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Landfill Disposal Systems

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The current status of landfill disposal of hazardous wastes in the United States is indicated by presenting descriptions of six operating landfills. These landfills illustrate the variety of techniques that exist in landfill disposal of hazardous wastes. Although some landfills more effectively isolate hazardous waste than others, all landfills must deal with the following problems. Leachate from hazardous waste landfills is generally highly polluted. Most landfills attempt to contain leachate at the site and prevent its discharge to surface or groundwaters. To retain leachate within a disposal area, subsurface barriers of materials such as concrete, asphalt, butyl rubber, vinyl, and clay are used. It is difficult to assure that these materials can seal a landfill indefinitely. When a subsurface barrier fails, the leachate enters the groundwater in a concentrated, narrow band which may bypass monitoring wells. Once a subsurface barrier has failed, repairs are time-consuming and costly, since the waste above the repair site may have to be removed.

The central problem in landfill disposal is leachate control. Recent emphasis has been on developing subsurface barriers to contain the wastes and any leachate. Future emphasis should also be on techniques for removing water from hazardous wastes before they are placed in landfills, and on methods for preventing contact of the wastes with water during and after disposal operations. When leachate is eliminated, the problems of monitoring, and subsurface barrier failure and repair can be addressed, and a waste can be effectively isolated.

A surface seal landfill design is recommended for maintaining the dry state of solid hazardous wastes and for controlling leachate. Any impervious liner is utilized over the top of the landfill to prevent surface water from seeping into the waste. The surface barrier is also the site where monitoring and maintenance activities are focused. Barrier failure can be detected by visual inspections and any repairs can be made without disturbing the waste. The surface seal landfill does not employ a subsurface barrier. The surface seal landfill successfully addresses each of the four environmental problems listed above, provided that this landfill design is utilized for dry wastes only and is located at a site which provides protection from groundwater and temporary perched water tables.

Introduction

Although landfills are probably the most commonly used and the oldest methods of hazardous waste disposal, until recently landfill disposal has received relatively little study. Largely because of an increased awareness of environmental effects of anthropogenic activities and the occurrence in the past decade of several hundred damage incidents related to disposal of hazardous wastes (*1*), there has been an increased interest in identifying sources of hazardous wastes, learning what present disposal practices are, and assessing the adequacy of these procedures. The largest portion of such studies has been sponsored by EPA's Office of Solid Wastes through its general study of reduction, treatment, and disposal of approximately 600 hazardous wastes (*2*) and through assessments of hazardous waste generation and disposal in 13 industrial categories. Generally, as more has become known about the need for isolation of hazardous wastes, landfill disposal procedures have been developed to provide for increased waste isolation. Considerable variety still exists, however, among types of landfills used (and the extent of waste isolation achieved) for hazardous waste disposal.

This paper summarizes the current status of landfill disposal of hazardous wastes in the United States. The general types of landfills will be defined and will be illustrated by descriptions of several operating hazardous waste landfills. The advantages, disadvantages, and problems of each landfill will be discussed. The paper will conclude by summarizing the environmental problems associated with landfill disposal of hazardous wastes and introducing a suggested landfill system which may solve some of these environmental problems.

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General Types of Landfills

Although considerable variety exists for hazardous waste landfills, there is no uniformly used nomenclature in the field. Among the commonly encountered terms are open dump, sanitary landfill, and secure landfill. Definitions for these are presented below. Other commonly used terms include: chemical landfill, industrial landfill, hazardous waste landfill, general-purpose landfill, special-purpose landfill, isolation burial, and environmental containment site.

Open Dump

As the name implies, an open dump is a disposal site where wastes are piled on the surface of the ground. There are generally no provisions for controlling vectors, littering due to wind action, or runoff to surface or ground waters. The Resources Conservation and Recovery Act of 1976 specifically prohibits open dumping, and most states also have existing regulations against open dumps. As enforcement becomes more complete, open dumps should be phased out of existence.

Sanitary Landfill

The sanitary landfill is defined as "a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical area, to reduce it to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation, or at such more frequent intervals as may be necessary" (*3*).

Secure Landfill

There is no widely accepted definition of a secure landfill. Descriptions of secure landfills (*2, 4, 5*) vary considerably; however, the following design and operating criteria are generally mentioned in descriptions of secure landfills. The subsurface soil or soil and liner combination has a permeability of less than 10^{-8}cm/sec. The water table is below the lowest level of the landfill. Adequate provisions are made for diversion and control of surface water. Cover material or liners are used, as needed, to suppress air emissions. Provisions are made for leachate collection, for gas venting, as needed, and for monitoring wells. The composition and volume of each waste is known. Incompatible wastes are segregated. Complete records are kept of waste burial.

Figure 1 illustrates one possible design for a secure landfill (*4*). The use of the term, "secure," is probably unfortunate because of the implication that a waste deposited in a secure landfill is completely isolated for a prolonged period of time. Much additional research is needed to determine how "secure" existing landfills are; indications are that few existing landfills are "secure."

Examples of Hazardous Waste Landfills

Landfills are used for the ultimate disposal of a wide variety of hazardous wastes. These include petroleum refinery wastes, waste paint sludges and slurries, sludges from industrial wastewater treatment, and industrial dry process residues. Six operating hazardous waste landfills are described below. Among them are examples of open dumps, sanitary landfills, and "secure" landfills. They not only illustrate the status and variability of hazardous waste disposal, but also illustrate problems with the use of the above terms. The general features of the landfills are summarized in Table 1. Two landfills are on-site industrial facilities; four landfills accept most types of liquid and solid hazardous wastes.

Landfill 1: Chromium Sludge Disposal Site

This facility is an on-site disposal facility operated by a leather tanning and finishing plant. All solid wastes from the plant—leather trimmings, blue trim and shavings, buffing dust, finishing residues and wastewater screenings, dewatered wastewater treatment sludge—are dumped along the edges of a small ravine in the back of the plant. The hazardous constituents in the wastes include chromium, lead, zinc, copper, and various organic

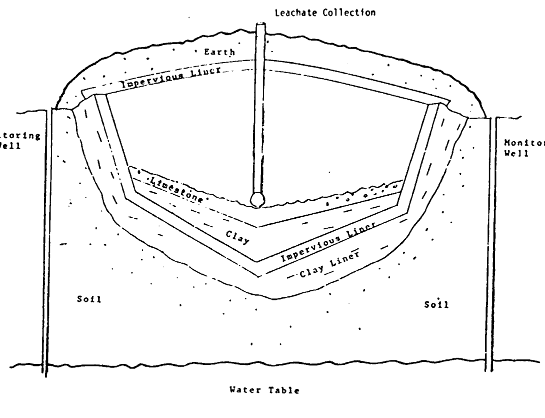

FIGURE 1. Secure landfill. Data of Farb (*4*).

Table 1. Disposal of hazardous wastes in selected landfills.

Landfill no.	Type of waste accepted	Location	On-site vs. off-site	Landfill type
1	Chromium sludges from leather tanning and finishing	Southeastern U. S.	On-site	Open dump
2	Reject batteries and dry battery process residues	Southeastern U. S.	Off-site	Open dump/sanitary
3	Hazardous liquid and solid wastes, commingled with municipal refuse	California	Off-site	Sanitary
4	Solid hazardous wastes	Northeastern U. S.	Off-site	Secure
5	Liquid and solid hazardous wastes	Southeastern U. S.	On-site	
6	Liquid and solid hazardous wastes	Northwestern U. S.	Off-site	Secure

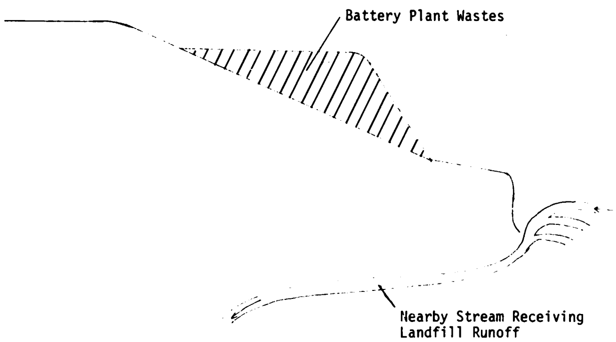

FIGURE 2. Battery waste disposal site.

dyes and pigments. Sources of pollution include surface runoff, leachate to groundwater, and air emissions through wind erosion. Although in 1974 it was estimated that about 90% of the wastes from leather tanning and finishing facilities was disposed of in various types of open dumps (6), the enforcement of the Resources Conservation and Recovery Act could result in virtual elimination of this practice.

Landfill 2: Battery Waste Disposal Site

The battery landfill shown in Figure 2 is also an open dump. Some engineering practices such as grading, contouring, and compacting have been employed, and small amounts of cover material have been used. The landfill has been operating for over 25 years. Over this period approximately 25,000 tons (23 Gg) of crushed batteries, battery components, cardboard wastes, and mercury-contaminated absorbent resin have been deposited in the landfill. The main hazardous constituents in the waste are mercury, cadmium, lead, and zinc, which comprise approximately 10% of the waste material. Studies of heavy metal migration in the vicinity of the landfill have shown that mercury, lead, cadmium, and zinc have migrated through the soil beneath the site to the bedrock, and, through surface runoff, have contaminated the sediment in a nearby stream.

This landfill illustrates one of the important problems in hazardous waste disposal—determining whether migration of any hazardous constituents is acceptable. The company involved has acknowledged that heavy metals migrate from the site; however, they maintain that the rate of migration is slow and that levels are low and are environmentally acceptable (7).

Landfill 3: Hazardous Liquid and Solid Wastes Commingled With Municipal Refuse

The landfill shown in Figure 3 is typical of hazardous waste disposal sites located in Southern California (8). In design and operation, this landfill fits the above definition of a sanitary landfill; however, it is also classified as a Class I landfill (similar to a "secure" landfill) in the state of California and therefore accepts a wide variety of hazardous wastes. General design features are as follows. The landfill is located in a blue clay-type soil which has low permeability. The lowest portion of the landfill is at least 10 ft above the water table. The completed cells of compacted fill material are sloped in such a way that any leachate from the waste will flow to one point in the landfill where there is a small dike. Any leachate found at this point is collected and returned to the fill material. Surface water penetration is minimized by daily contouring and covering with compacted blue clay-type soil.

The hazardous wastes buried at this facility consist of a large variety of liquid and solid hazardous wastes. Some of the more common materials are oily wash-out from oil tanks, weak acid solutions, weak alkaline solutions, waste solvents, petrochemical sludges, digested sewage sludges, and similar materials.

Figure 4 illustrates the procedure for burial of

FIGURE 3. California class I landfill.

hazardous wastes. A depression is made in the municipal refuse at the active disposal area, tankers back to the edge and drain their liquid wastes into the depression. A few minutes is allowed for the liquid waste to percolate into the refuse before more refuse is added in the area and a new depression is made. When the flash point is too low, no moving equipment is allowed in the area until the flash point has increased to acceptable levels. Records are kept of waste locations, and incompatible wastes are kept segregated.

The advantages of this type of landfill are that the disposal procedures are simple, disposal costs are relatively low, many sites (in California) can be used for hazardous waste disposal, and the design and operating procedures are virtually identical to those commonly used in sanitary landfills; thus many disposal site operators are familiar with the procedures.

This type of landfill has several disadvantages. Hazardous liquid and solid wastes are intimately commingled with municipal refuse. Because of the tremendous variety of possible materials in municipal refuse, one cannot completely safeguard against commingling incompatible wastes. There is not complete assurance that the bottom of the landfill is impermeable. Throughout the approximately 15-acre (60,000 m^2) area it is unlikely that no cracks, intrusions of other types of soils, or probable fault areas occur. The one monitoring site will detect leachate flowing through the refuse above the clay bed, but the monitoring site will not detect leachate migrating vertically from the floor of the landfill.

Landfill 4: Solid Hazardous Waste Disposal Site

Figure 5 shows a cross-sectional view of one cell of a hazardous waste landfill located in the Northeastern U. S. (*8*). The disposal site is located in a flat area with clay-soil about 50 ft (15 m) deep. Generally, there is a 10-ft (3 m) distance between the bottom of the site and the water table. The landfill area comprises a series of cells. For each cell an area approximately 300 ft (90 m) long, 80 ft (24 m) wide, and 12 ft (4 m) deep with 45° sloping sides is excavated. A reinforced 30-mil (0.75 mm) Hypalon liner is applied, followed by about 2 ft (0.6 m) of additional clay soil. Cells are prepared for use, filled, and sealed one at a time.

Wastes destined for land disposal are generally sealed in barrels (drums), paper bags, or otherwise encapsulated in cement or lime, but containers are commonly crushed or split during burial. The wastes are segregated according to waste material, e.g., brine sludge, type of pesticide, paint sludge. Common wastes are disposed together in a designated area of the landfill, and form a pile or piles. An inventory is kept of the location of each waste type to facilitate future recovery and to prevent mixing or close disposal of incompatible wastes. Minimal amounts of soil separate the various stacks of materials and minimal amounts of soil are buried with the drums. During active disposal, which may last several months, many of the drums are exposed. Precipitated inorganic chemicals are also used as fill material. Disposal activities proceed until the total disposal height is about 22 ft (7 m) or about 12 ft (4 m) above ground level.

Standing pools of rainwater are common within active disposal cells. Periodically the water is tested for impurities, and pumped out to the treatment system. When a disposal cell is completely filled, a 2-ft (0.6 m) layer of compacted soil is placed over the resulting mound. The area is not revegetated. Monitoring wells are located around the perimeter of the disposal area.

Among the positive aspects to this method of hazardous waste disposal are the following. Wastes received at the facility are converted to the solid form before being placed in the landfill. Most wastes are containerized in drums or paper bags prior to disposal. Because most wastes are solidified, encapsulated in concrete or lime, or otherwise fixed, rainwater contacting the waste becomes much less contaminated than for similar unsolidified wastes. In addition to a clay soil layer, a liner is used to prevent leachate migration.

Although this landfill is basically a well run facility, it does have some problems and disadvantages. The type of surface cover of the finished cells at this landfill is a potential problem. Because the clay-type soil is not revegetated, erosion will increase and periodic maintenance is needed to prevent re-exposure of the waste. Revegetation would solve the erosion problem but also could, through root action, increase the rate of rainwater percolation in the waste.

Wastes placed in active cells are not covered with soil and compacted each day, and there is no provi-

FIGURE 4. Commingling of municipal refuse and hazardous wastes.

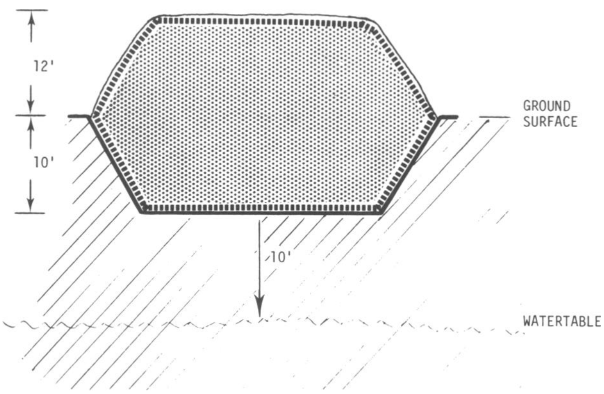

FIGURE 5. Cross-sectional view of solid hazardous waste disposal landfill located in the northeastern U. S.

sion for rainfall to drain away from the wastes quickly. Since the landfill is located in a region with high rainfall, the waste in an active disposal cell is wet much of the time. Therefore, although wastes are solidified prior to being placed in the landfill, the finished waste cell does contain some leachate. It is felt that the surface soil used for final waste cover also allows some water to percolate into the waste, but the amounts are small.

Very little information exists upon which to base estimates of leachate quality at this site. The only indication of leachate quality is that when standing water within an active cell is pumped out, tests have sometimes indicated that treatment is needed before the water is discharged. This would lead one to suspect that any leachate within a finished cell would also require treatment before discharge.

If a barrier failure occurred in a finished cell any leachate in the landfill would flow through that point, and the chances of leachate detection by the monitoring wells would be small.

Landfill 5: Liquid Hazardous Waste Disposal Site

Figure 6 shows a diagram of a landfill which handles a wide variety of liquid and solid wastes from a chemical manufacturing facility (*9*, *10*). The landfill is located on the side of a hill. A 2-ft (0.6 m) layer of compacted clay was used to seal the bottom of the landfill, and a "leaky" earth-holding dike was

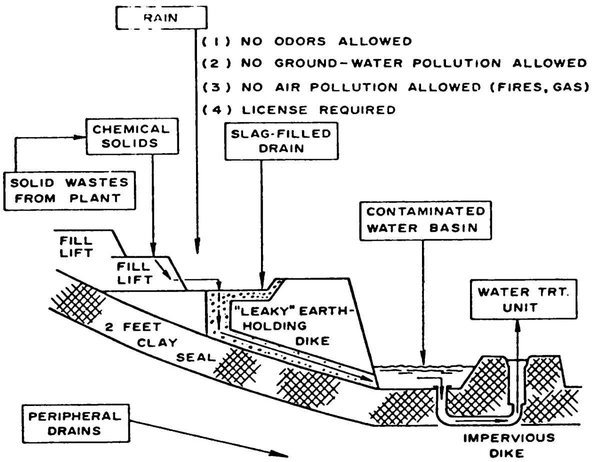

FIGURE 6. Goff Mountain chemical landfill (9).

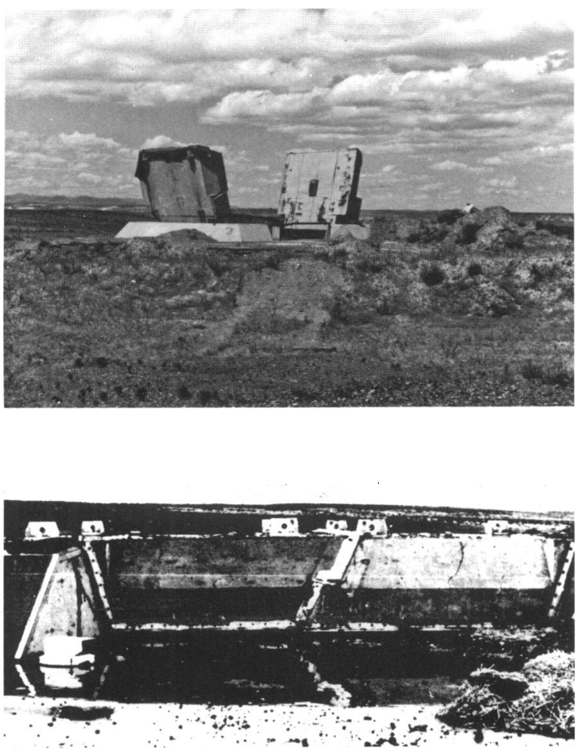

FIGURE 7. Disposal in concrete silos.

constructed at the lower level of the landfill. Liquid and solid wastes are combined in a one to one ratio with soil and placed above the dike. Leachate from the waste runs down the slope to the dike where the water is directed to a holding basin and piped to the wastewater treatment unit. Operating practices include waste segregation, continuous blending, and daily coverage. The facility has a projected 20-year life. Types of wastes accepted by the landfill include waste oils and oil sludges (the major waste material), plasticizers, detergents, pitch, tars, polymers, and inorganic solids such as carbonates and alumina. Occluded metals and toxicants are apparently impounded in concrete prior to emplacement in the landfill.

The primary advantage of this landfill is that the problem of leachate generation is recognized and methods are provided for leachate collection and treatment. Potential problem areas include the clay seal (which probably should have been thicker), structural integrity of the dike, and methods of closing the site after the 20-year period.

Landfill 6: Disposal in Concrete Silos

The final example of a hazardous waste disposal landfill represents a unique approach to secure landfill design (*11, 12*). The facility, located in the Northwestern U. S., uses a former missile launching site for hazardous waste disposal (Fig. 7).

Liquid and solid wastes are placed in underground structures consisting of a series of silos and vaults. The walls and floors are of reinforced concrete that has been treated with asphalt emulsion on the outside. The silos are approximately 49 m deep with walls 1.8 m thick and floors 4 m thick. Clay and water are also added to absorb the impact of the dropping load and to minimize the potential for fire or explosion. About 95% of the total wastes handled are pesticide wastes, primarily process waste from pesticide manufacturing plants.

This disposal method relies on the thickness of the reinforced concrete to isolate the waste from the environment. During active use of some silos and vaults as launching sites, however, sump pumps were required to remove water seeping in through concrete walls. Therefore, leakage of hazardous liquids outwards can occur. No monitoring wells are used.

Environmental Problems Associated with Hazardous Waste Landfills

The above descriptions show the variety of hazardous waste landfills. Although some are obviously better than others, there are common problems with which each type of landfill must deal.

Many hazardous wastes have a high water content which causes a leachate to be generated during compaction and filling activities. Other sources of leachate include rainwater seepage through the waste, and contact with groundwater or perched water tables. An important area of research needed is the study of landfill leachate and the determination of what concentrations and quantities, if any, of hazardous materials in leachate are environmentally acceptable. The general approach in most landfills is to contain leachate at the site and to prevent its discharge to surface or groundwaters.

To retain leachate within the disposal area, subsurface barriers of materials such as concrete, asphalt, butyl rubber, hypalon, vinyl, and clay are used. None of these can seal a landfill indefinitely. For example, asphalt and concrete are sufficiently porous to allow the passage of small quantities of water. An average rate for concrete is 25 pt/yd^2/yr (14 l./m^2/yr) (National Redi-Mix Concrete Association 1977). Also, cracking is a problem with both asphalt and concrete. Rubber, polyethylene, and vinyl will more effectively prevent leachate from leaving a disposal site; however, the thinness of these materials renders them susceptible to rupture by heavy equipment during disposal operations, and by settling processes after site closure.

Monitoring wells are commonly used to detect pollution from landfills. These generally sample the groundwater down-gradient from the landfill. Since groundwater flow is laminar and in one direction, the assumption is that monitoring wells placed in the direction of groundwater flow from the landfill will detect any pollutants.

Actually the chances of detecting the pollutants are rather small with even the best monitoring well systems. When a subsurface landfill barrier fails, the leachate enters the groundwater in a concentrated, narrow stream. In the aquifer essentially no mixing occurs, thus the leachate will flow in a very narrow band and may easily miss the monitoring wells. In addition, until the groundwater is reached, leachate from landfills travels vertically through the soil, through cracks, and along the surfaces of any clay seams that may be encountered. This increases the difficulties of correctly placing monitoring wells.

The best monitoring system, then, would be one which could be located directly beneath a landfill and would monitor the integrity of the subsurface barrier itself. Monitoring wells are not suitable for this purpose, since their installation would penetrate the barrier itself. One possible monitoring system would detect changes in conductivity (such as that caused by landfill leachate). Once a subsurface barrier has failed, repairs are time-consuming and costly because the waste above the repair site must be removed. Due to the large quantities of wastes involved in most landfills, barrier failure and repair present significant problems.

For many years these problems have presented a dilemma to persons involved in landfill disposal of hazardous wastes. The economic advantages and simplicity of landfills make them the disposal technique of choice in many instances, yet the problems of leachate, barrier failure, monitoring, and barrier repair remain.

The central problem in landfill disposal is leachate control. Recent emphasis has been on developing subsurface barriers to contain the wastes and any water. Future emphasis should also be placed on removing water from hazardous wastes to be landfilled and on preventing contact with water during and after disposal operations. When leachate is eliminated, the problems of monitoring, and subsurface barrier failure and repair can be addressed, and a hazardous waste can be effectively isolated.

Surface Seal Landfill

The surface seal landfill concept was developed in 1976 by the author as a method for landfill disposal of hazardous wastes which would avoid the problems of leachate migration, and subsurface barrier failure and repair. Figure 8 illustrates the surface seal landfill concept. An impervious liner (line AEB in Fig. 8) is utilized over the top of the landfill to prevent surface water from seeping into the waste. The liner would have sufficient width to prevent lateral water infusion. This surface barrier is also the site where monitoring and maintenance activities are focused. Barrier failure can be detected by visual inspections and any repairs can be made without disturbing the waste. The surface seal landfill shown in Figure 8 does not employ a subsurface barrier, since it serves no useful purpose. Among other advantages of this landfill are simplicity, and low cost. The landfill can also be located in virtually any kind of terrain, i.e., not necessarily in clay, since no leachate will be generated. The landfill will also maintain its integrity even during mild geological disturbances as long as a major shift in the water table does not occur. This technique for land disposal successfully addresses each of the central environmental problems for land disposal stated in the previous sections, provided that this landfill design

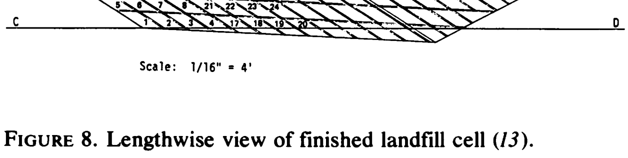

FIGURE 8. Lengthwise view of finished landfill cell (*13*).

is accompanied by land siting which provides protection from groundwater and perched water tables. It must be emphasized that only dry wastes can be put in a surface seal landfill.

In a recent TRW study of disposal of dry waste from advanced flue gas desulfurization (*13*), it was concluded that the surface-seal type landfill was the most attractive disposal alternative from both environmental and economic aspects.

Summary

Important aspects of the landfill disposal of hazardous wastes are as follows. There is a great deal of variability in design and operating parameters such as siting requirements, landfill design, and types of wastes accepted. Among the reasons for this variability are the site-specific nature of landfill disposal, differences of opinion regarding what is environmentally acceptable, variations in state and local regulations, and economic factors.

There is no consensus on the degree of waste isolation that is necessary in landfill disposal of hazardous wastes.

Because a site-specific evaluation is so important in determining selection of a disposal method and subsequently in determining landfill design and operating procedures, it is difficult to establish (and apply) uniform landfill criteria, although general guidelines can be formulated.

Common problems with landfill disposal systems are leachate control, inadequacy of existing monitoring systems, eventual barrier failure, and difficulties in subsurface barrier repair.

At the present time, few landfills exist which can assure complete and continued isolation of wastes. The surface-seal landfill shows promise as a simple, economical method for disposal of certain hazardous wastes.

More research and development on landfill disposal is needed. Some important research areas include: leachate reduction techniques, barriers for landfills, detecting landfill barrier failures.

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