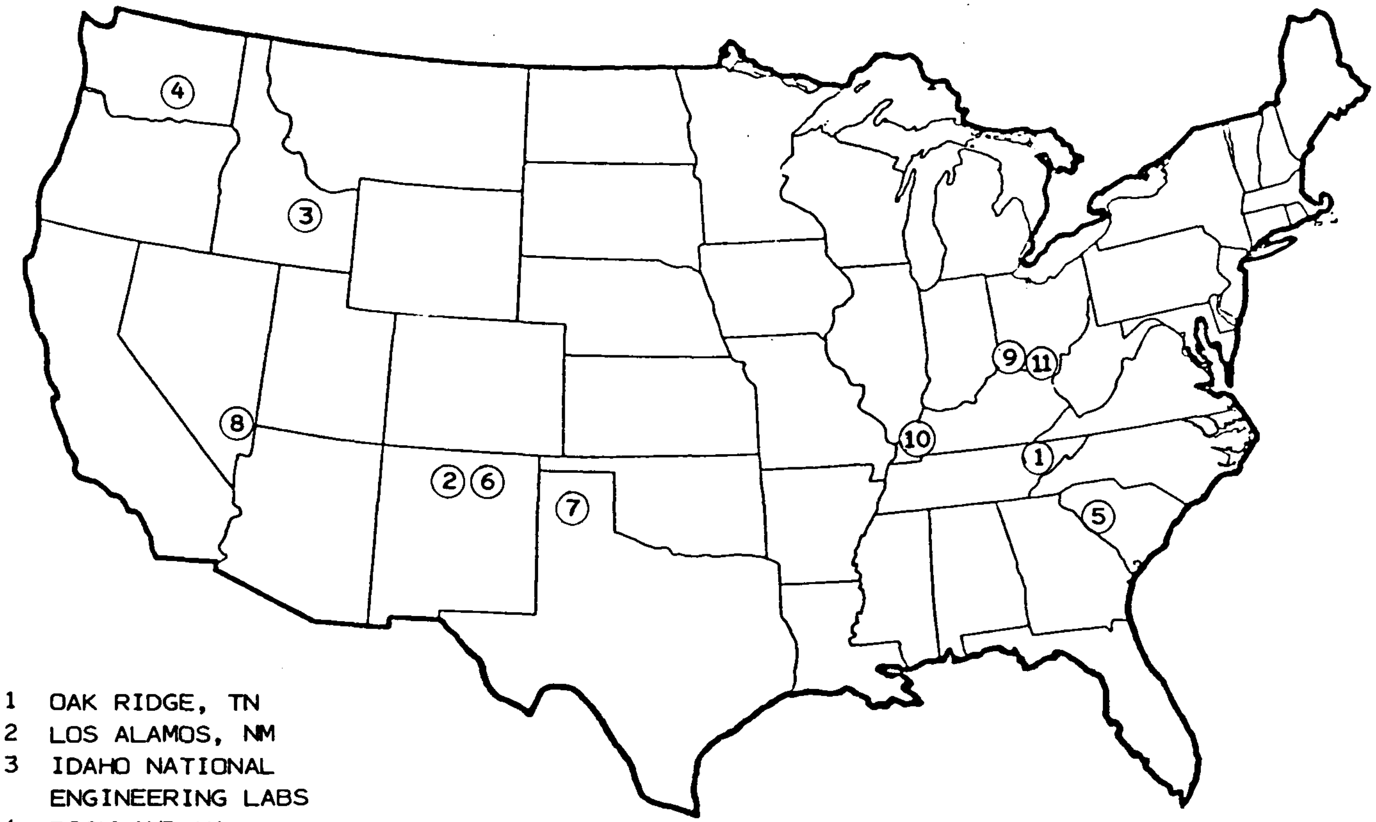
WASTE TYPES AND CHARACTERISTICS

Every operation involved with radioactive material produces wastes which either are, or may be, contaminated with radioactive isotopes. To date, nuclear weapons manufacturing has accounted for 83 percent of the radwastes generated; this is expected to decrease to 6 percent by the year 2000 (if nuclear power plant construction continues at the predicted rate) (Gerald H. Daly, 57). Most of the remainder of radwastes is from power plants and associated fuel reprocessing. A small fraction of the radwastes comes from hospitals, schools, and industries using radioisotopes. The AEC and ERDA have classified these wastes as "high-level" and "other" or "low-level." This report is limited to a discussion of low-level radwastes, defined as having a radioactivity of less than or equal to 1μCi/gal (3.785 liters) or cubic ft (0.028 cubic meters).

Physically, low-level radwastes may range from paper and rubber gloves to a contaminated 25-ton semitrailer (44). Commercial burial sites were originally licensed for low-level radwastes from hospitals, research facilities, and industry (68). However, the burial sites have been used increasingly for the disposal of contaminated wastes from the nuclear power industry. The radwastes buried at ERDA sites are wastes from nuclear weapons manufacturing.

Weapons-related low-level radwastes, to date, have totaled about 1.2 million cu m (43 million cu ft) (Gerald H. Daly, 57). These wastes are buried in five principal ERDA sites (Oak Ridge, Tennessee; Los Alamos, New Mexico; Richland, Washington; Savannah River, South Carolina; and the Idaho National Engineering Laboratory (INEL); and six minor ERDA sites (Sandia, New Mexico; Amarillo, Texas; Fernald, Ohio; Paducah, Kentucky; Portsmouth, Ohio; and the Nevada Test Site) (Figure 1). One million cu m (36 million cu ft) containing 1.8×10^7 Ci have been buried at the five principal sites, including 740 kg (1,632 lb) of plutonium at INEL and 212 kg (467 lb) of plutonium at Richland (46). The low-level radwastes from weapons manufacturing are currently being generated at a rate of about 37,000 cu m (1.3 million cu ft) per year, a rate not expected to change significantly before the end of the century (46).

There are six commercial burial sites operated by three private companies - Nuclear Engineering Company (Hanford, Washington; Beatty, Nevada; Sheffield, Illinois; and Maxey Flats, Kentucky), Chem Nuclear Systems, Inc. (Barnwell, South Carolina), and Nuclear Fuel Services (West Valley, New York), (Figure 2). To date, 258,000 cu m (9.1 million cu ft), or about 17 percent of the total low-level radioactive wastes generated, have been buried at these sites (Gerald H. Daly, 57). With the projected increase in nuclear power production, the commercial sites are expected to contain 94 percent of the low-level radwastes by the year 2000 (Gerald H. Daly, 57). Table 2 presents the projected average annual volume of low-level radwastes through the year 2000.



1 OAK RIDGE, TN
2 LOS ALAMOS, NM
3 IDAHO NATIONAL ENGINEERING LABS
4 RICHLAND, WA
5 SAVANNAH RIVER, SC
6 SANDIA, NM
7 AMARILLO, TX
8 NEVADA TEST SITE
9 FERNALD, OH
10 PADUCAH, KY
11 PORTSMOUTH, OH

Figure 1. ERDA radwaste disposal sites.

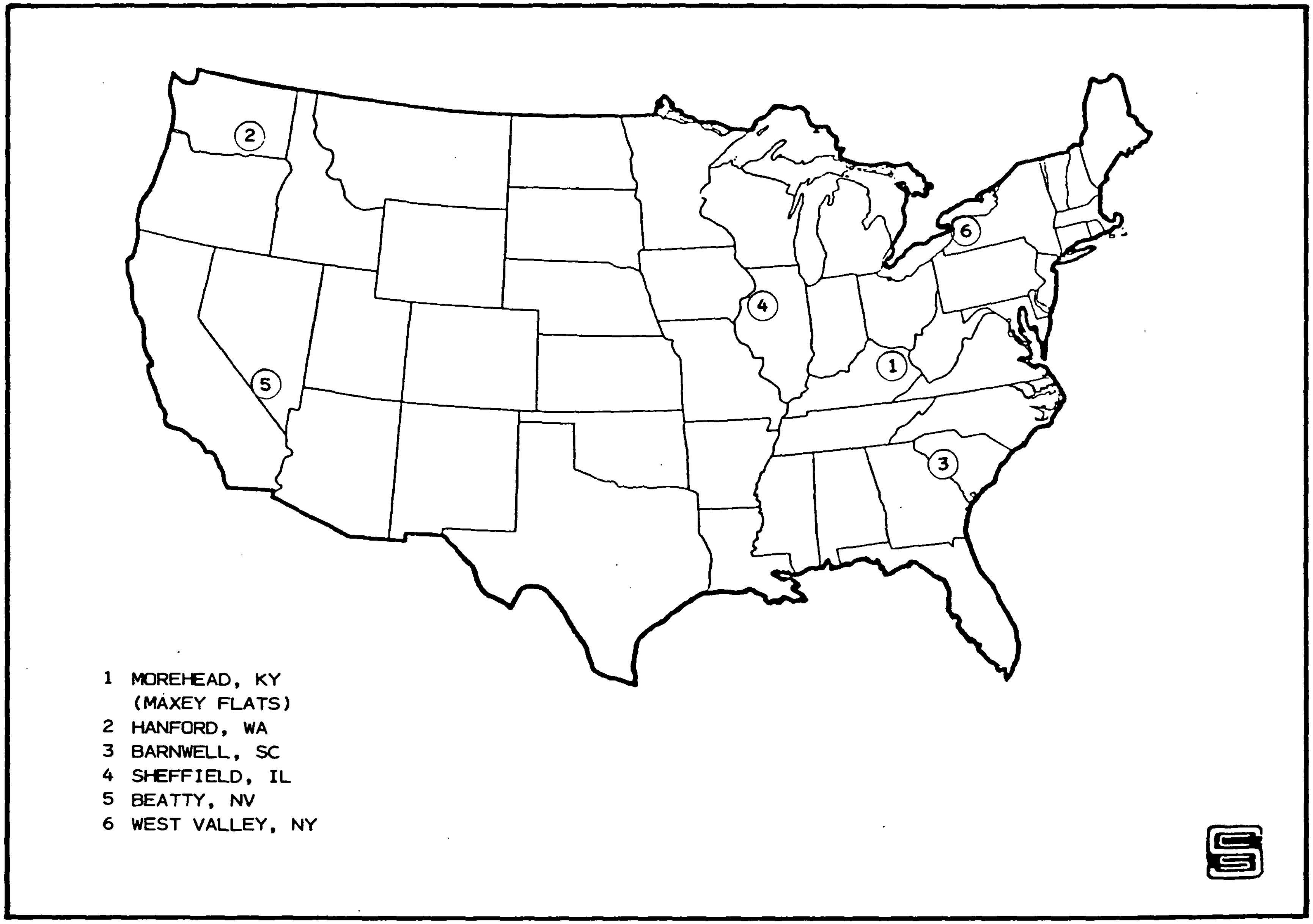


Figure 2. Commercial radwaste disposal sites.

TABLE 2. PROJECTED AVERAGE ANNUAL LOW-LEVEL RADWASTE GENERATION VOLUMES (68)

Type	(10^3 cu m/yr) 1976-1980	1981-1990	1991-2000
Fuel cycle waste	57	300	1,926
Non-fuel cycle waste	45	110	311
Total	102	410	2,237

Table 3 presents the total volumes and quantities of each type of waste buried at the six commercial sites through 1975.

DISPOSAL PRACTICES

Essentially all low-level radwastes generated in the United States are buried in trenches. Typical trench dimensions are about 90 m (300 ft) long by 12 m (40 ft) wide by 6 m (20 ft) deep, with 6 m (20 ft) between trenches (66). In practice, however, trench sizes vary somewhat: the trenches at Maxey Flats are 110 m (360 ft) by 21 m (69 ft) by 6 m (20 ft), while those at West Valley are 180 m (590 ft) long by 6 m (20 ft) deep (4). Each trench bottom is designed to be sloped at about 1 degree from end to end (10). A stone-filled sump at the low end of the trench permits collection and removal of any water that accumulates during filling and after the trench is completed.

The trenches are filled from the high end. The wastes may either be dumped randomly or stacked neatly, depending on their nature and a given site's operational procedures (Figure 3). Wastes generally arrive at the site in cardboard or wooden boxes, 55-gal drums, bulk (for equipment, demolition wastes, reactor shielding, etc.), or containerized liquid form. Much of the liquid radwaste is solidified with newspaper and concrete before disposal. Increasingly, paper trash and other loose or boxed wastes are solidified or encapsulated in concrete. One unofficial estimate is that up to 90 percent of all low-level radwastes being buried at present are solidified.

The trenches are backfilled as needed to keep radiation levels below federal government-set limits (100 mRem/hr around open trenches) (10). A minimum of approximately one meter of

TABLE 3. TOTAL VOLUMES AND QUANTITIES OF LOW-LEVEL RADIOACTIVE WASTES BURIED AT COMMERCIAL SITES THROUGH 1975[a] (Nuclear Regulatory Commission, 57)

Site	Volume (1000 Cu m)	By-product Material (1000 Ci)	Source Material (1000 lb)	SNM (1000 g)	Plutonium (1000 g)
Beatty, Nevada	52	128	110	178	14[b]
Maxey Flats, Kentucky	126	1,912	343	375	69
Hanford, Washington	12	440	17	33	13
Sheffield, Illinois	55	40	180	72	13
West Valley, New York[c]	68	538	605	55	4
Barnwell, South Carolina	60	253	283	343	0
Total	373	3,311	1,538	1,056	113

[a]*Numbers rounded to nearest thousand*

[b]Does not include 1974

[c]Closed March 1975; does not include 1975

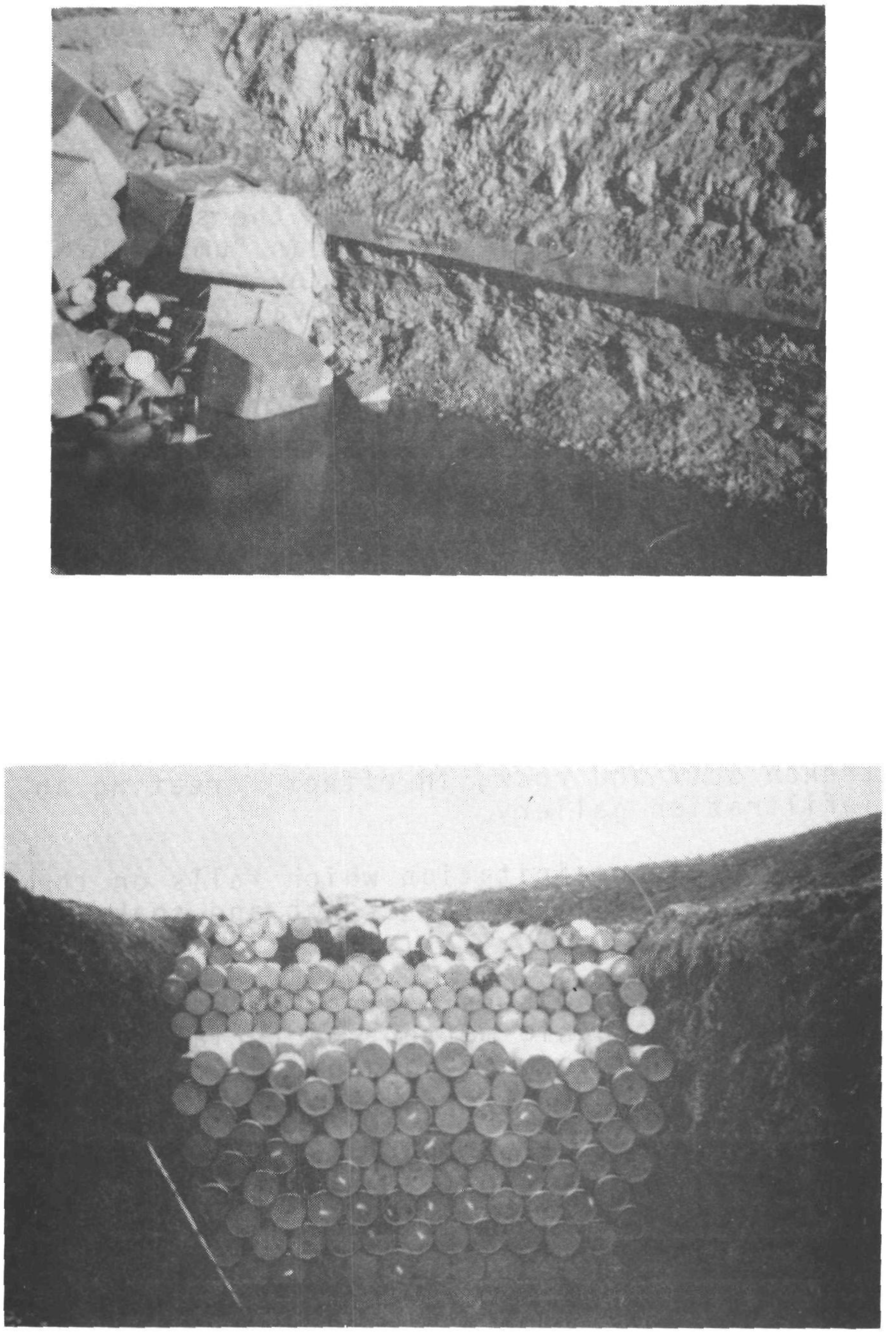


Figure 3. Radwaste disposal practices.

soil is required to prevent alpha and beta radiation leaks from the trenches. The radwastes themselves generally are not compacted. Thus, as much as 30 percent of the trench volume is void space (85).

As will be noted shortly, lack of compaction can lead to problems, which are largely avoidable, since the wastes are compactible and could be reduced in volume by factors of 2 to 10 (4, 12). As each trench is filled, the surface soil cover is compacted and shaped to form an "umbrella" to seal out groundwater and divert surface water (10). A standpipe is left in the sump to facilitate removal of any water which might collect in the trench bottom.

Meyer (60) has described what he calls a typical trench life cycle:

1. The trench is excavated from soils with relatively low permeability.

2. The trench is filled with high porosity, permeable, compressible wastes which contain organics and a wide range of chemical forms.

3. The wastes are covered with an earthen cap, which is often more permeable than the original pre-trench soil and rock, in effect creating an infiltration gallery.

4. Some of the precipitation which falls on the cap infiltrates into the trench and soaks the wastes.

5. Leaching of the wastes begins, aided by the presence of organic matter, bacterial action, formation of organic and inorganic acids, and chelating agents.

6. Trench leachate begins to (a) migrate downward and laterally, because of the hydraulic head imposed by the leachate in the trench and/or (b) to overflow at the land surface in springs and seeps at some low point between the cap and the undisturbed soil.

7. As the wastes are soaked and leached, they compact, undermine the cap, cause surface cracking, increase infiltration into the trench, and thereby increase leachate generation.

Furthermore, at the time the six low-level radwaste burial sites were selected, systematic site selection criteria had not been established. The geological, geochemical, hydrological, soil, climatological, and other criteria necessary to ensure that a given site would retain its radioactivity had not been clearly formulated. Tentative site selection criteria are now being developed, and it is becoming evident that many of the sites currently in use are not suitable as radwaste burial sites (George D. DeBuchananne, 57).

With the increase in solidified wastes and the decrease in loose, compressible, biodegradable organics, much of this settlement/trench cover collapse problem has been overcome. There may still be a problem of settlement in the loose backfill between and around the solidified wastes.

Among the other potential problems that can be encountered at radwaste burial sites are gas generation and nearby new trench construction. Any organic, biodegradable materials will generate methane and CO_2 upon biodegradation. Unless the gas is allowed to escape through the cover cap or vents, pressure buildup can rupture a cap. Furthermore, the methane can present an explosion hazard if allowed to accumulate in enclosed spaces. Gas hazards are also minimized by increasing waste solidification, but older burial trenches may still present problems.

The construction of new burial trenches can also pose a threat to completed trenches because of nearby heavy equipment traffic. Unless care and planning are devoted to new trench construction, it is possible for heavy equipment to inadvertently drive over completed trenches and damage covers. Also, construction of new trenches adjacent to previously filled ones may affect the integrity of trench side walls, depending on soil conditions and separation distance.

PROJECT OBJECTIVES

Radioactive contaminants are reportedly leaving the burial trenches at several disposal sites. It is generally conceded that these contaminants are being (or at least may be) leached out of the buried wastes by infiltrating surface water from rainfall and runoff. The principal objective of this report is to investigate methods for selectively improving current and future land disposal operations for low-level radioactive wastes by:

1. Minimizing infiltration of incident rain water and surface runoff;

2. Maximizing surface stabilization to prevent rupture of the trench cap; and

3. Minimizing perpetual care requirements.

Secondary objectives include an investigation of methods to evaluate the water budget at low-level radwaste disposal sites and an evaluation of the economics for implementing improved infiltration control practices.

METHOD OF APPROACH

The core of this report was based on an extensive search of the literature. Because of the nature of the problem, not only literature on radioactive waste disposal, but also literature on solid and hazardous waste disposal, sanitary landfills, soil hydrology, channel and reservoir construction, seepage and mine drainage control was reviewed. The bibliography at the end of this report is by no means exhaustive, but it does present an excellent cross section of the pertinent literature available on these subjects.

Interviews with acknowledged experts in related fields were used to verify and update information from the literature. These individuals brought to the preparation of this report expertise in radioactive waste disposal, soil hydrology dynamics, and water infiltration prevention. Experience in solid waste and hazardous waste disposal was used to relate and evaluate all of the concepts and suggestions from these sources.

CHAPTER 3

WATER BALANCE CONSIDERATIONS AT LAND BURIAL SITES

INTRODUCTION

The various physical, chemical, and biological processes that occur within a land disposal trench produce compounds that are susceptible to solution or suspension in water percolating through the disposed wastes. This percolating water containing contaminants derived from the solid waste is leachate. The volume of leachate produced at any particular site is dependent on many factors but generally is determined by surface water infiltration and/or interception of groundwater. The relationship between precipitation/groundwater and leachate generation is not necessarily linear, nor does the presence of precipitation/groundwater necessarily result in leachate. Leachate generation is more directly related to the quantity of water which actually reaches the buried waste. The quantity of water, in turn, depends not only on precipitation but also on such factors as the surface and subsurface conditions and climatological characteristics in the area. Water balance concepts have been developed to assess the potential leachate problem for a given area in light of the variety of factors influencing leachate production. The usefulness of water balance in regard to radwaste disposal sites is twofold: (1) water balance evaluations can be used to help evaluate a candidate site's suitability in terms of leachate generation potential; and (2) water balance assessments can help establish the extent of any infiltration problem which might exist at a site in use and thus help determine what type(s) of controls, if any, are necessary.

WATER BALANCE FACTORS

Water balance is based principally upon the relationships among precipitation, evapotranspiration, surface runoff, and soil moisture storage. Also, regional geological factors, such as the site's location with respect to recharge and discharge areas, must be known to properly assess a site's water balance. Figure 4 shows a schematic of a typical waste disposal trench and the various water pathways available. Table 4 presents the equations relating the various water balance terms.

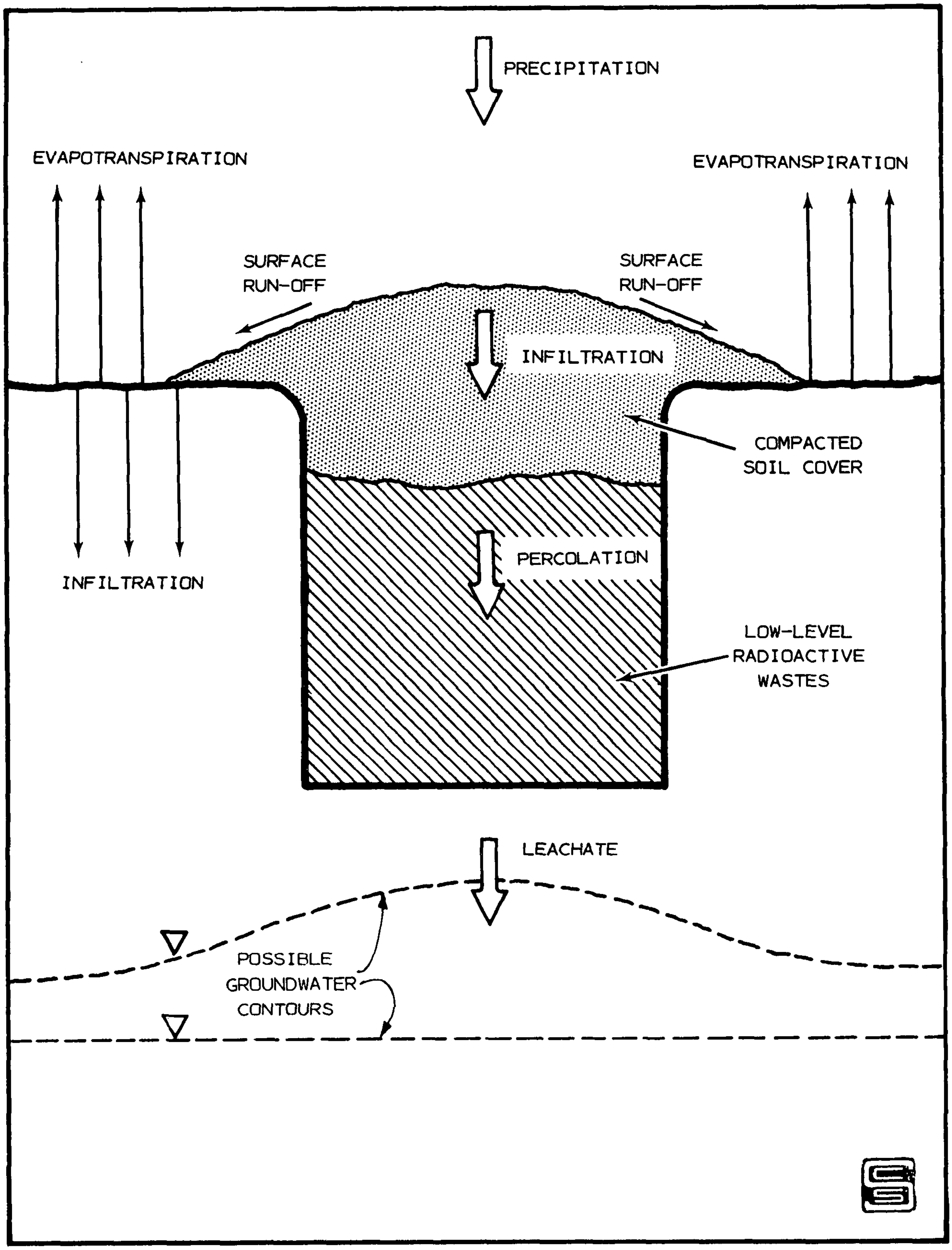


Figure 4. A typical waste disposal trench and water balance pathways.

TABLE 4. GENERALIZED WATER BALANCE EQUATION AT A WASTE DISPOSAL SITE (46)

$$W_R + W_{SR} + W_{GW} + W_{IR} = I + R + E$$

where:

W_R = Input water from precipitation

W_{SR} = Input water from surrounding surface runoff

W_{GW} = Input water from groundwater

W_{IR} = Input water from irrigation

I = Percolation

R = Surface runoff

E = Evapotranspiration

and:

$$I = S_S + S_R + L_G + L_S + W_D$$

where:

S_S = Change in moisture storage in soil

S_R = Change in moisture storage in solid waste

L_G = Leachate flow to groundwater

L_S = Leachate flow to surface waters

W_D = Water contributed by waste decomposition

Surface Water Inputs

The principal water source at most burial sites is precipitation (W_R). Irrigation water (W_{IR}) can also be a significant source, if the closed trenches have a vegetative cover which must be maintained by artificial means. In fact, irrigation has been implicated as a primary leachate source in semi-arid areas, where rainfall is insufficient to produce much leachate (22). Vegetation will be discussed later. At this point it should be noted that leachate from radwaste disposal sites is a sufficiently serious problem to prohibit irrigation, if such added water appears likely to increase the leachate production potential. The only other likely water source is site flooding (W_{SR}). Given proper site selection, flooding is a remote possibility; it is mentioned only because it happened at the INEL disposal site (Carl Kuhlman, 57).

Water applied to the surface of a burial site has four possible destinies: evapotranspiration (E), runoff (R), percolation (I), and retention (S_s). Evapotranspiration is the combination of evaporation from the soil and transpiration by the vegetative cover. Transpiration is usually the greater of the two (22). Surface runoff is that fraction of the added water which is lost to overland flow before it has a chance to infiltrate. Retention is the fraction of the water that is retained by the soil. The total amount of water that can be stored by a given soil is referred to as its field capacity and consists of two components - hygroscopic water (zero soil moisture to the wilting point) and available water (the wilting point to field capacity). Percolation water is that fraction of the soil moisture which exceeds the field capacity; it is this fraction which is responsible for saturating wastes in trenches and causing leaching.

Groundwater and Waste Moisture Content

Most water balance discussions dismiss groundwater (W_{GW}) and the initial moisture content of the wastes (Wo) as negligible relative to precipitation. There are exceptions, however. The groundwater table at the Holifield low-level radwaste disposal site rises periodically and floods several disposal trenches for a few months; radioactive material leaches out of the wastes during these periods and contaminates the nearby Clinch River. To date, this is the only reported incident of leachate directly related to groundwater infiltration.

Much of the low-level radwaste is metal, plastic, concrete, or other material with virtually no free moisture. Most liquid wastes are encapsulated; some wet wastes, such as filter sludges, are sealed in steel drums before disposal. Disposal trenches full of these drums could be a major leachate source if the drums rupture due to corrosion. Several ERDA low-level radwaste disposal sites are presently exhuming drums to encapsulate the wastes (80).

SITE FACTORS AND WATER BALANCE

Precipitation, groundwater, irrigation, soil moisture, evapotranspiration, runoff, retention, and percolation constitute a site's water budget. In addition, there are a number of variables which can affect a site's water budget and thus influence the quantity of leachate produced. These variables include site characteristics (soil types, topography, hydrology, ecology, meteorology), waste characteristics, waste disposal practices, and trench and site construction and management.

Site characteristics are perhaps the most important variables. It is conceivable that site characteristics could be such that no leachate would ever be produced, regardless of how poorly controlled the other variables might be (as in certain arid regions where annual rainfall seldom exceeds a few millimeters). It is sometimes possible to adjust these other variables to overcome otherwise prohibitive site characteristics, but ultimately, the natural site characteristics will determine, to a large degree, how much leachate a disposal trench can produce.

Soil Characteristics

The three soil characteristics which most strongly influence the water budget are (1) water intake (infiltration), (2) hydraulic conductivity, and (3) evaporation. Water intake is influenced by the amount of water applied and surface condition. Hydraulic conductivity (under saturated conditions) is influenced by particle size, compaction, aggregation, organic matter content, fracturing, etc. Evaporation is influenced by water availability, temperature, wind speed, and surface conditions. Soils with small particles (clays, silts) have a low hydraulic conductivity; large particle soils (sands) have a high hydraulic conductivity and poor water retention properties. This relationship is shown quantitatively in Table 5.

Topography

Topography most strongly affects runoff both onto and off of a disposal site. A site situated on a hillside would lose more incident precipitation to runoff than would a valley site, which might actually gain water from upstream runoff. For sites on a slope, steeper slopes have greater runoffs. As runoff increases, the amount of water available for infiltration decreases. The potential for local soils replaced as trench cover to erode and form gullies is also influenced by topography at the site. Such erosion may disrupt the

TABLE 5. WATER TRANSMISSION UNDER SATURATION (82)

Soil description	Hydraulic[a] conductivity cm/sec	Hourly transmitted volume m^3/ha
Well-graded gravels or gravel-sands, no fines	$> 10^{-2}$	$> 3.6 \times 10^{3}$
Poorly-graded gravels or gravel-sands, little or no fines	$> 10^{-2}$	$> 3.6 \times 10^{3}$
Silty gravels, gravel-sand-silt mixtures	10^{-3} to 10^{-6}	3.6×10^{2} to 3.6×10^{-1}
Clayey gravels, gravel-sand-clay mixtures	10^{-6} to 10^{-8}	3.6×10^{-1} to 3.6×10^{-3}
Well-graded sands or gravelly sands, little or no fines	$> 10^{-3}$	$> 3.6 \times 10^{2}$
Poorly-graded sands or gravelly sands, little or no fines	$> 10^{-3}$	$> 3.6 \times 10^{2}$
Silty sands, sand-silt mixtures	10^{-3} to 10^{-6}	3.6×10^{2} to 3.6×10^{-1}
Clayey sands, sand-clay mixtures	10^{-6} to 10^{-8}	3.6×10^{-1} to 3.6×10^{-3}
Inorganic silts, very fine sands, rock flour, silty or clayey fine sands, clayey silts with slight plasticity	10^{-3} to 10^{-6}	3.6×10^{2} to 3.6×10^{-1}
Inorganic silts and organic silts of low plasticity	10^{-4} to 10^{-6}	3.6×10^{1} to 3.6×10^{-1}
Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	10^{-4} to 10^{-6}	3.6×10^{1} to 3.6×10^{-1}
Inorganic clays of high plasticity	10^{-6} to 10^{-8}	3.6×10^{-1} to 3.6×10^{-3}
Inorganic clays of medium to high plasticity, organic silts	10^{-6} to 10^{-8}	3.6×10^{-1} to 3.6×10^{-3}
Inorganic clays of low to medium plasticity, gravelly clays, silty clays, sandy clays, lean clays	10^{-6} to 10^{-8}	3.6×10^{-1} to 3.6×10^{-3}

[a]Assumes that soils are saturated and uniform, and that sufficient water is available

integrity of trenchcaps. Table 6 gives typical runoff and infiltration characteristics for different topographical conditions.

Hydrology

Hydrology is the study of water in natural systems. Such study includes consideration of groundwater location, quantity, and movement and the hydraulic characteristics of the soil and the disposal strata. Characterization of the hydrological regimen for site selection will preclude groundwater interception of the disposal trenches throughout seasonal variations or intense periods of precipitation. USGS recommended site selection criteria include stipulations that piezometric levels be several meters below the burial site (68). The site's hydrological system, especially the groundwater, will play a major role in determining the pathways available to any leachates emanating from the fill.

Vegetation

Vegetative cover at a disposal site can influence runoff, infiltration, and evapotranspiration. Table 6 demonstrates how vegetation decreases runoff under all soil and slope conditions. Vegetation also increases infiltration by providing channels for water flow into the soil. However, vegetation does consume large quantities of soil moisture (Table 7), and this, in turn, increases evapotranspiration. Vegetation can also prevent site erosion, but long-rooted flora may intercept the trenches and carry radioactive material to the surface (51).

Climatology

Climatology includes precipitation and those weather factors which affect evapotranspiration or infiltration. Precipitation is the major water source at virtually all disposal sites. The quantities and seasonality of the precipitation strongly influence leachate generation: 125 cm of rainfall annually is more likely to lead to leaching than is 10 cm annually; 100 cm yearly falling in one month will have a different impact than 8 cm monthly for 12 months. The relative humidity of the air above the site will affect evaporation rates; dry air favors increased evaporation. Freezing temperatures prevent infiltration during the winter, but may disrupt natural or artificial infiltration barriers.

WATER BALANCE

Several mathematical models have been prepared incorporating water components and site characteristics (22, 79, 82). These models can be used to predict the percolation of water

TABLE 6. RUNOFF AND INFILTRATION FOR
A 2.5 cm RAINFALL (82)

Surface Condition	Slope	Rational Runoff Coefficient			Runoff (m^3/ha)			Infiltration (m^3/ha)[a]		
Cover Crop (Pasture or meadow)	%	Sandy loam	Clay or silt loam	Clay	Sandy loam	Clay or silt loam	Clay	Sandy loam	Clay or silt loam	Clay
Flat	0- 5	0.05-0.10	0.30	0.40	25.7	77.1	102.5	230.3	179.5	153.2
Rolling	5-10	0.10-0.16	0.36	0.55	41	91.1	141.0	215.3	163.6	114.7
Hilly	10-30	0.15-0.22	0.42	0.66	56.3	107.2	155.1	199.3	148.5	102.5
Cultivated (no vegetation, not compacted)										
Flat	0- 5	0.30	0.50	0.60	76.7	127.8	59.2	179.5	127.8	102.5
Rolling	5-10	0.40	0.60	0.70	102.5	153.2	179.5	153.2	102.5	76.7
Hilly	10-30	0.52	0.72	0.82	132.5	184.2	209.6	123.1	71.7	46.1

[a]Hydraulic movement directed downward

TABLE 7. APPROXIMATE SEASONAL CONSUMPTION OF WATER BY EXAMPLE TYPES OF VEGETATION (82)

	mm
Coniferous trees	102-229
Deciduous trees	177-254
Potatoes	177-280
Rye	≥457
Wheat	509-560
Grapes	≥152
Corn	509-1910
Oats	711-1020
Meadow grass	560-1525
Lucern grass	660-1400

into disposal trenches. Fenn, et al. (22) actually calculated water balances on a monthly basis for case study (nonradioactive) municipal refuse disposal sites in Cincinnati, Orlando, and Los Angeles. The calculations included actual and potential evapotranspiration, precipitation, surface turn-off, as well as infiltration, soil moisture storage, and changes in soil moisture storage. Historical climatological data was used as a basis on which to calculate expected leachate generation rates. Table 8 summarizes the results of these calculations. Similar calculations could be employed to determine the potential for leachate production at any site.

Radwaste characteristics, burial practices, and site management method influence percolation and leachate generation. Dry or anhydrous wastes will take longer to begin leaching than saturated wastes. Wastes sealed in steel drums or concrete will not leach until the casings begin to corrode and/or disintegrate. Radwaste characteristics will have little direct impact on percolation if the wastes are loosely packed in the trenches. However, decomposition of organic wastes can produce gas that may, in turn, affect the trench soil or membrane cover.

Current radwaste burial practices were discussed in Chapter 2. Many of the more serious radionuclide migration problems could possibly have been prevented with better placement practices. As the photographs in Figure 1 indicate, under past practices wastes remained in water-filled trenches for some time. Although now largely controlled, this is still a potential problem area and could be overcome by more efficient trench pumping operations and/or diversion of off-site runoff. At the very least, if there is a possibility that a trench may accumulate standing water, any exposed wastes could be covered to inhibit radwaste-water contact.

Another problem is the lack of waste compaction. As noted, filled trenches may be as much as 30 percent void space (68). This allows water to collect in a trench to such an extent that the wastes are often sitting in water. Technologies currently exist which could reduce the volume of radwastes by a factor of about 2.5, minimizing the problem (64). Compaction would help inhibit the settlement and cover-undermining discussed in Chapter 1. Trench life and disposal site life could be extended by compacting the low-level radwastes.

Compaction is not without problems. Aside from the added costs, there is increased risk of exposure to site personnel engaged in the disposal and compaction operations because of closer and longer contact with unshielded radwastes in open trenches. Shielding and shorter working periods could

TABLE 8. SUMMARY OF EXAMPLE WATER BALANCE CALCULATIONS FOR THREE AREAS[a] (22)

Location	Mean annual precipitation (mm)	Mean annual runoff (mm)	Mean annual infiltration (mm)	Annual mean actual evapotranspiration (mm)	Mean annual percolation (mm)	Time of first appearance of leachate (yrs)	Average annual leachate quantity expected (liters)[b]
Cincinnati, Ohio	1,025	154	872	658	213	11	40
Orlando, Florida	1,342	100	1,243	1,172	70	15	30
Los Angeles, California	378	44	334	334	0	--	0

a Not specifically related to existing radwaste burial sites.

b Landfill areas assumed: Cincinnati - 2×10^5 m^2
Orlando - 4×10^5 m2
Los Angeles - 5×10^4 m2

probably overcome this objection. Another possible solution to both the hazards and the compaction problem is encapsulation of the radwastes before disposal. Although beyond the scope of this study, encapsulation does appear to avoid many of the problems which plague current disposal operations.

When filled, each trench is designed to be covered with an umbrella shaped cap to encourage runoff of the trench surface. There are some advantages to placing disposal sites on slopes to discourage surface ponding and encourage runoff; this requires some sort of upslope ditch or berm to prevent the upslope runoff from draining into the disposal site.

Ultimately, the entire problem revolves around surface infiltration control. If no water percolates into the trenches, no hazardous leachate will percolate out. While easy to state in concept, such control is not so easy to accomplish in the field. A variety of barriers is available to prevent infiltration, but none is universally applicable, and all have serious flaws under some conditions. There have been few, if any, long-term (i.e., hundreds of years) studies done on these barriers, so their lifetimes are largely conjectural. However, proper coordination of barrier(s) and site conditions does hold promise as a leachate control method. The different types of barriers available and their advantages and disadvantages are discussed in the following chapters.

CHAPTER 4

TRENCH CAPS AND COVERS

INTRODUCTION

Meyer (60), in his description of a typical low-level radwaste disposal trench "life cycle" (discussed in Chapter 1), attributes the presence of water in trenches to rainwater infiltration through the trench cap. While this may not always be true, infiltration through the cap must be considered a serious potential pathway: a highly permeable cap will pass water readily. Consequently, it would be beneficial to consider concepts by which the trench caps may be made impermeable to infiltrating rain water.

Before discussing the concepts in depth, it should be noted that the integrity of many types of caps is dependent on the material in the trench. Meyer (60) describes virtual cap collapse due to settlement in the trench; this would occur with consolidation and decomposition of uncompacted paper and other organic, biodegradable wastes. Much of the radioactive waste in place at Maxey Flats, for example, is paper (60). Researchers (4, 68) have indicated that compaction of low-level radwastes in the trenches is, at best, poor and in some cases may be absent altogether. Under such conditions settlement is virtually inevitable, and the probability of trench cover collapse increases greatly. When the cover collapses, any water infiltration control methods previously implemented become superfluous.

Essentially, there are two ways to avoid this problem: 1) construct a trench cap of inherent structural integrity, or 2) bury only well-compacted or nonsettleable wastes. The first method calls for a rigid trench cap, such as a roof, steel sheet, or reinforced concrete. However, this approach has several disadvantages:

- The prohibitive costs of materials and construction,
- The questionable ability of such covers to last several decades because of corrosion or structural failure, and
- The possibly difficult access to the wastes in the event removal should become necessary.

Advantages include:

- Greatly decreased susceptibility to damage from vegetation, erosion, or nearby waste-handling activities; and

- Positive monitoring control.

The second option involves the nature of the wastes themselves. Much low-level radwaste (e.g., demolition rubble, concrete-encapsulated and/or metallic wastes) has the necessary structural stability to support a trench cap, especially in the absence of appreciable corrosion or water damage from infiltration. Biodegradable organic wastes (paper, boxes, carcasses, protective clothing, etc.) would require some sort of baling or dense compaction before disposal to inhibit settling. Even with the best compaction methods currently available, some settlement is likely, but uncompacted radwastes could settle by as much as 20 to 30 percent, assuming all void space is eventually filled by settlement.

ROUTINE TRENCH COVERING

As part of all trench completion procedures, approximately the top one meter of trench space would be filled with excavated soil, compacted, mounded, and sloped (Figure 5). It is doubtful that mechanical compaction will return the excavated soil to its original, undisturbed density, but compaction will help minimize infiltration. Mounding and sloping is necessary to facilitate runoff from the trench covers; the optimum slope is about 5 percent. A lesser slope could soon settle and create depressions for ponding of water, while a greater slope may be subject to erosion by surface runoff.

TRENCH CAPS

Frequently the soil of the trench cover is more permeable than the undisturbed soil between the trenches, even after compaction. Under certain circumstances, soil can be compacted to a lower permeability than the undisturbed soil, especially for porous soils. For most soils, however, the trench cover soil is invariably more permeable. Consequently, a further barrier may be necessary to completely inhibit surface water infiltration. This barrier, or cap, should be placed over the soil cover. There are a variety of materials available which can provide a relatively impermeable trench cap, but not all are equally suited for low-level radwaste disposal trenches. The materials discussed here are concrete, asphalt, soil cement, synthetic polymer membranes, clay, and various combinations of these materials with each other and the soil.

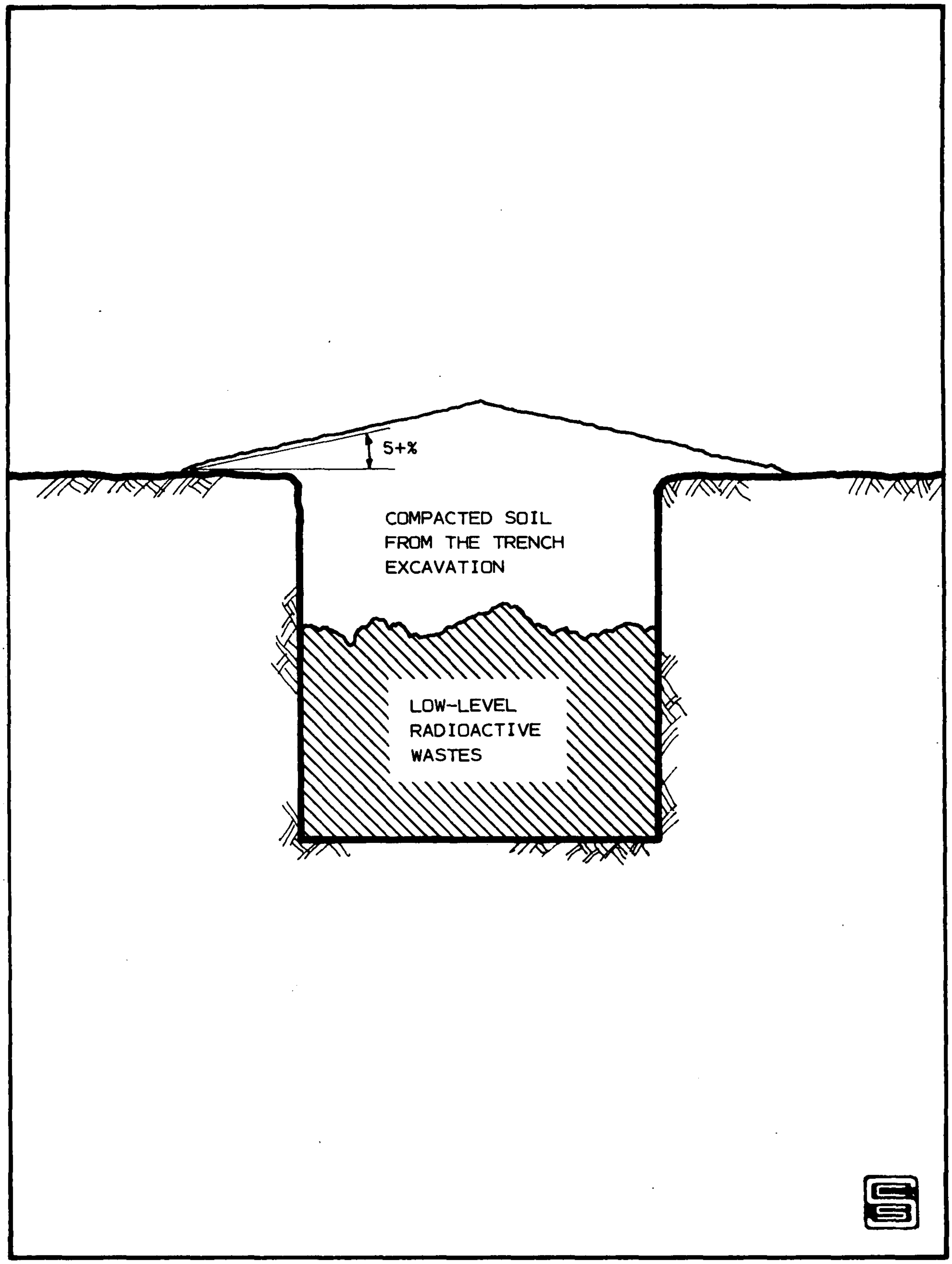


Figure 5. Typical trench completion.

Table 9 lists these materials with a summary of their characteristics. It should be noted that these cap concepts are largely untested in regard to radwaste disposal. Some of the concepts are almost hypothetical, in that no large-scale testing has been performed with any waste. They are presented because they are potentially valid concepts, not because they are proven solutions.

In evaluating and comparing the various trench cap concepts, several generalizations and assumptions are made. It is unlikely that any burial system can be kept intact and watertight for thousands of years, time enough for total decay of some low-level radwaste. However, perpetual maintenance may be unnecessary. If a burial trench can be kept tight for at least 40 to 50 years, most short-lived isotopes will have decayed, and infiltration will result only in the slow release of any radioactive isotopes remaining. Consequently, many experts consider that a burial trench concept life of 40 to 50 years is sufficient.

Concept costs given are for materials and installation costs above regular trench construction costs. They do not include backfilling, compacting, or maintenance. Maintenance costs can add significantly to the overall costs of some concepts, but these costs can be controlled through the proper selection of final cover materials.

Concrete

The usefulness of concrete as a water barrier is well documented. Concrete structures are expected to be watertight and, on the whole, they have performed well. Countless dams, canals, and water tanks are constructed of concrete. Properly designed and built concrete canal linings have been known to last 40 years or longer (52). A concrete cap is probably the strongest structurally of the cap types under consideration here.

Application--

In practice, a concrete cap could be applied several ways (Figure 6); the simplest is to lay a concrete cap several inches deep over the compacted soil mound. Given the expense of installing concrete (about $9/yd^2 for a 4-in layer, adjusted to January 1977 (28)), this is the least expensive application, as it uses the least amount of concrete, but it is also the most susceptible to damage from either waste or soil settling or freeze/thaw. Frost heave or freeze/thaw damage possibly could be averted by covering the cap with a layer of soil or gravel, while damage due to settlement of buried wastes could be

TABLE 9. SUMMARY OF TRENCH CAPS AND COVERS[a]

Trench Cap Description	Advantages	Disadvantages	Expected Longevity	Approximate Cost/Trench, Installed[b]	Reference No.
<u>Concrete (in general)</u>	Longevity. Structural strength. Proven success as a water barrier and radwaste container.	Expense. Susceptible to cracking due to settling or frost heave of buried waste and/or soil cap in certain environments; chemical attack in acid, alkaline, and high-sulfate soils; erosion due to freeze/thaw cycles. Difficulty of access in the event that relocation of wastes becomes necessary.	40+ years		52 36, 80
- 10 cm (4-in) layer	Cost, as compared to other concrete caps.			$16,200	28
- 100 cm (40-in) layer extending below the top of the trench	Less susceptible to cracking than the thin concrete layer.			$140,000	
- Concrete encapsulation/trench filling/cover	Least damageable of the concrete caps.	Most expensive concrete cap. Wastes are least accessible		$500,000	

TABLE 9 (continued)

Trench Cap Description	Advantages	Disadvantages	Expected Longevity	Approximate Cost/Trench, Installed[b]	Reference No.
Asphaltics (in general)	Ease of placement. Cost. Proven worth as rad-waste encapsulation material. Versatility.	Susceptible to chemical degradation. Photosensitive. Susceptible to cracking due to settling or frost heave. Difficulty of access in the event that removal of the wastes becomes necessary.	15+ years		28, 37, 55
- Normal asphalt concrete, 4-in layer				\$3,600-5,400	39
- Hydraulic asphalt concrete, 4-in layer	Decreased permeability over normal asphalt concrete.	More difficult to apply than normal asphalt concrete.		\$5,400-7,600	39
- Soil asphalt	Cost. Flexibility.	Increased permeability. Questionable quality control in installation. Temperature sensitive.		\$2,250	39
- Catalytically blown bituminous seal (0.5-1 cm)	Flexibility.	Questionable homogenaity of cap. Become brittle at low temperatures. Little structural strength.		\$2,700-3,600[b]	39

TABLE 9 (continued)

Trench Cap Description	Advantages	Disadvantages	Expected Longevity	Approximate Cost/Trench, Installed[b]	Reference No.
Soil Cement	Costs. Proven worth as a water barrier. More flexible than concrete.	Variable permeabilities. Susceptible to chemical attack and freeze/thaw erosion. Reduced longevity compared to concrete.	25+ years		74
- 15-20 cm (6-8 in) layer with a bituminous seal coat				$2,250	39
- Carbonate bonding (15 cm (6-in) layer)	Works better in heavy clay soils than normal soil cement.			$2,400	5
- Synthetic polymer membranes					
- Butyl rubber	Very permeable.	Cost.	20+ years	$5,000-7,700[c]	39
- Polyethylene	Cost	Poor quality. Poor weatherability. Poor puncture resistance.	10+ years	$1,800-3,400[c]	28, 39, 40
- Polyvinyl chloride	Strength, chemical resistance. Impermeability.	Stability. Temperature sensitive.	10+ years	$2,300-4,500[c]	28, 39

TABLE 9 (continued)

Trench Cap Description	Advantages	Disadvantages	Expected Longevity	Approximate Cost/Trench, Installed[b]	Reference No.
- Ethylene-propylene diene	Resistant to weathering and temperature deterioration.	Poor chemical resistance.		\$4,900-7,600[c]	28
- Chlorinated polyethylene	- - see ethylene propylene diene - -			\$4,300-6,300[c]	28
- Hypalon	Resistant to chemical attack, puncture, temperature deterioration.	Cost. Low Tensile Strength.		\$4,300-6,300[c]	28
<u>Clay</u>	Proven success as a water barrier. High impermeability. Self-sealing properties. Flexible.	Susceptibility to mechanical damage (animals, plant roots). Susceptibility to chemical deterioration. Must be kept wet.	1,000+ years	\$1,300 \$10,000+	39 36 1, 36
<u>Soil sealants</u>	Relatively low cost. Ease of application.	Lack of control over polymerization or sealing process. Subject to chemical and biological attack.	unknown	\$1,100+[c]	33, 35, 86, 87

a All trench caps can be used either as remedial measures on old trenches or on new trenches.

b Costs approximate for a trench 100 m long by 15 m wide by 6 m deep. Includes only the materials and installation of the cap itself.

c Includes a 15 to 30 cm soil cover.

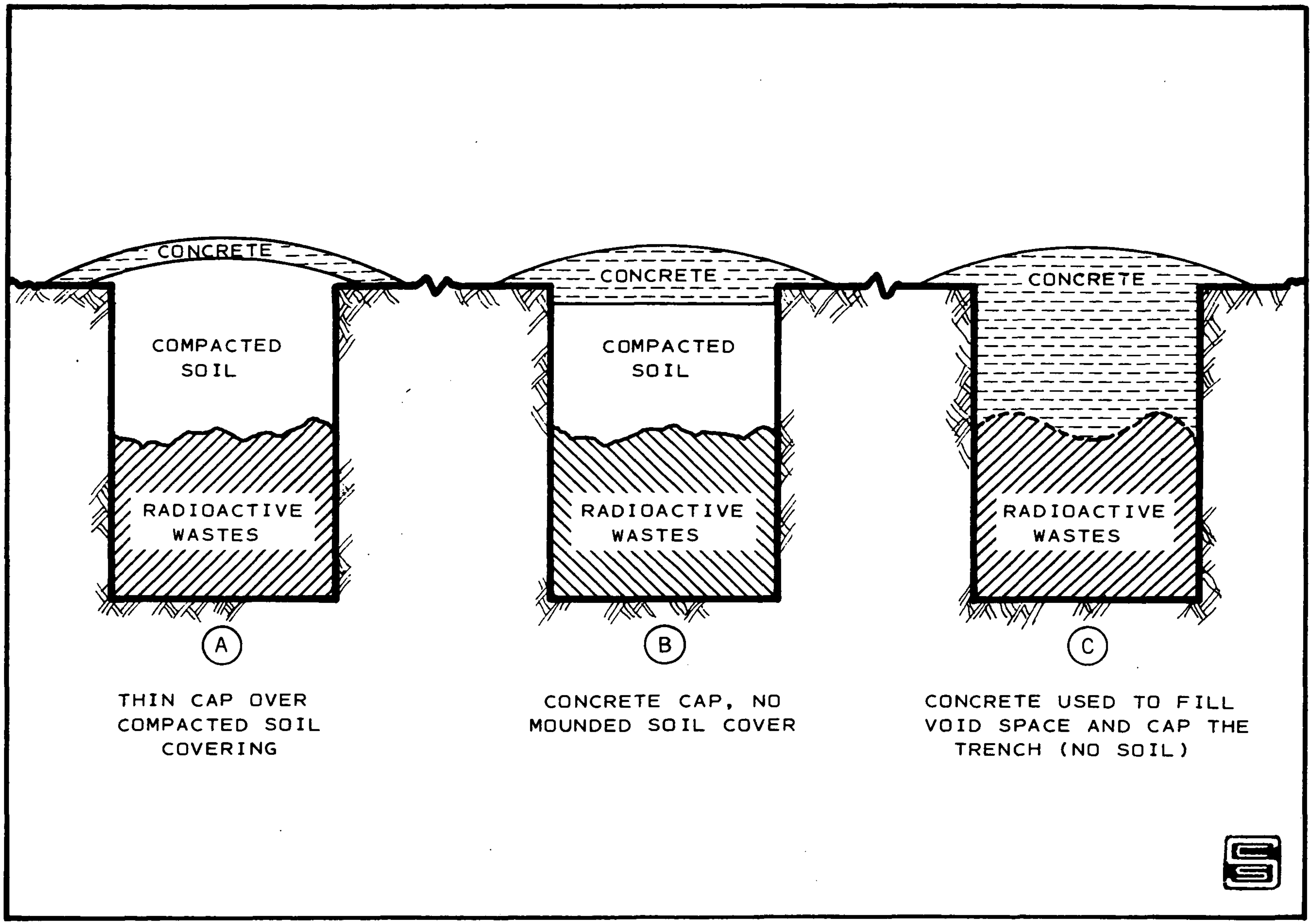


Figure 6. Concrete capping concepts.

controlled by efficient waste and cover compaction (although some repair to the concrete cap may be necessary if settlement is severe).

The second type of concrete cap would be much less susceptible to mechanical damage due to frost heave or settling, although the exposed concrete surface is susceptible to chipping and flaking from freeze/thaw cycles. Because the quantity of concrete is increased, the overall cost for capping the trench is increased likewise (Table 9).

The third type of cap is actually a combination of void-filler and cap. The concrete is poured on top of the wastes, filling voids and essentially encapsulating the wastes. The trench is filled with concrete, and the surface mounded. Structually, only freeze/thaw, which can be largely overcome by covering the concrete with soil or gravel, presents any problems to this cap (see Chapter 6). This concept does have the disadvantage of requiring a complete, filled trench for a homogenous concrete cover; filling the trench in sections creates joints which are more prone to failure than a contiguous cover. Leaving the trench open until completely filled may violate radwaste disposal safety regulations (100 m Rem/hr (10)). This concept is also the most expensive by a wide margin (Table 9).

Disadvantages--

Concrete is easily the most expensive of the capping materials under discussion (28). It is completely inflexible and will tend to crack under certain kinds of environmental stress. Low temperatures can freeze interstitial water in the concrete, expanding and cracking it. Concrete is susceptible to chemical attack under both acid or alkaline conditions, while concrete exposed to soils containing sulfates will gradually dissolve (36).

In one sense, the permanence of concrete may become a problem. If, in the future, it becomes necessary to remove any transuranic radwastes and recover or relocate them, a concrete cap would be a liability; removal would be costly and time consuming.

Advantages--

On the positive side, concrete has a long record of successful application as a watertight barrier with a long lifetime. A variety of concrete casks and boxes has been and is being used at several low-level radwaste disposal sites (Los Alamos, Oak Ridge, Hanford, Savannah River) to store plutonium and other transuranic wastes (80). These casks and boxes are usually buried in burial trenches, and, to date, they have held up well with no leakage or mechanical failure reported. At slightly higher cost, concrete can be impregnated with one of several polymers and made even more impermeable. A properly designed and constructed concrete trench cap, protected from the environment, should, with minimum maintenance, be able to provide an effective barrier to water infiltration for at least several decades, based on the apparent success of concrete dams, for example.

Asphaltics

Asphaltics include a variety of natural or refined liquid, semi-solid, or solid hydrocarbon mixtures. Asphaltic linings are used regularly in canals and reservoirs, and asphaltic patches are used to repair cracks in concrete or other linings. There are several types of asphaltic materials which could be used as a trench cap - asphalt concrete, hydraulic asphalt concrete, soil asphalt, and catalytically blown bituminous seals.

Applications--

Normally, asphalt concrete is applied as a heated mixture of asphalt, aggregate, and filler; hydraulic asphalt concrete differs in the asphalt content and aggregate gradation. Both are mixed and laid using the same equipment and techniques, although the hydraulic asphalt concrete is somewhat more difficult to handle (39). The major differences in the two types of asphalt concrete are permeability and expense. Hydraulic asphalt concrete, at \$3.00 to \$4.20/yd^2, 4 in thick, installed, runs about 30 percent higher than normal asphalt concrete (39). The added expense buys a decreased permeability - from 1.2×10^{-8} cm/sec for normal asphalt concrete to 3.3×10^{-9} cm/sec for hydraulic asphalt concrete (37).

Soil asphalt is a mixed-in-place surfacing made by mixing a liquid asphalt into the soil. Compared to other asphaltic caps, it is relatively inexpensive - \$1.25/yd^2 installed (39). The permeability of a soil asphalt can be controlled by the amount and type of asphalt used. One study used a soil asphalt of an initial permeability of 1.7×10^{-3} cm/sec, which decreased to 2.8×10^{-8} cm/sec after one year in the field (37).

Catalytically blown bituminous seals are produced by air-blowing hot asphalt in the presence of a catalyst. One to one and one-half gal/yd^2 are required to form a film 3/16 to 5/16 in thick (39). This type of membrane is supposedly impervious to water, but it is prone to mechanical damage. A soil cover is usually necessary, bringing the total cost to \$1.50 to \$2.00/yd^2 installed.

The use of asphaltics as water barriers is well established. The main canal of the Boise Project, Idaho, has a 14-yr-old asphalt concrete surface which has shown no cracks or signs of failures (55). Experience with asphaltics as sanitary landfill liners is not very extensive. One of the first such liners was constructed in 1971 at Montgomery County, Pennsylvania. This liner was a 3-in tar cement with a 1/8-in hot tar sealer coat covered with crushed rock and incinerator ash (28). Similar systems have been constructed elsewhere, but their relatively short time in place does not allow a full evaluation of their success or failure as long-term sanitary landfill liners.

Disadvantages--

Organic acids attack asphaltics to a limited extent, and oily materials can cause failures. Neither of these should present a problem at radwaste burial sites. Asphaltics are generally photosensitive and will decay in direct sunlight (39). Due to settlement or freezing, asphalt concretes are susceptible to cracking. Soil asphalts and bituminous seals are more flexible, but can become embrittled at extremely low temperatures (-35°C). Bituminous seals lack sufficient structural integrity to withstand much surface traffic, animal or plant damage, or tearing due to settlement. Soil asphalts may be the best compromise as trench caps in terms of flexibility and strength, but they also are the most permeable of the asphaltics (37).

Advantages--

Asphaltics are relatively inexpensive and, while placement requires a certain expertise, this expertise is readily available nationwide. A structurally sound asphaltic membrane is almost impermeable to water. Its sensitivities and weaknesses can be overcome through the proper use of cover materials over the membrane. Bituminous seals or soil asphalt could even be used to seal each section of trench as it is filled. This, in conjunction with an overall trench cap, could ensure that a cap failure would at least be localized in only one section of a given trench. At best, the double seal could eliminate leachate due to surface damage, or retard it until the cap could be repaired.

It should be noted that several nations, including the United States and U.S.S.R., are seriously considering using asphalt or bitumen as an encapsulating material for high-level radwastes. Preliminary tests have been favorable, thus establishing its potential applicability to low-level radwaste sites.

The asphaltics also have the same disadvantage as concrete in that their permanency precludes easy removal of the wastes, should this ever become necessary. Otherwise, asphaltics could be a good trench cap material for preventing water infiltration into the trenches.

Soil Cement

Soil cement is a mixture of soil and Portland cement, compacted at optimum moisture content and cured to hydrate the cement. It is generally used for strength or seepage control, where the expense or longevity of concrete is unnecessary. The installed cost of a 6 to 8-in soil cement layer with a bituminous seal coat is $\$1.25/yd^2$ (39) as compared to $\$7.90/yd^2$ for a 4-in concrete layer (5). However, the reduced cost reflects a somewhat reduced quality. Soil cements are seldom used where the 50+ year longevity of concrete is required. Furthermore, depending on the quantity of cement and the soil type, soil cements vary widely in permeability. Reported permeability coefficients range from a high of 10 cm/sec (39) to 10^{-6} cm/sec (74) to 1.5×10^{-8} cm/sec (37).

Soil cements are susceptible to attack by acids. They are readily degraded by environmental factors such as wet-dry or freeze-thaw cycles (39). Soil cements are more flexible than concrete and thus could withstand some differential settling and frost heave to a greater degree, although they too will crack under sufficient stress.

Soil cements have a long history of successful applications as low-cost liners for reservoirs, canals, ponds, sewage lagoons, and dam facings. Rogers (74) lists a variety of actual applications of soil cement, including site descriptions and general specifications. The longest lifetime he reports is 23 years for a soil cement-lined reservoir in Port Isabel, Texas. At the end of that period, the lining, with minimum maintenance needs, was still performing satisfactorily.

A variation on traditional soil cement is carbonate bonding (5), which incorporates lime hydrate instead of Portland cement; it requires carbon dioxide gas to set up properly, and it is cost competitive with normal soil cement ($\$1.30/yd^2$ for a 6-in layer installed (5), and $\$1.25/yd^2$ for a 6-in layer installed (39)). Its permeability to water is comparable to that of concrete, and it resembles normal soil cement in other respects. It might find its greatest application in heavy clay soils where the carbonate bonds form best and where good soil cements are most difficult to attain. Carbonate bonding has not yet been evaluated in full-scale applications.

Synthetic Polymer Membranes

Flexible polymeric membranes are assuming increased importance as liner materials because of their low permeability to water. The polymeric materials used in the manufacture of these liners includes synthetic plastics and rubbers. The membrane sheeting is usually available in rolls about 2 meters wide and 60 meters long. Several sheets can be factory seamed by the fabricator to form larger panels. The sheets can be heat sealed, cemented, or solvent welded in the field. Often two sheets are plied together to increase strength and reduce the effects of pinholes and other defects. Sometimes a nylon or polyester scrim fabric reinforcement is sandwiched between the plies to give added strength to the liner.

The use of plastics and synthetic rubbers as watertight liners is a relatively recent innovation. In fact, most of the synthetic polymers under consideration today did not even exist commercially 25 years ago. Their use as sanitary landfill or reservoir liners is even more recent. Consequently, it is difficult to estimate longevities for many of the membrane types simply because there has not been sufficient time to test them.

Types--

There are at least seven types of synthetic polymer membranes currently used or under consideration for landfill liners - butyl rubber, Hypalon, chlorinated polyethylene (CPE), polyethylene (PE), polyvinyl chloride (PVC), Neoprene, and ethylene-propylene diene monomer (EPDM). These membranes vary widely in characteristics and costs. Table 10 lists the costs for each commonly used synthetic membrane.

Butyl rubber is one of the older synthetic polymers. As such, it has demonstrated longevities in excess of 20 years (38, 39). It is one of the least permeable membrane materials, but is also one of the more expensive. Butyl rubber has excellent resistance to permeation of water and swelling in water. Butyl liners age well although they are susceptible to cracking in the presence of ozone. They are difficult to splice in the field.

Polyethylene is the least expensive membrane material. It is probably the least durable as well. Membranes of this material are often full of pinholes and blisters which can go undetected (39). Polyethylene weathers poorly and has poor puncture resistance (28). Despite these drawbacks, there are examples of effective PE liners with lifetimes exceeding 10 years (40). These liners are usually multi-ply and are often reinforced.

TABLE 10. COSTS OF SYNTHETIC POLYMER MEMBRANE LINERS

Liner	Installed Cost/yd^2 [a]	Reference No.
Butyl rubber	$2.70-3.80	28
Hypalon	2.30-3.00	28
Neoprene	4.40-5.40	39
Chlorinated polyethylene	2.30-3.00	28
Polyethylene	0.90-1.40	39
Ethylene-propylene diene monomer	2.60-3.70	28
Polyvinyl chloride	1.20-2.00	28, 40

[a] Soil cover over membrane not included, cost of which could range from $0.10 to $0.50/$yd^2$/ft of depth.

Polyvinyl chloride is one of the more common synthetic liners. It is strong, puncture and chemical resistant, and very impermeable. Its stability is variable, however, depending on the particular plasticizer used. As a result, PVC may be subject to deterioration from wind, sunlight or heat (39). Some plasticizers are biodegradable or water soluble. PVC tends to stiffen and become brittle at sub-freezing temperatures (28). It is probably the most popular liner material.

Ethylene-propylene diene monomer is very resistant to weathering or temperature deterioration. It is heat resistant and retains its flexibility at low temperatures, but it has poor chemical resistance.

Chlorinated polyethylene is a relatively recent development. It makes durable linings for wastewater, or chemical storage pits, ponds, or reservoirs. It withstands ozone, weathering, ultraviolet light, and microbial attack.

Hypalon is a high cost membrane material. It is highly chemical resistant with good puncture and temperature resistance. It has a low tensile strength, however, which makes it somewhat susceptible to breakage due to settling or frost heave in the underlying soil or wastes. It is the second most popular liner material.

Most of these membranes have been used as liners in sanitary landfills, reservoirs, sewage lagoons, or similar applications. Some, such as PVC, PE, and butyl rubber have demonstrated longevities of at least 10 to 20 years (39, 40). For further information on the properties of these membranes, with examples of their applications, see Geswein (28), Haxo (37, 38, 39), Hickey (40), Goldstein (30), Cluff (11), or Moeller and Ryffel (62).

Applications--

As trench caps, the membrane liner would be laid on over the mounded soil cover. In general, the membranes come in rolls and may need to be seamed to provide a continuous surface. Large panels are available for some types of membranes. Seaming can be a construction problem for some polymer types and generally is the weak link in the liner. One-yr leachate tests on PVC, CPE, and Hypalon have shown that the seams may fail even when the membranes remain intact (37). Under mechanical stress, the seams often given way first.

As trench caps, the membranes would generally be exposed only to infiltrating rain water which is relatively weak chemically. As a result, membranes susceptible to chemical attack might still be suitable as trench caps. The major threats to synthetic membranes as caps are microbial attack, sunlight, burrowing animals, plant roots, or weathering.

The membrane could be covered with a layer of soil to prevent mechanical damage or deterioration from sunlight. The proper synthetic polymer membrane correctly emplaced can provide an impermeable trench cap of at least 30 yr duration, with the added advantage of providing a good cap while being easily removable in the event that the trench contents need to be removed. Reclosing the trench would require a new membrane, but this is much less expensive or troublesome than replacing a concrete or asphalt trench cap.

Clay

Clay is a natural, polymeric hydrous alumino-silicate mineral. Structurally it is formed of layers of connected tetrahedral or octahedral molecular units. Because of the charge distribution of these units, the surfaces of the sheets are populated by cations, usually sodium or calcium. The addition of water causes the cations to hydrate, generating electrical charges that repel the sheets. Physically, the clay particles "swell." A layer of the "swollen" particles is virtually impermeable to water because of the negligible pore space between particles.

This sealing property makes clay an ideal liner for water-containing structures - reservoirs, ponds, canals, etc. Clay layers have also been used, with varying success, to line sanitary landfills.

Clays are available from several sources. Often, natural clay deposits in the vicinity of disposal sites are used. These clays are generally combinations of illite, kaolinite, attapulgite, and montmorillonite in varying quantities (1). Most native clays contain substantial nonclay portions consisting of sand and silt, which diminishes the value of the clay as a sealant. The alternative is to buy proprietary clay mixtures (e.g., bentonite, Volclay) which adds to the expense of the clay, but ensures chemical and physical quality. Most successful clay liners have relied on commercial clays.

The chemical nature of the clay can strongly affect its permeability. Sodium bentonite (standard Wyoming bentonite), for instance, is several times more "swellable" than calcium bentonite; that is, calcium bentonite swells to a much lesser degree. Consequently, sodium bentonite is generally less permeable. It is also less stable. If sodium bentonite comes in contact with water containing divalent cations (e.g., calcium, magnesium), the sodium will be replaced by the divalent cations. This, in turn, affects the structural integrity of the clay and shortens its usable lifetime dramatically. Calcium bentonites are generally unaffected by this type of situation and are chemically more stable.

Applications--

As a trench cap, a clay layer would be placed over the mounded soil cover and covered with another layer of excavated soil. The soil layer must be thick enough to prevent the clay from drying out; when the clay dries out, it cracks. Swelling will close the cracks when the clay is wet again, but sand or soil particles will undoubtedly have gotten into the cracks, making the closure incomplete. After several such wet and dry cycles, the incompletely closed cracks could go through the clay and breach the layer. The thickness of the soil cover required to prevent such drying out will vary, depending on local climatic conditions. Hawkins and Horton (36) found that a 1-ft soil layer was insufficient to protect a clay layer during a 3-mo drought, whereas 2 ft of soil protected the clay and prevented cracking.

Often, especially in sanitary landfill applications, clay is used in conjunction with another liner, such as plastic membranes. While more costly than either liner type separately, the combination is stable, very impermeable, and not subject to many of the disadvantages which hamper the use of clay alone.

Advantages and Disadvantages--

Clay liners are extremely susceptible to biological damage. Insects and animals can burrow through them with little difficulty. Plant roots can be especially damaging. Use of pesticides or plastic membranes along with the clay can prevent much of this type of damage.

Clay liners are generally flexible and can tolerate some deformity due to differential settling. The clay must be protected from freezing temperatures, as the expansion of the water of hydration can crack the liner and threaten its integrity. A soil or gravel cover of sufficient thickness can prevent this.

Cost estimates for bentonite clay vary. Haxo (39) gives an installed cost for a 9-lb mixture of soil and bentonite of $0.72/yd^2. Hawkins and Horton (39) state that the installed cost of a bentonite cover in 1967 was about equal to that of concrete. Since clay has not increased in cost at the same rate as Portland cement, concrete covers would be slightly more costly than clay in 1977. In either case, it has been estimated that, in the absence of mechanical damage, a clay liner has an expected longevity of thousands of years (36).

Soil Sealants

Applications--

Soil sealants are chemicals, usually polymers of some sort, which can be admixed with the soil or clay of a trench cover to form a relatively impermeable layer. They work by polymerizing or swelling between the soil particles and forming a sheet effect around the particles, sealing the surface of the trench cover. They are applied as liquids to the trench cover and generally penetrate several millimeters or centimeters into the soil. They are polymerized either through drying or with steam heat. These sealers are fairly new and relatively untested in full-scale applications.

There are a wide variety of soil sealers: calcium lignosulfonate, alumino-silicate gels, elastomeric polymers, latex, asphalt emulsions, and styrenes. Gulf South Research Institute (33) has done considerable research with these materials and reported that bentonite alone worked better than any of them.

Disadvantages--

The major problem with the sealers is lack of control over the polymerization or sealing process. Consequently, incomplete seals are rather common. Soil sealants are of marginal stability, subject, in many cases, to both chemical and biological attack. These defects have led Uniroyal, for instance, to conclude that latex will not work as a soil sealant (87).

In general, soil sealants have found their greatest applicability in the stabilization of mine tailings piles (35, 86). Sealants provide structural stability even when they do not form impermeable surface layers.

Advantages--

The greatest advantage of soil sealants is their cost. Many soil sealants can be formulated from waste polymers and consequently, are quite inexpensive. Havens and Dean (35) estimate that either DCA-70, an elastomeric polymer, or Norlig A, a calcium lignosulfonate, would cost less than $\$0.10/yd^2$ installed. In conjunction with a better cap, such as bentonite or synthetic membranes, they would be a good backup system. It might be possible to mix some of these sealants in with the fill and cover soils in the trenches before capping to provide an additional safety factor against water infiltration, in the event that the basic material cap does fail.

TRENCH CAP COVERS

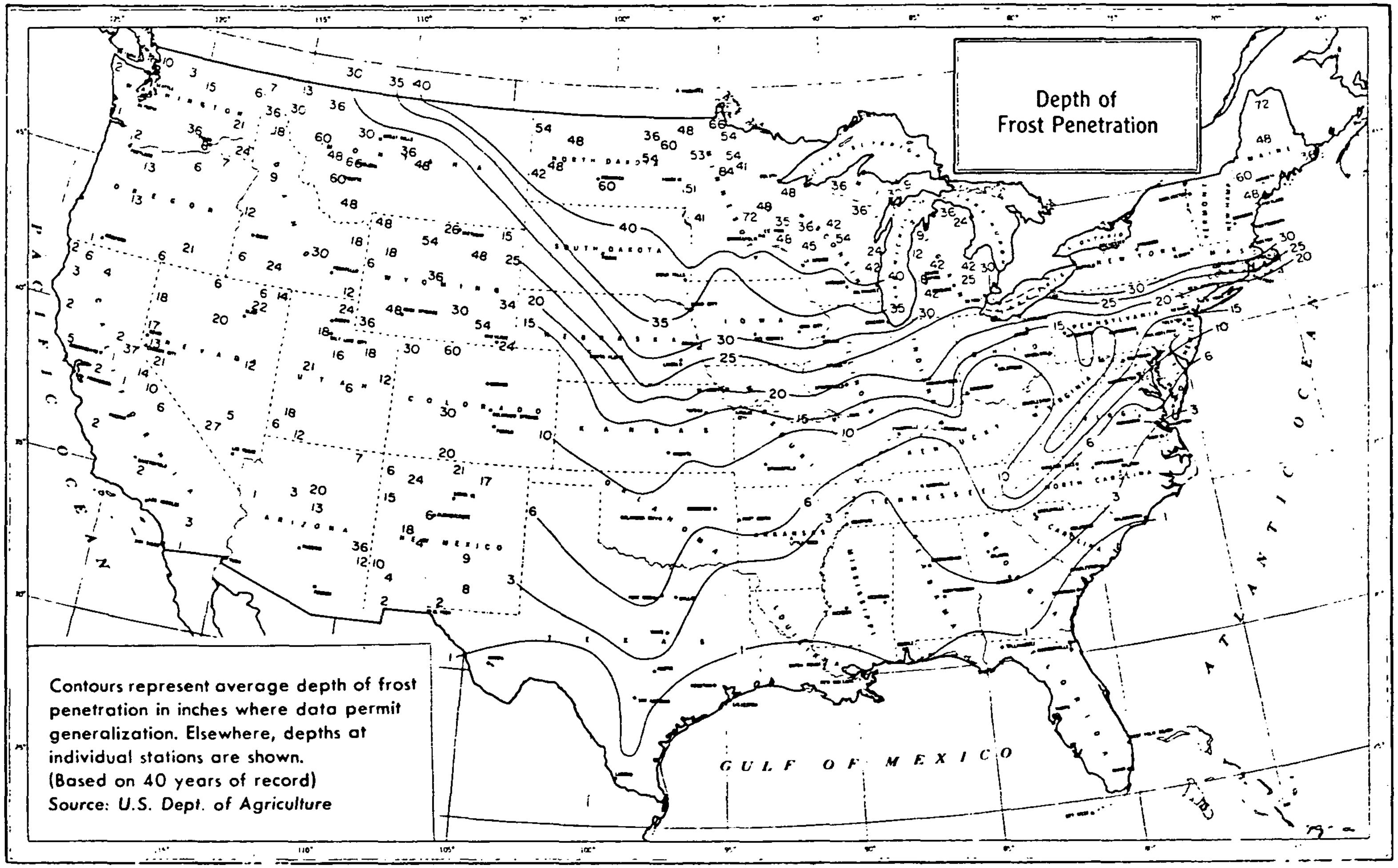
None of the trench cap concepts mentioned so far is completely resistant to environmental stresses: concrete will flake under freeze-thaw or crack due to frost heave; asphalt will crack from frost heave or degrade in sunlight; soil cements will degrade like concrete; many synthetic membranes will degrade in sunlight or suffer mechanical damage. Consequently, some sort of cover is required to protect the trench cap. This cover will prevent mechanical damage, protect the cap from sunlight, freeze/thaw and frost heave, and keep clays damp.

The two principal cover materials are gravel and soil. Excavated trench soil material could be used for the soil cover; gravel would usually need to be purchased and brought in from off site. The placement of gravel directly on top of some trench caps (e.g., synthetic polymer membranes) may damage the cap material. For those caps most susceptible to mechanical damage, a thin layer of soil can be laid down first and covered with gravel.

The depth of the cover is largely dependent on the local climate. Since one of the purposes of the cover is to protect the cap from frost heave, it must be deep enough to thwart frost penetration to the cap. Figure 7 shows the average frost penetrations in the United States. For some caps, such as clay, the cover must also be deep enough to prevent drying. A depth of 2 ft was previously cited as being sufficient to prevent clay drying and cracking under severe conditions. In this context, a soil cover would probably work better than gravel. A gravel cover would allow freer air circulation at the cap surface with probable drying. Of course, vegetative damage to a clay cap would be more likely with a soil cover than with gravel. A layered cover, half soil and half gravel, might be the best compromise for a clay cap cover.

Soil covers are susceptible to erosion or mechanical damage. Normally, a vegetative cover could be used to prevent such damage, but there may be the threat of root damage to the cap. It would be possible to use some of the soil sealants mentioned earlier to stabilize the soil surface, prevent erosion, and inhibit vegetation growth. Herbicide application to the surface may be necessary, where excessive weed growth is expected.

In general, for most cap materials, the multi-layer cover concept appears best. The soil cover protects the cap, and the gravel protects the soil cover. An average trench would then resemble Figure 8: waste material, soil fill and mounded cover, trench cap, cover soil, and gravel top cover. Use of this type of system can reduce maintenance costs dramatically.



Source: The Clow Corporation. Pipe Economy, 1975.

Figure 7. Depth of frost penetration.

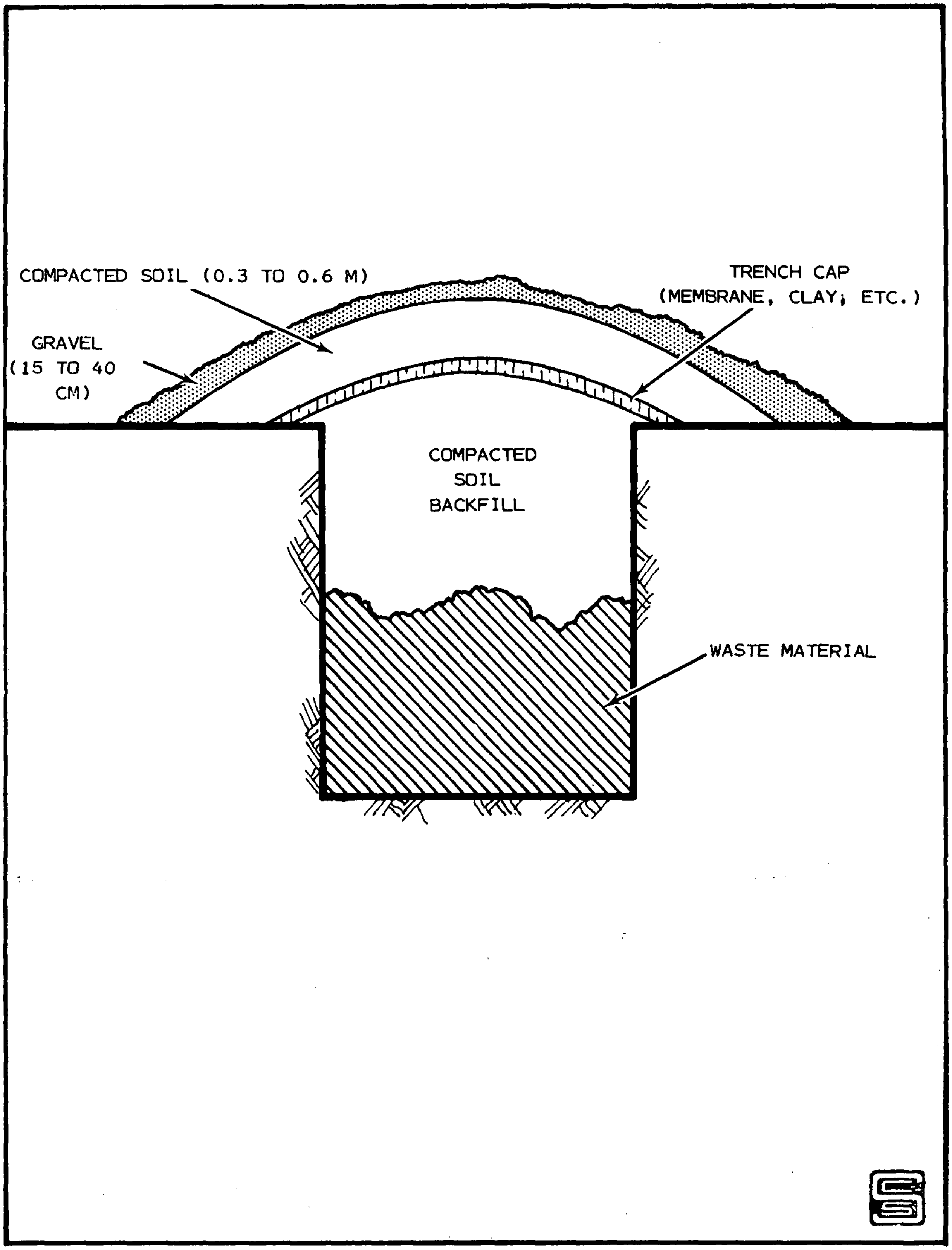


Figure 8. Conceptual completed low-level radwaste disposal trench.

CHAPTER 5
ALTERNATIVE TRENCH AND SITE CONSTRUCTION METHODS

INTRODUCTION

Two concepts will be discussed in this chapter:

1. Methods that can be implemented prior to the deposit of radioactive wastes in a disposal trench, i.e., during the initial trench excavation and generally applicable only at future or partially completed disposal sites.

2. Methods or procedures that can be implemented during or after disposal operations (other than trench covers, which are discussed in Chapter 4) and as remedial measures at existing sites where trenches are completed.

The trench and site construction concepts discussed in this chapter are not intended to be considered as infiltration controls independent of the trench covers discussed in Chapter 4; rather, the concepts should be viewed as complementary. Optimally constructed disposal trenches depending on particular infiltration control needs at a given site would probably include features presented in both chapters. Whereas the concepts developed in Chapter 4 are concerned primarily with infiltration through the cover, this chapter addresses such problems as surface runoff control and curtailment of horizontal groundwater percolation in saturated soils.

Table 11 presents a summary of the concepts addressed in this chapter. Some of these concepts are theoretical, and thus largely untested, but potentially usable; others have been used, but not at low level radwaste disposal sites. In most cases, the estimated longevities are conjectural, since the methods have not been evaluated over the time spans considered applicable for radwaste decay and/or degradation. Even those concepts of proven utility in management of other types of wastes have not been evaluated in the radwaste disposal environment, although such methods are valid concepts for potential radwaste disposal applications. However, direct application of methods developed for other wastes to radwaste disposal conditions may not be possible without modifications or adjustments in design, construction technique, and/or monitoring procedures.

TABLE 11. SUMMARY OF TRENCH AND SITE CONSTRUCTION ALTERNATIVES

Concept Description	Comments	Expected Longevity	Approximate Cost/ Trench, Installed[a]	Reference No.
Situate disposal site on a slope or hillside	Applicable for new sites only	NA	--	42
Situate disposal site on flat ground	Applicable for new sites only	NA	--	42
Construct system of berms/drainage ditches on the site	Applicable as a remedial measure and at new site construction	Indefinite with regular maintenance	$10/linear meter of berm or ditch	
Construct trenches with level bottoms	Applicable for new trenches only	NA	--	42
Construct trenches with sloped bottoms	Applicable for new trenches only	NA	--	42
Line trench bottom with permeable soil or other material	Applicable for new trenches only	NA	$500-1,000	42

[a]Costs are for a "typical" 100 m by 15 m x 6 m trench

TABLE 11. (continued)

Concept Description	Comments	Expected Longivity	Approximate Cost/ Trench, Installed[a]	Reference No.
Construct narrow gravel-filled diversion trenches around entire site and/or individual disposal trenches	Applicable at new sites or as a remedial measure	Indefinite with regular maintenance	$100/linear meter of diversion trench	36
Trench liners	Applicable for new trenches only	Varies with material and exposure conditions; at least 5 to 40 years	$40,000 to $275,000, depending on linear material	28, 39, 75
Grout curtains around sites and/or trench periphery	Applicable primarily as a remedial measure, but can be used at new sites		Up to $70,000, depending on grout material used	2, 8, 75
In-situ encapsulation-injection of a slurry of impermeable material into each trench to fill void spaces	Applicable primarily as a remedial measure in closed trenches	Variable, depending on the filler material; 10 to 50 years	$140,000 to $700,000, depending on material	--

[a] Costs are for a "typical" 100 m by 15 m x 6 m trench

TRENCH CONSTRUCTION

The typical trench configuration described in Chapter 2 shows each trench with a sloped (3 to 5 percent) bottom. This method of construction allows any water entering the trench during fill operations (e.g., direct rainfall and undiverted runoff) to drain to one end of the trench where it can be conveniently pumped out. However, a sloped bottom may actually contribute to the presence of water in the trench, as noted by Horton (42). In his study of soil moisture flow in relation to radwaste disposal, he suggests that radwaste disposal trenches be constructed with level trench bottoms. However, flat bottoms do not prevent rain water or runoff from entering trenches during fill operations, and removal of any water is difficult, if it is in a relatively shallow layer. If a trench can be filled in such a manner as to avoid standing water during the operation (e.g., by location of sites in arid climates; rapid excavation and filling of trenches during dry spells; dewatering at the site during excavation; a system of berms and temporary tarps to cover open trenches), then the level bottom probably is less likely to allow horizontal water movement into the trench. Trenches with level bottoms may cost more to monitor and remove water from, than trenches with sloped bottoms.

The potential for horizontal percolation of water in the unsaturated zone contacting radwaste through sloped bottoms can be mitigated somewhat by providing a 30- to 60-cm thick gravel floor in the trench before placement of wastes, preventing contact between the wastes and any standing water. Frequent monitoring would be necessary to ensure that the depth of the standing water did not rise above the depth of the gravel layer.

TRENCH SITING

Trench siting, whether on flat ground or slopes, can significantly affect the potential for infiltration of surface runoff into disposal trenches. If a trench is located on an incline, horizontal water percolation in the unsaturated zone into the trench is possible, because the original ground surface slopes toward and intersects the trench. Water infiltrating in homogenous soils through the zone of aeration will naturally tend to move toward the area of lower potential, in this case the trench, depending upon the nature of the backfill (Figure 9). One way to avoid this is to place trenches only on a relatively flat ground. However, surface drainage at flat sites is often poor, allowing rainfall or spilled water to pond between the mounded trench covers. In such cases, a series of drainage ditches would be necessary to maintain water-free surfaces between the trenches. Normally, however, percolating waters will flow in a vertical pathway until reaching the groundwater table.

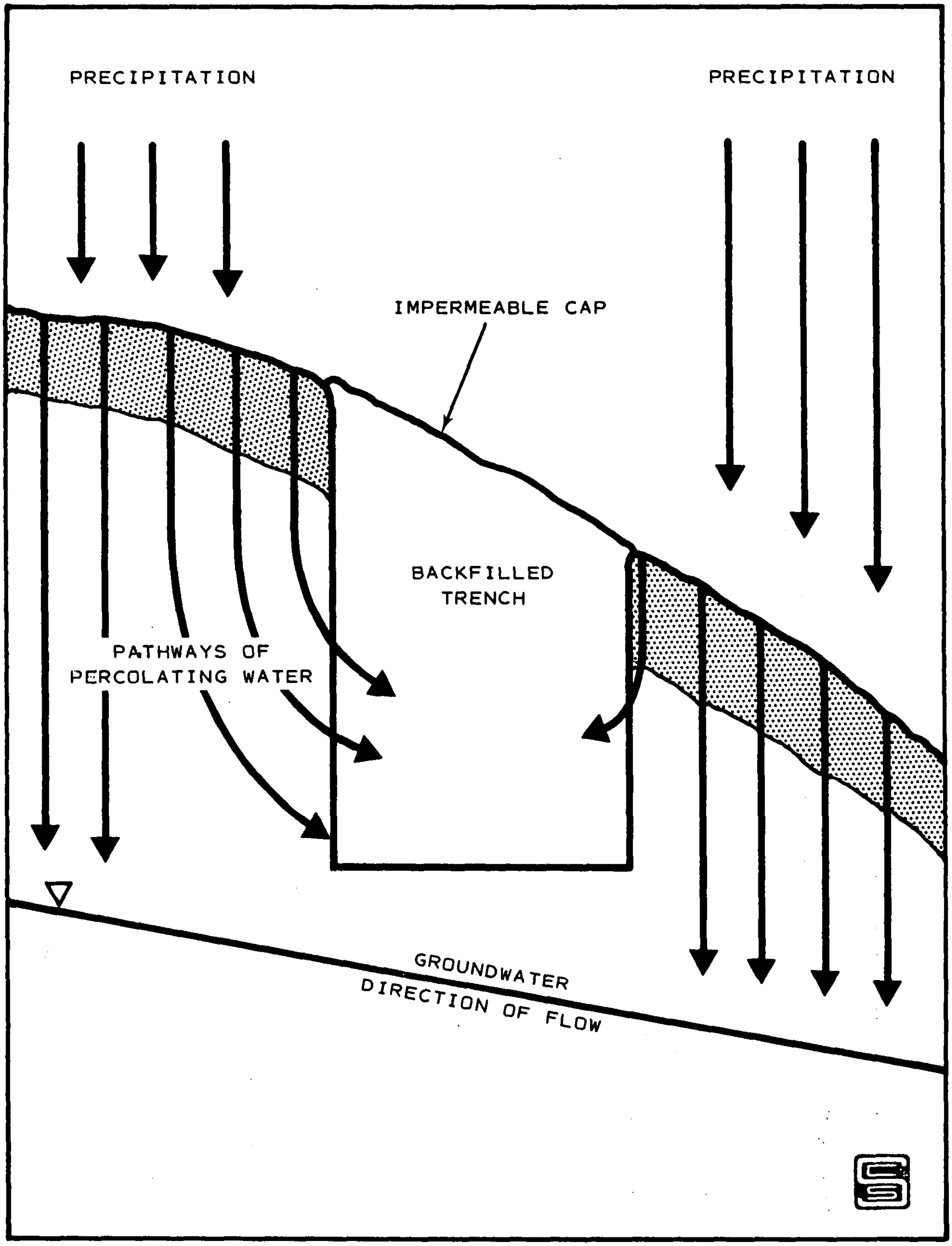


Figure 9. Possible horizontal flow of water into a backfilled trench.

Placement of trenches on grades should not be ruled out. Figure 10 depicts a slope site, with the topsoil removed, protected by a series of berms and an upslope diversion ditch. The natural slope allows precipitation runoff with little danger of ponding, while the ditch and berms divert most surface water away from the trenches. This configuration will inhibit both horizontal movement in the saturated zone and surface runoff into the trenches.

DIVERSION TRENCHES

Deep narrow trenches filled with a permeable medium (e.g., gravel) are sometimes used to prevent or control horizontal groundwater movement and divert water away from the individual disposal trenches or even the entire site. Groundwater encountering one of these diversion trenches will follow the diversion trench around the disposal trench or site if there is a sufficient gradient within the trench. This system, which has been successfully applied to groundwater control at sanitary landfills, has been proposed by other researchers for use at radwaste disposal sites (36).

The narrow trenches provide a high permeability path for the water to flow around the site. This type of approach is analogous to electronic shielding problems where a circuit is isolated from outside voltage gradients by putting the circuit in question inside a conducting box. There is no need to dewater the trench as long as the hydraulic potential is less than in the surrounding soil. If groundwater periodically rises into the wastes, then falls again, the diversion trench system will not prevent contamination from this pumping action.

In practice, the trenches should be about 50 cm wide, deeper than the level of the disposal trench bottom, and usually filled with gravel or other permeable material to within one meter of the surface and then backfilled with the excavated soil. Such diversion trenches down to the aquifer will prevent the water table, in areas of high water table, from rising into the disposal trenches from beneath.

In arid regions, it might be possible to limit construction of diversion trenches to the periphery of the site, rather than around each trench, while for sites in wetter regions or in high water table areas, diversion trenches throughout the site, or possibly around each trench (Figure 11) would provide better protection. Economics might be a factor for this concept; construction of diversion trenches will cost about $100/linear meter.

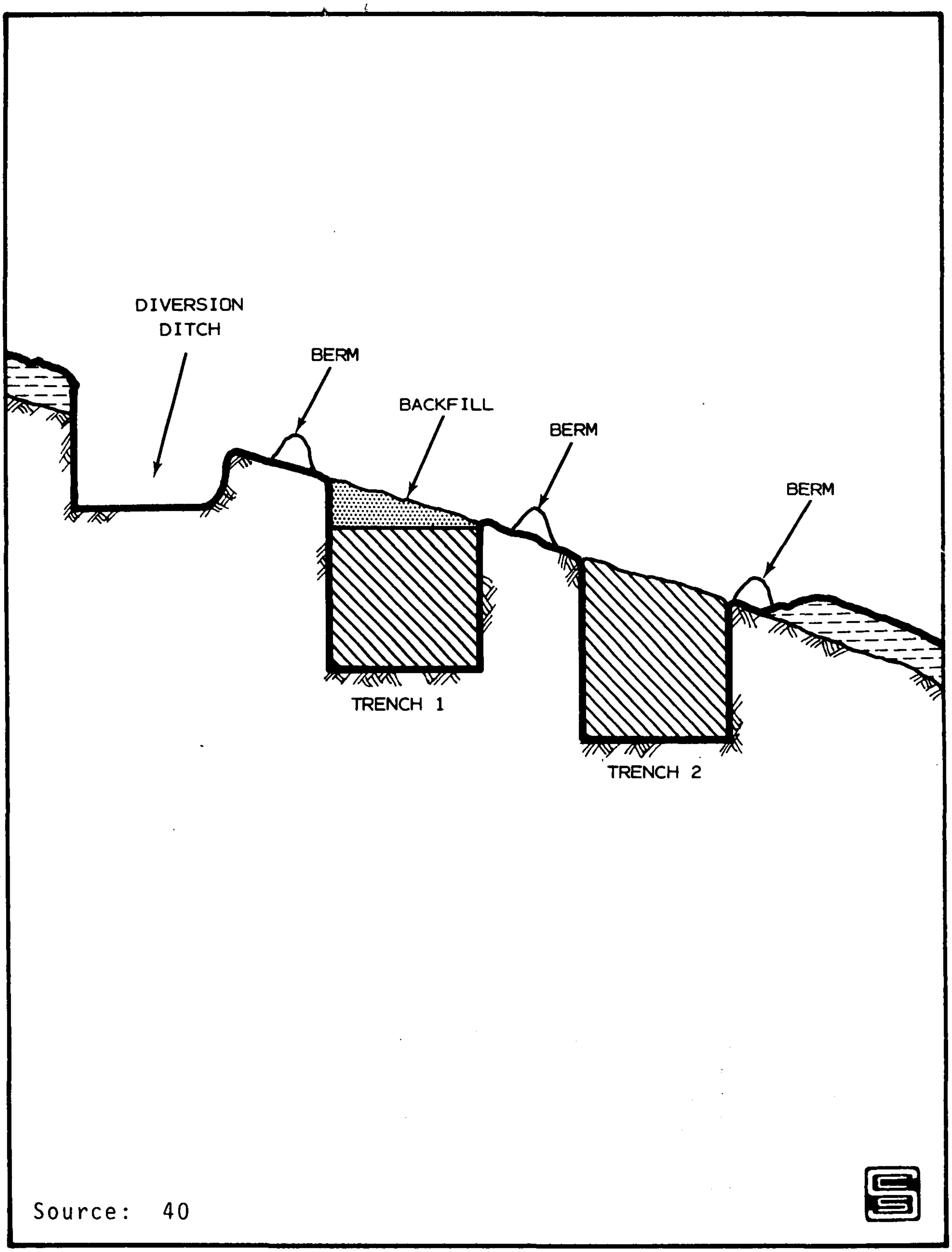


Figure 10. Burial trench arrangement to impede horizontal water infiltration through the topsoil

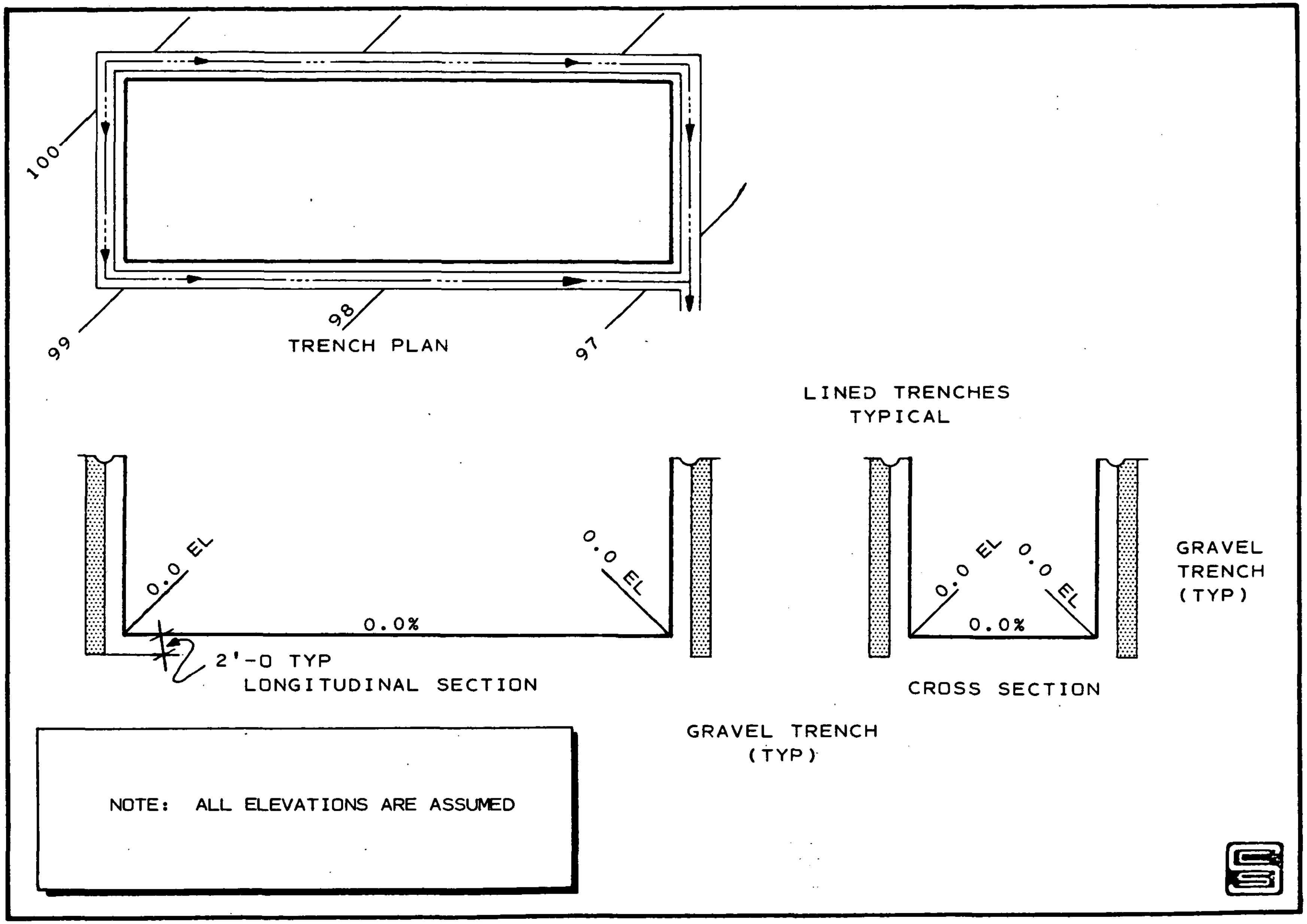


Figure 11. Radwaste disposal trench with diversion trenches.

TRENCH LINERS

Nearly all of the materials previously discussed as being applicable for trench caps could also be used as trench liners; most information referenced in the discussion of trench cap materials concerns use of these materials as liners for sanitary landfills, ponds, reservoirs, and canals. Most of the information on material properties, costs, advantages, and disadvantages presented in Chapter 4 are, therefore, largely applicable here as well. In general, since materials used as liners are generally buried, damages from frost heave, freeze/thaw, settling and sunlight are less a problem for liners than for caps. However, chemical damage (due to soil alkalinity, acidity, sulfates, and leachate) may be more severe.

Advantages and Disadvantages

Aside from the behavior of individual liners, the concept of trench lining has numerous advantages and disadvantages. A good liner can prevent groundwater infiltration into the trenches through both the bottom and the sides. If water infiltrates into the trench through the surface, any leachate formed will be retained for extended periods and should not enter the environment, as long as the liner remains intact.

However, the ability to hold water can also be viewed as a major disadvantage of trench liners. Lined trenches are essentially bathtubs; they trap and hold any water that may have entered the wastes, leaving it in contact with the wastes for an indefinite time. Under such conditions, more highly concentrated leachates than might otherwise be encountered can be produced. As a result, lined trenches may require more rigorous monitoring and more frequent remedial pumping than unlined trenches. This, in turn, could create a radioactive liquid waste disposal problem. In general, most experts have been unenthusiastic about the applicability of the trench liner concept to low-level radwaste disposal situations.

GROUT CURTAINS

Grouting is the process of injecting appropriate material into soils and rocks thus reducing the strata's permeability and/or increasing its strength. As a water sealant, grouting has a history of successful application in mines and tunnels, and under dams (7, 8). Grouting materials include cement, clays, asphalts, bitumens, silicates, lignochromes, lignosulfates, epoxy resins, acrylamide, polyester resins, polyphenolics, resorcinolformaldehyde, and other chemical polymers (6, 7).

At a low-level radwaste disposal site, grout curtains could be placed around a burial trench (Figure 12) at any time during the life of a trench site in such a way as to prevent the horizontal movement of subsurface water, either into or out of the trench. Grout curtains would work better as a remedial measure as new trench construction could damage adjacent grout curtains around existing trenches.

The longevity of grout curtains can be expected to vary with the materials used; in general, they are expected to last the life of the dam (7). References 7 and 8 contain lists of many sites where old grout curtains are still intact.

The soil or rock beneath a trench could conceivably be grouted as well, but such practice could lead to the formation of a "bathtub," as discussed above. In areas of fractured bedrock grout could be used to seal some of the fissures, thus providing a more secure and better delineated foundation for a disposal site. Grout injections could also be used to seal leaks in the other liner systems.

The variety of grout materials and injection techniques available allows considerable versatility in how and where grouts can be used. In general, grouting is easiest in loose, dry soils, since wet soils can inhibit and slow grout gelling, sometimes to the extent that the grout material can dissolve or be washed away before it has a chance to set. Fine grain soils require low viscosity grouting materials to ensure proper spreading. Despite these and similar problems, enough different materials are available to provide sufficient sealing in almost every soil environment to be expected at a disposal site.

Recently, Applied Nucleonics Company, Inc., Los Angeles, studied radwaste relocation at Hanford, Washington; the feasibility of grouting around radwaste trenches was investigated[2]. Although final results of this study are not yet available, indications are that grouting does have potential for controlling water infiltration at this site.

Grouting has several disadvantages. Considerable research is required to determine precise site soil conditions and to select suitable grout material. Skilled personnel are needed to properly place the grout, and it is difficult to assess whether the grout curtain is working unless it fails. Costs are generally in the range of $400/m^3$ installed, or up to $70,000 per typical trench for a complete curtain (around all four sides).

For more complete information, Reference 2 contains an extensive bibliography on all aspects of grouting.

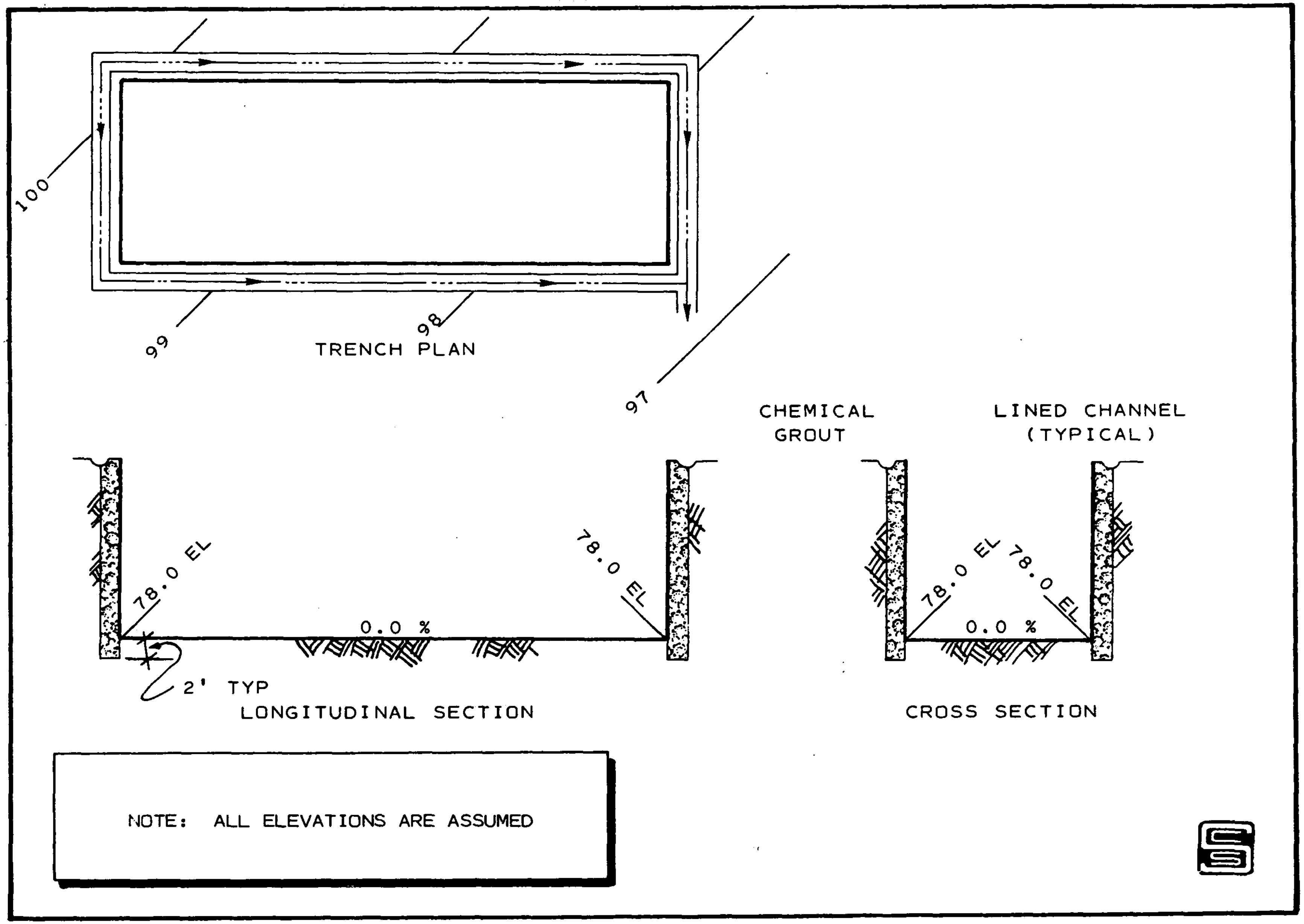


Figure 12. Radwaste disposal trench with chemical grout curtain.

IN-SITU ENCAPSULATION

Because of the loose packing of radwastes in many burial trenches, there may be up to 2,000 m^3 of void space per typical trench of 7,000 m^3 total volume. If water does enter a trench, the amount of waste surface area available for contact suggests that highly concentrated leachates could be generated. Thus, it would be advantageous to prevent or minimize infiltration into the wastes (and thereby reduce potential leachate production) by filling (encapsulating) the void space with a relatively impermeable material. Water contact with the wastes would be reduced and, as an added benefit, settlement of the waste as it decomposes could be decreased significantly, especially if the void filler material had some structural strength.

The same basic methodology would be used for encapsulation as in grouting. In general the nature of the wastes in the trenches is such that less care is needed in selecting a suitable void fill material, and, in fact, it might be possible to use certain wastes, such as fly ash or spent drilling muds. Fly ash will set up like concrete and provide a nearly impermeable fill material, and, being a waste product of combustion the major costs would be in transport to the disposal site and application. Materials costs would be very low or zero, although the use of fly ash for encapsulation would be limited to sites near facilities producing such a waste. Drilling muds can provide a seal of permeability comparable to bentonite. Being fluid, drilling muds should readily fill void spaces in radwaste trenches, and the water in drilling muds is such an integral part of the mud structure that little excess water (and thus, little leachate production) need be expected from the mud/radwaste contact. Drilling muds being inorganic and basically clay, would not degrade in the anaerobic environment of a trench. There are examples of drilling mud linings which have successfully withstood mechanical and chemical assault for many years (8).

Due to the variety of materials that could be used, costs of in-situ encapsulation would vary widely. For instance, costs for fly ash filler would be limited almost exclusively to the installation. In general, costs will range from \$2 to \$10/ft^3, or up to \$140,000 to \$700,000 per trench.

Advantages and Disadvantages

Filling the void spaces with a material of some structural strength can inhibit the waste settling which undermines trench caps, causes cracks, and allows surface water infiltration. Many fillers have indefinite life spans and employ relatively inexpensive waste materials.

On the other hand, there might be an initial danger of leachate production from the injection of some slurried fillers. Furthermore, some of the filler materials (such as fly ash) may themselves contain constituents that are capable of producing hazardous leachate. There would likely be a lack of quality control when injecting into a closed trench; void filling may be incomplete. The skilled personnel necessary for application would make the costs high even though low cost waste materials are used as fillers.

CHAPTER 6

BURIAL TRENCH MAINTENANCE AND MONITORING

INTRODUCTION

No trench burial method can be completely secure indefinitely. However, it is questionable whether truly indefinite security is really necessary. Unlike other hazardous materials, radwastes will decay to innocuous forms. And, although centuries may be necessary for complete decay, much shorter time spans will yield relatively safe wastes. The issue, then, becomes one of maintaining tight control over water infiltration for a relatively short period of time, fifty years for instance, after which limited infiltration and leakage can be tolerated, since any leachate that would then be generated would not be radioactive.

How soon and how much leakage and leachate can be tolerated is dependent largely on the hydrogeology and concomitant attenuation mechanisms of the disposal site and regional environment. In some respects, the true working life of a disposal site includes not only the secure lifetime of the trench itself but also the movement time of contaminants from the trench to the biosphere. The factors affecting this movement time include:

- Distance to groundwater;
- Direction and rate of groundwater movement;
- Size and use of aquifer (volume of water);
- Hydraulic conductivity, porosity, and mineralogy of the sub-trench lithology;
- Ion-exchange/adsorption capacity of the subsurface soils;
- Position and extent of any fractures in the bedrock; and
- Distribution coefficients for nuclide movement through the hydrostratigraphy.

Theoretically, without extensive trench modification or sealing, a radioactive waste requiring X years to decay to a safe level could be placed in ordinary trenches in an environment which had an X-year delay between trench and biosphere. On the other hand, an environment allowing rapid transport of contaminants to ground or surface water would require a trench with a water-secure lifetime of at least X years. In practice, to account for unknowns and emergencies, safety factors dictate a combination of trench life and movement rate controls which exceed the X years. Consequently, site factors play a large role in determining not only site acceptability but also the nature and duration of the trench seal required to prevent water infiltration. It will likely be beneficial to incorporate some combination of sealing, capping, or encapsulation at all burial sites, regardless of the natural attenuation characteristics present.

A good example of this type of reasoning is found in the design of the Barnwell, South Carolina, burial site (43). Although in a high rainfall area, this site possesses a highly favorable groundwater hydrology. A hydrostatic head reversal prevents downward flow into an aquifer; thus, migration of nuclides is confined to the direction of surface streams. Given the depth to the water table, the short flow path to a surface stream, and the groundwater movement rate, the estimated travel time for subsurface water from the solid radioactive waste storage site to this stream is about 70 years. Consequently, little attempt is made to prevent infiltration into the trenches. Trenches are pumped regularly to produce a short residence time and a less contaminated leachate. The 70 years is considered sufficient to allow for complete attenuation of any radionuclides in the leachate.

SURFACE MAINTENANCE

Regardless of the type of cap, cover, trench, or berm, some degree of site maintenance will undoubtedly be required to ensure cap integrity and to minimize infiltration. Any system, especially a poorly-designed system, is subject to failure from settlement or cover erosion. Even the best systems will require periodic inspection to identify problems and to indicate repairs if problems are found.

The causes and effects of settlement have been noted previously. If waste settlement within a trench threatens the integrity of a cover or cap, the only alternatives available are to replace the cover and/or arrest the settling. In severe cases, where settlement has caused cover failure, it may be necessary to remove the existing cover, recompact the wastes, add soil or additional waste to fill the void, and place a new cover. For the non-permanent cover types (soil sealants, synthetic membranes, clays, etc.), it might be possible to simply compact the cover material well and place a new cover on top of the old one. However, further settlement could cause a repetition of the problem.

It might be possible to arrest settling by injecting a non-settleable material, such as spent drilling mud, bentonite slurry, concrete, or similar grouting substances, into the trenches. The major objection to such injection is that these all contain water and water is the liquid to be kept out of the trenches. However, for some injectable materials, such as drilling muds, the water is such an integral part of the slurry that leaching will, at most, be minimal. Significant leaching will not likely occur with any of the materials.

Erosion of the trench cover can be caused by wind, water, or temperature extremes. In the earlier discussion of trench caps, it was determined that a multi-layer system where the cap was covered with soil and gravel layers could effectively control erosion. Gravel covers for upstream runoff diversion berms would also help prevent erosion of the berm material.

Berms and trench covers can still be damaged by severe weather incidents or changes (e.g., torrential rains, tornados, hurricanes, heavy freezes, spring thaws) or earthquakes. Close inspection following such incidents is necessary to locate and assess any damage. In the event of collapsed berms, rebuilding might be necessary. Damaged gravel and soil covers would need to be replaced where necessary. Cracks in permanent caps (e.g., concrete, asphalt) could be patched with a suitable synthetic or asphaltic patching compound.

In extreme cases where a cap or berm is too extensively damaged to repair, replacement would be necessary. This is not likely if the disposal site is properly designed, constructed, and maintained.

Maintenance also includes keeping the trenches water free. A sloped-bottom trench with a stone-filled sump at the low end and a permanent standpipe in place can be checked periodically to see if, in spite of all precautions, water has infiltrated. If it has, the trenches can be pumped out. If trenches are allowed to fill or if water is allowed to stand in the trenches for very long, opportunities for the formation and movement of hazardous leachate are present. The pumped water could be examined for radioactivity and, if necessary, routed to holding ponds for further treatment before disposal. There should be a series of standpipes or a length of perforated collection pipe along the bottom of flat-bottomed trenches. Construction of the sump and standpipe are considered routine. Thus, they add nothing to the trench construction costs over the normal. A portable generator and pump could be used to dewater the trenches. Lengths of flexible hose would be needed to route the water into temporary holding ponds. A capital outlay of less than $1,000 should be sufficient.

Because of the nature of the wastes, it may be necessary to monitor and pump indefinitely. Leachate from radwastes could be hazardous at any time during the hazardous lifetime of the wastes.

VEGETATION AND LANDSCAPING

Vegetation and landscaping can serve a dual purpose at a disposal site: erosion control and aesthetic improvement. A nicely landscaped site is far more pleasing to look at than a series of mounds covered with concrete, asphalt, or gravel. Figure 13 shows a closed burial site which has been contoured and planted with grass at Oak Ridge National Laboratory. Shallow-rooted grasses are used for erosion control at Maxey Flats (60).

Vegetation serves a variety of purposes other than aesthetics. Roots hold the soil and prevent water and wind erosion of covers and the soil between the trenches. Fenimore's studies show that once a grass cover is established, very little further care and maintenance is required to maintain the cover. Vegetation also plays a significant part in water infiltration control through evapotranspiration.

The issue of landscaping is not simple, however. Kenny (51) reports that deep-rooted plants on the site of buried waste from a nuclear reactor accident are radioactively contaminated due to the raising of radionuclides through the plant. Hawkins and Horton (36) reported similar aftereffects in Bermuda grass and small plants. They further concluded that plant growth must be completely prevented if bentonite caps are used, since the clay has little resistance to root penetration. Also, plant growth could conceivably aggravate minute cracks or holes in other types of caps. Such root penetration into the cap will tend to increase the potential for water infiltration. Fenimore examined several grasses for use as possible covers at radwaste burial sites (21). He found that Carpet grass roots could penetrate to 46 cm (18 inches), Bahia and Dallis grass roots to 16 inches, Centipede grass roots to 30 cm (12 inches), and Bermuda grass roots to 26 cm (10 inches).

Overall, the benefits derived from planting cover vegetation on completed burial trenches (erosion control, aesthetics) may be more significant than the costs of continuing surface maintenance. There are no published reports of any vegetation-related problems at the Oak Ridge or Maxey Flats disposal areas, for example.

Figure 13. Grass covered radwaste disposal site.

Alternatively, gravel cover can provide erosion control similar to that provided by vegetation, without the potential side-effects of cap penetration and radionuclide translocation. Burial sites prone to root damage could be kept free of unwanted vegetation through the use of gravel covers or the regular use of herbicides. If, in the future, aesthetics prove to be a major issue, the site could be screened with a line of trees, hedges, walls, or similar screening devices.

Although gravel and other non-vegetative covers can prevent erosion and vegetation growths on the actual trench cover, the uncovered areas between the trenches are subject to both. In fact, it is not unusual for deep-rooted vegetation to become established in the uncovered soil or for severe erosion to occur, both of which can undermine cap integrity. Non-vegetative covers would require periodical herbicide treatments to keep down all vegetation growth. Erosion control would be considerably more difficult. Gravel covers have a further advantage in that they discourage burrowing animals far more than vegetation would.

MONITORING

In the past, most solid waste land disposal sites have incorporated a total site monitoring system consisting of monitoring devices situated along site property boundaries. These systems have a serious flaw in that they detect leachate only after it has been forming for some time, possibly long after the site is closed. Remedial measures at that time can only stop the further formation of leachate; the leachate already formed may continue to transport hazardous contaminants off the site. The site boundary system serves only to provide an indication of the direction and rate of leachate movement so that precautions can be taken ahead of the flow. For a more complete discussion of total site monitoring systems, the reader is referred to the several studies on monitoring in the bibliography (15, 24, 25, 27, 73, 90).

A proper monitoring system must anticipate leachate and its probable rate and flow path and detect it before contamination (if any) has progressed very far. If leachate can be detected while still in the immediate vicinity of a burial trench, remedial steps can be implemented which will prevent or significantly delay off-site movement of hazardous materials. To this end, a monitoring system involving detectors in and around each burial trench is also desirable.

Trench Monitoring Systems

In the context of this report, individual trench monitoring involves the detection of moisture in the trench and is primarily meant to:

- Determine when field capacity of the trench cover and walls is reached;
- Determine the efficiency of the infiltration control systems of each trench; and
- Establish when pumping might be necessary to reduce water levels in trenches with inadequate or faulty infiltration controls.

Ideally, the monitoring system needed to achieve these goals includes moisture cells in the compacted soil backfill, in the trench bottom, to the sides of the trench, and in the soil beneath the trench. In practice, field conditions may necessitate variations in the placement, but the overall purpose of the system - to detect infiltration into the trench and leachate flow out of the trench - must be kept in mind.

Commercial electro-couple moisture cells, such as the Soiltest® MC-310A, are the simplest means for remotely monitoring soil moisture. Use of this type of cell requires preliminary engineering analysis to determine the field capacity of the soils around the trench and the backfill material. The moisture cells can then detect any changes in soil moisture or simply the approach of saturation and flow. Cells in the soils around and below the trench can monitor groundwater and soil moisture levels and flow; cells in the radwastes and backfill soils can monitor moisture levels in the trench.

The number and placement of the cells is largely dependent on local moisture conditions; higher water tables, more rainfall, more permeable soils would require greater numbers of cells, for example. For the worst case, cells should be placed in the mounded soil cover, below the trench bottoms, and in two horizontal planes about 2 and 5 m deep (Figure 14). Cells placed about 2 to 3 m apart can cover most normal soil moisture conditions. It is not necessary to maintain vertical planes of cells.

Although easier to place in new trenches, moisture cells can be added to filled trenches by simply drilling holes into the fill. If it is undesirable to drill through the cover, slant drilling can be used to place probes in the trench. If it appears impossible to place a cell beneath each filled trench without rupturing covers, liners, or radwaste containers, cells can be placed between trenches below the plane of touch bottoms.

The cells are connected to the surface by labelled leads. These leads can be gathered into groups at appropriate places

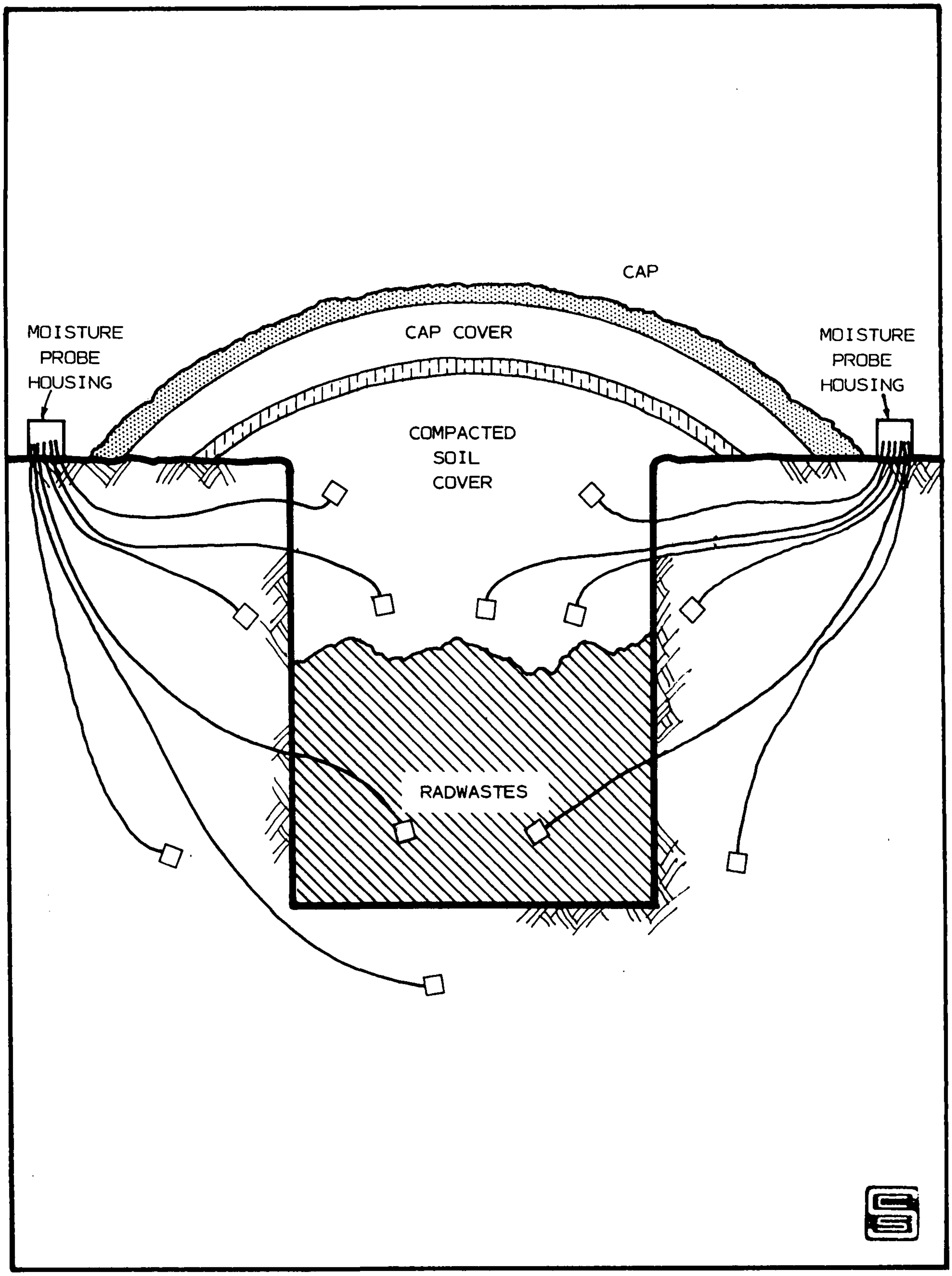


Figure 14. Cross section of moisture monitoring cells for a burial trench

and routed to a common moisture probe housing at either side of the trench. Monitoring would be a simple matter of attaching a lead to a portable moisture meter and reading the electrical resistance. Graphs could be kept for each cell to maintain "moisture profiles" of each trench. At current (1977) prices, moisture cells cost about $10 to $12 each and another $10 to $20 to place in a filled trench, depending on the equipment used. Placing cells as a trench is filled can reduce placement costs substantially. Complete costs for placing cells in a filled trench could run as high as $9,000 per trench in a wet area. Costs would be less in arid regions or for placement during filling. A portable moisture meter can be purchased for under $300. Maintenance would consist of periodic inspection of leads or replacement of faulty cells.

Monitoring Frequency

The frequency of monitoring is a function of site climatology and hydrogeology, and the completeness of the hydrogeologic data; it will probably vary somewhat from site to site. As a general rule, from a practical, cost point of view, monthly monitoring intervals will likely suffice. In extremely arid regions (e.g., Beatty, Nevada), bimonthly sampling with weekly sampling following major rains might be preferable. For excessively rainy or high-watertable sites, weekly or biweekly sampling might be necessary to ensure safe trench operation.

Whatever monitoring method is selected, it should be noted that monitoring is useless without an authority to react and a set of criteria specifying when or how to react. The lack of criteria or authority has plagued environmental control attempts from the beginning and could serve to undermine any attempts to establish safe radwaste land burial sites.

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GLOSSARY

Curi$^{(Ci)}$ - Arbitrary unit for specifying the amount of radioactivity. It was originally defined as the rate of decay of 1g of radium, but it has more recently been redefined as 3.70×10^{10} disintegrations/sec. (μCi - microcurie (10^{-6}Ci), nCi - nanocurie (10^{-9}Ci))

Radwaste - Radioactive wastes

Rem - Roentgen equivalent man; radioactive dose unit which produces a biological effect equivalent to the absorption of one roentgen of X-radiation

Transuranics - Those elements having atomic numbers greater than 92. In practice, plutonium is essentially the only element in this category.

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16. ABSTRACT

This report is the final output of a U.S. Environmental Protection Agency contract which was funded to review present engineering and water management practices to minimize the infiltration of precipitation through trench caps. The objective of this effort was to evaluate and compare the existing practices in use at sanitary landfills, hazardous waste disposal facilities and experimental burial sites, and to apply these practices to the commercial low-level radioactive waste sites.

The report is based on a review of the literature and general knowledge of the state-of-the-art in sanitary engineering developments. The report describes presently available techniques which may be applicable to current and future shallow land burial operations.

17. KEY WORDS AND DOCUMENT ANALYSIS

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