HAZARDOUS WASTE DISPOSAL ALTERNATIVES: FOUR OPTIONS FOR HAZARDOUS WASTE DISPOSAL PAPER FOR PUBLICATION IN CIVIL ENGINEERING MAGAZINE SPETEMBER 1981 ISSUE

Summary

Approximately 41,235 thousand wet metric tons of hazardous waste were produced in 1980. Nearly 83 percent of this waste was treated and disposed of on-site by the producer. The remaining 17 percent was handled by off-site commercial facilities. The methods used include secure landfills, land treatment, deep well injection, incineration, resource recovery, and chemical, biological, and physical treatment. This article focuses on four options: secure landfills with the option of fixation before landfilling, land treatment, mine storage, and deep well injection. Engineering design and construction information is presented for each option.

by

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Introduction

It has been estimated that the production of hazardous waste in the United States was 41,235 thousand wet metric tons in 1980. Figure 1 illustrates the industries that are the major contributors. The single largest source is the chemicals and allied products industry, accounting for 62 percent of the total. Approximately 83 percent of the hazardous waste produced is treated or disposed of on-site by the industry. The remaining waste is handled by commercial off-site facilities. Figure 2 presents the waste management options utilized. As noted, landfilling and treatment are the options utilized. As noted, landfilling and treatment are the options used for approximately 66 percent of the waste. The remaining waste is either incinerated, land treated, deep well injected, or recovered. This article will focus on four options: secure landfills with the option of fixation before landfilling, land treatment, mine storage, and deep well injection.

Secure Landfills

A secure hazardous waste landfill means a facility which has received a permit from the U.S. Environmental Protection Agency (USEPA) or from a state authorized by the USEPA to issue permits to dispose of hazardous waste by the landfill method.

The secure landfill concept encompasses much more than just the simple burial of hazardous material. Hazardous waste landfills must be carefully engineered to provide long-term protection of groundwater, surface water, air, and human health. Figure 3 shows a secure landfill. Although the state-of-the-art is still developing, a number of techniques are now available for effectively reducing the adverse health and environmental effects from landfills.

The environmental problems associated with hazardous waste landfills can be divided into two broad classes. The first class includes fires, explosions, toxic fume production, and other problems caused by incompatible materials being mixed. The second class includes contamination of surface and groundwaters. The first class of problems can be adequately handled by proper management through use of controlled mixing of incompatible wastes; segregation of materials in separate landfill cells; and pretreatment of wastes. The problems associated with the second class are more difficult, but can be handled by proper siting, appropriate design and operation of cover, waste cells and subcells, leachate management system, and provisions for long-term management of the facility through closure, post closure, and monitoring activities.

The following describes these considerations and elements of landfill design which are important as they relate to permanent status and to interim status standards of the USEPA. Since the currently proposed regulations reflect increased flexibility in permitting for hazardous waste landfills, no one set of design criteria is proposed or advocated.

In siting landfills four general areas need to be considered: groundwater quality, surface water quality, air quality, and potential for subsurface migration of leachates and gases. In addition, specific requirements have been established, such as location with 200 feet (61 m) of a fault and/or in a 100-year flood plain. Groundwater and surface water quality cannot be adversely affected. The following eight factors need to be considered:

- Volume and physical and chemical characteristics of the waste;
- Hydrogeological characteristics of the facility and the surrounding land;
- Quantity, quality, and direction of groundwater flow;
- Proximity and withdrawal rates of groundwater uses;

- o Establishment of existing groundwater quality including other sources of contamination;
- o Potential for human health risks;
- o Damage to wildlife, crops, vegetation, and physical structures caused by exposure to waste constituents;
- o Persistence and permanence of the potential adverse effects.

All surface water discharges must be in compliance with the National Pollutant Discharge Elimination System (NPDES) requirements. Rainfall patterns in the area need to be considered to determine the appropriate controls for diversion of runoff from adjacent lands and control of runoff from the facility. Runoff which has contacted the waste is assumed to be contaminated and must be specifically tested to determine appropriate discharge conditions.

Air quality needs to be considered in order to prevent adverse effects to the air caused by volatilization, gas generation, gas migration, and wind dispersal of landfilled hazardous wastes. Subsurface migration of leachate is considered to be a distinct form of environmental degradation apart from contamination of groundwater, which is subsequently drawn for use. Subsurface migration is of primary concern in relation to contamination of nearby subsurface structures and vegetative kill. Both the saturated and unsaturated zone must be considered in evaluating the potential for subsurface migration. Knowledge of waste characteristics and the geology of surrounding area is needed, as well as land use patterns in the immediate vicinity.

A design consideration for landfills is a liner to contain the waste and intercept the leachate. Although the regulations do not require the construction of a liner for all landfills, it is recognized that many landfills will be constructed using liners in order to contain the hazardous waste. Liners can either be of earthen material or synthetic membranes. Generally, the liner requirement will involve the placement of materials onto the floor and sides of the disposal area. Under appropriate conditions, it might be possible to use the natural in-place material which underlies the facility as part of the liner. The amount of leachate that will be generated in the landfill is a critical factor in assessing the liner design. This assessment must involve a consideration of the waste type (e.g., liquid content, biodegradability, solubility, migratory potential), the volume of waste, and climatic conditions in the area (e.g. rainfall). In assessing the performance of the liner, the characteristics of the liner material must be examined. The permeability of the liner material is a central concern. Thickness, susceptibility to cracking or tearing, and resistance to adverse weather conditions are important liner considerations. For earthen liners, the compacted density and moisture content of the material is also significant. For synthetic membrane liners, longevity based on degradability (chemical resistance) and resistance to wear (structural integrity) are significant. Any emplaced liner must be installed in a manner that will protect the function and physical integrity of the liner. For example, the operator must assure that the installation process does not cause rips or tears in the liner material and that any seams in the liner are properly joined.

All landfills must have some kind of leachate and runoff control system for management of these liquids. The design and operation of the facility significantly affects the amount of contaminated liquid which must be managed. If the facility intends to discharge collected leachate or runoff to surface waters, compliance with the USEPA and the state water quality standards and discharge requirements must be met. Any leachate or runoff which qualifies as a hazardous waste must be managed in accordance with hazardous waste regulations.

The concept of landfill cells has been incorporated into the regulations. A landfill cell is "a discrete volume of hazardous waste landfill which uses a liner to provide isolation of wastes from adjacent cells or wastes." Cells may be physically separate areas of landfills or trenches, and as such can be used to separate incompatible wastes. The use of the cell concept will permit different cells to have different closure requirements and financial arrangements. A leachate monitoring system is required for new landfills and landfill cells.

All landfills must have some type of cover when it is closed. The function and design of the cover will depend on the operator's strategy. The cover may be used as a means to prevent wind dispersal and to avoid public contact with the waste in the landfill. Under other circumstances it may be used as a barrier designed to keep liquids out of the facility and to minimize the production of leachate. Whatever approach is taken, the development of the cover specifications should be coordinated with the design of the liner in order to avoid the "bathtub" effect. This occurs when a relatively permeable cover is placed over a facility that has a relatively impermeable liner. Such a facility may simply fill up with water and overflow, carrying waste constituents with it. A minimum set of technical factors needs to be considered in cover design. These factors include cover materials, final surface contours, porosity and permeability, thickness, length and steepness of slope, and type of vegetation. Allowances should be made for deep-rooted vegetation and to prevent water from pooling. The design will depend on the availability and characteristics of on-site or nearby soils, and a number of other site specific factors. The final cover design could simply be the placement, compaction, grading, sloping, and vegetation of on-site soils, or it could be a complex design utilizing a combination of compacted clay or membrane placed over a graded and sloped base and covered by topsoil and vegetation.

A detailed plan describing the manner in which the landfill will be closed and maintained during the post-closure period is required. The subjects to be addressed in the closure plan are: (1) control of pollutant migration from the facility via groundwater, surface water, and air; (2) control of surface water infiltration including prevention of pooling; and (3) prevention of erosion. The factors that must be considered in properly closing a landfill are: waste characteristics (type, amount, mobility, rate of migration); cover characteristics (material, surface contours, porosity, and permeability, slope, length of run of slope, type of vegetation on the cover); and characteristics of the local environment (climate, location, topography, surrounding land use, geological and soil profiles, surface and subsurface hydrology).

The overall objectives of the closure and post-closure are to minimize the need for further maintenance of the facility and to restrict the escape of hazardous materials. The relevant factors are essentially the same as those considered for closure. An additional factor that is important during the post-closure period is the maintenance of any groundwater monitoring system or leachate and runoff control system at the facility. These measures are often necessary because leachate can continue to be produced and to migrate long after the waste is placed in the landfill.

To assist in the design of hazardous waste secure landfills, there has been a compilation of all research efforts to date in documentary form, i.e. Technical Resource Documents (TRD's). These documents are a compilation of research efforts and state-of-the-art techniques to date and were developed primarily for use by the permit writers for evaluating facility designs and potential performance of new waste disposal facilities. These documents can also be used as (a) guidance by owners/operators of interim status facilities especially for closure and post-closure cover consideration and (b) assistance to the owner/operator and permit official in identifying and evaluating the technologies which can be used to control potential adverse effects of human health and the environment and in complying with the regulations. Eight TRD's have been completed to date. Six documents have been prepared that relate to secure landfills. They are:

TRD 1, Evaluating Cover Systems for Solid and Hazardous Waste (SW-867):* This document presents a procedure for evaluating closure covers on solid and hazardous waste to assess a complete evaluation.

TRD 2, Hydrologic Simulation on Solid Waste Dipsosal Sites (SW-868); This document provides a computer package to aid planners and designers by simulating hydrologic characteristics of landfill operation to eliminate percolation through the waste and control the formation of leachate.

*TRD's are available from Solid Waste Publications, U.S. Environmental Protection Agency, Cincinnati, Ohio 45268. Use SW numbers when ordering.

TRD 3, Landfill and Surface Impoundment Performance Evaluation (SW-869): This document describes how to evaluate the capability of various landfill designs to control the leachate release.

TRD 4, Lining of Waste Impoundment and Disposal Facilities (SW-870): This document provides information and guidance on the performance, selection, and installation of specific liners for various disposal situations based on the current state-of-the-art of liner and other pertinent technology.

TRD 5, Management of Hazardous Waste Leachate (SW-871): This document presents management options that a permit writer or hazardous waste landfill operator may consider in controlling and treating leachate.

TRD 6, Guide to the Disposal of Chemically Stabilized and Solidified Wastes (SW-872): This document provides basic information on stabilization/solidification of industrial waste to ensure safe burial of waste containing harmful materials.

Stabilization/Solidification

Waste stabilization/solidification is a pretreatment process that has been proposed to insure the safe disposal of wastes containing harmful constituents. Terminology has been developed and borrowed from other fields to describe the technology. "Solidification" is the pretreatment process that will improve the handling and physical characteristics of the waste. This could be as simple as adding soil, saw dust, cement, lime, fly ash, etc., to change a sludge from a semi-solid/liquid to a solid material, either a monolithic block, soil-like material, or pellets. Generally, the solidification process does not chemically change the waste. "Stabilization" is the pretreatment process that induces a chemical change to the waste constituents. This chemical change produces an insoluble form of the waste constituent or places the waste in a matrix that is insoluble. Physical enhancement of the waste usually accompanies the stabilization process.

The types of waste streams usually treated by this technology are the inorganic sludges. Although organic sludges have been treated, the treatment has not been as successful as with inorganic wastes, especially when compared to the durability of the product and its capacity to prevent leaching of the wastes. However, research activities by industry are developing treatment processes which will stabilize/solidify organic wastes.

Treatment processes currently available include cement based processes, pozzolanic processes (not containing cement), thermoplastic techniques (including bitumen, paraffin, and polyethylene), organic polymer processes, self cementing processes, and glassification and production of synthetic minerals or ceramics. These processes are described in detail elsewhere.* Depending on the waste streams and the degree of hazard to be treated, the options are quite varied. Needless to say, all options will not work with all wastes. Each treatment has to be tailored to the individual waste. In situations where a variety of wastes is received at a central treatment facility, blending of several wastes may result in a waste material that is suitable for treatment.

Due to the relative newness of the technology, physical properties of the end product are usually described by soil or concrete terminology.

*Guide to the Disposal of Chemically Stabilized and Solidified Waste. USEPA Report SW 872, Washington, D.C., 1981.

These are useful in making comparisons with other materials that are well described in the literature. There are limitations on the use of the physical property data. Properties that are important to the containment success of the different types of treatment processes vary greatly with the treatment type. For example, the unconfined compressive strength of a treated waste is meaningful only for those processes that limit containment loss by producing a solid monolith. Processes that produce soil-like or plastic, spongy masses or encapsulates require completely different testing regimes.

Unconfined comprehensive strength and permeability are most commonly reported for the treatment processes that produce monolithic products for which high strength values and low permeabilities are said to be indicative of good containment. Compressive strengths of 10^5 to 10^6 N/m^2 and permeabilities of 10^{-5} to 10^{-7} cm/sec are not unusual for concrete based systems. Organic admixtured systems are usually plastic (low strength) and vary from highly permeable to impermeable depending on the kinds and amounts of additive used. Treatments that produce clay or soil-like products cannot be tested using the physical property testing procedures designed for concrete-like products. These products usually have relatively high permeability and depend on containing the pollutants by binding them inside a molecular matrix.

Results of leaching tests are commonly reported by vendors of waste treatment systems. The leaching test protocol becomes very important. Unfortunately, there is no universally accepted procedure. Results are reported for quick 1-hour distilled water tests to long-term field tests. Presently, there is no required chemical leach test available to predict the ultimate containment of treated toxic waste, but test protocols developed for the nuclear waste industry can be employed to model waste containment. The problem of radionuclear waste escape from solids formed using matrices of cement, asphalt, ceramic, or glass media can be modeled using expressions that take into account diffusion and concentration-dependent dissolution.

In many stabilized/solidified wastes the containment properties depend on limiting the surface area across which transfer of potential pollutants can occur. Physical testing systems are required to judge the durability of the solidified waste.

Physical testing of waste materials becomes very important when the conditions for shallow land burial are not ideal. For example, durability testing is important where cover will not be sufficient to prevent cyclic wetting and drying, or freezing and thawing. If the cover is permeable, all of the containment for the waste may depend on the production of an impermeable monolith. However, for treated materials that can be ground to a powder and still not lose materials to leaching, the durability tests would be important only for structural integrity and would have little meaning for containment characteristics.

In general the stronger, more impermeable, and durable a treated waste, the more effective will be its containment. If the material does not fragment to create dust or increase the surface area for exchange, losses will be minimized. Cement-based treated wastes can be prepared with properties that approach commercial concrete. Tests have shown compressive strengths up to 2,500 lbs/sq in., with excellent durability, permeabilities of 7.9×10^{-4} cm/sec and less that 20 percent weight loss after 12 freeze-thaw cycles. Small column leach testing (IAEA method) has shown that in cement-based systems the strongest material has the minimum contaminant loss.

Where the maximum possible concentration tests show potentially hazardous levels of toxicants, durability would have to be very high to demonstrate that physical characteristics of the material will prevent this "worst case" situation from occurring.

When solidified wastes are buried, the major factor limiting the loss of material from the monolithic mass is diffusion of the chemical constituents to the surface of the solid. The rate of solution of material at the surface is large compared to the diffusion rate. Diffusion in a solid can be assessed using tests such as the Uniform Leaching Procedure (ULP). The results of the ULP are given as effective diffusivities (measured in cm^2/sec).

Effective diffusivities or leachability constants can be used in comparing the containment afforded by different solidification systems and for predicting the long-term losses from masses of wastes. Very little information is available on effective diffusivities of solidified industrial wastes. Most data on leachabilities of solidified waste come from nuclear waste treatment. Usually the elements and the types of material treated differ greatly from typical industrial wastes. In general, glass-fused wastes have had lower loss rates than plastic (bitumen) encapsulated materials, and plastic (bitumen) materials have lower loss rates than cement-based materials. Determining effective diffusivities appears to be the best documented system for comparing the retention of different constituents of waste using the same solidification system as for comparing the containment produced by different solidification systems on one waste.

Treated waste material may vary greatly from batch to batch due to variation in wastes incorporated or the conditions of treatment. In cement or pozzolan-based systems, small amounts of interfering materials can drastically reduce strength, durability, and chemical containment. In some solidificiation operations in which the material is poured out to solidify as a monolithic mass, solidification may not occur, and if an additional layer is poured over the unsuccessfully solidified wastes, a highly leachable zone in the waste mass is created. Such poor operating practices should be avoided.

Any treatment process should include a system for determining the character of the treated waste and a provision for reprocessing the material before final deposition if the treatment process was unsuccessful. The exact sampling pattern for determing treatment quality would depend on the variability of the feedstock for the treatment system and the quantity of waste treated. In batch operations, each separate batch should be leach tested and tested to determine selected physical properties. In a cement- or pozzolan-based system, any large changes in set-time or texture of the treated waste should be cause for a more complete testing sequence.

Periodically, samples should be cored from aged solidified wastes to determine if breakdown and loss of contaminants have occurred. If the physical properties, strength, and durability have not decreased and the permeability of core materials has remained low, the assumption of a low-permeability monolith of waste is justified. Leach testing of core material can be used to ascertain any decrease in containment properties with age. If a landfill operation can demonstrate that the treated waste is not breaking down, longer periods can be permitted between resampling of treated waste.

Most waste materials that are currently being considered for disposal have no present value, and thus all solidification/stabilization costs represent additional expenses to be added to the ultimate cost of the product or service sold. A complete economic analysis must consider costs of waste transportation, materials, and equipment required for stabilization/solidification, skill levels of treatment plant operators, fees or royalties for use of patented processes, and cost of transporting and landfilling treated wastes. This type of analysis often must be undertaken on a case-by-case basis. However, to obtain an initial impression of the usefulness of different waste treatment systems now and in the future, it is possible to restrict economic considerations to present and projected costs for materials, equipment, and energy. In most treatment systems, the cost of materials required is the major item regulating present and projected costs. Table 1 outlines the present and future economic considerations for major waste stabilization/solidification systems.

Land Treatment

Properly designed and managed land treatment systems are an acceptable technology for treating and disposing of selected industrial hazardous waste. Such systems are not the answer to all waste problems but, when properly applied, they can provide an efficient and cost effective treatment and disposal alternative.

Land treatment of hazardous wastes involves the planned and systematic use of the soil's top layer for biological, chemical, and physical treatment. The process is a dynamic one involving the interaction of waste, site, soil, climate, and biological activity (usually aerobic) to degrade, immobilize, or deactivate the waste constituents. The objective is to eliminate or reduce contaminants to acceptable limits, usually through biological degradation. Land treatment systems can be designed to treat almost any waste, but they should be used primarily for wastes that can be degraded or chemically altered to eliminate or reduce the hazardous components to acceptable levels.

The design and operation of a successful system depends on careful study and consideration of its key components: waste, site, soil, and climate. Essentially the design process involves determining the amount of an acceptable waste that can be applied to an acceptable site. Projected long-term use of the site is also an important design factor. If, for example, the intention is to use the completed site for grazing animals, the design and operation must prevent interactions of wastes, soils, and plants that could result in ingestion of contaminated materials.

Land treatment is an open process which can cause impacts on- and off-site to groundwater, surface water, air, and plants, and other environmental concerns. Thus, the design approach must consider the total system, including waste characterization, site selection and preparation, proper operation and management, monitoring, closure, and post-closure. Specific criteria may not be available to determine clearly many of the factors; however, information is generally available to provide reasonable ranges for design parameters. Values that fall outside of these ranges may indicate that additional data are required and/or that conditions are not acceptable for successful land treatment.

Most available data are for individual waste constituents and their reactions with soils. Design problems thus occur when the constituents are present in complex waste mixtures that have the potential for synergistic or antagonistic reactions. When wastes are complex and when values fall outside reasonable ranges, laboratory and pilot tests may be required before proper design can be completed. Data from waste-soil interaction studies must be interpreted to determine feasibility, acceptable waste loading rates, management needs, and monitoring requirements. The interpretation should consider each important waste constituent independently unless adequate information is available to do otherwise.

Application rates and feasibility are closely related. Almost any waste can be treated by land disposal, but allowable loading rates may require an impractically large area. Economics then becomes the limiting factor. Acceptable loading rates are calculated for each waste constituent based on its interaction with the soil, climate, and other site conditions. The component that most restricts the waste application is selected.

Several categories of limiting waste constituents must be considered when determining application rates:

- The constituent that limits the amount of waste that can be applied annually is called the rate limiting constituent (RLC). Once this factor is determined, the land area required to treat the waste can be estimated by simply dividing annual waste receipts (kg/yr) by acceptable loading rates (kg/ha·yr).

- The constituent that limits the amount of waste that may be applied in a single dose but that is rapidly decomposed or immobilized is the application limiting constituent (ALC). This factor does not necessarily control the annual loading rate, but it establishes the number of applications that can be made during that period. An example may be a constituent that becomes toxic to the active microorganisms in large quantities but that is acceptable in the same or larger quantities to the remaining system components. If the waste contains such a constituent, maximum annual waste applications are determined by dividing the RLC loading rate by the ALC loading rate. In many cases the rates will be the same.
- The constituent that limits the total quantity of waste that can be applied to a site is referred to as the capacity limiting constituent (CLC). This constituent is usually some accumulating species such as a heavy metal. The CLC may also be the RLC when a waste contains a large concentration of a specific rate-limiting metal. Since many industrial toxic wastes have low metal contents, some organic compound, water, or another constituent may control the RLC, and the metal may be the CLC. The CLC controls and establishes the maximum useful life of a facility unless other design features determine otherwise.

Individual constituents of concern in the design process include organics, water, metals, nitrogen, and selected nonhazardous constituents.

The hazards posed by waste organics may generally include acute toxicity to soil biota, phytotoxicity to plants, acute or chronic toxicity to animals, and danger of fire or explosion. These may occur during land treatment as a result of volatilization, leaching, runoff, and degradation. All of these possibilities must be considered in calculating the application rates. Degradation, which is the major objective of land treatment, can be determined by respirometer studies and by greenhouse and pilot studies in the field. These rates can be observed over a range of waste loading rates and soil conditions. Determinations can be made of waste levels above which essential biological activity is slowed or stopped. Plant toxicity assays can determine concentrations harmful to plants. When the waste half-life and its microbial toxicity and phytotoxicity are determined, the recommended safe loading rates can be determined.

A high water content in the waste may limit application rates because of climatic conditions. Site precipitation, evapotranspiration, and soil permeability data can be used to develop a water balance, which can then be used to determine the season for waste application and to develop an acceptable water management plan.

One important factor to be considered in facility design is that untreated wastewater must not leave the premises. Excess water can also create major management problems. Two options available are to design the facility for zero water discharge (in situations where annual water inputs are less than outputs) or to treat the wastewater.

Management of metals involves sorbtion of the applied elements in the soil so that no toxic hazard results. Environmental damage can occur through leaching of selected anions (e.g., selenium and molybdenum) or metals that are solubilized because of low soil pH. Most metals, however, are relatively immobile in soils with neutral to basic conditions.

Thus allowable metal applications often depend on site closure plans. For example, if the latter calls for removing the contaminated soil, total metals applied may be greater than in a closure plan calling for few restrictions to final land use.

Metal constituents will normally control the total amount of waste applied to a site even if another constituent controls the application rates. Allowable amounts for selected metals that show little movement in soils are shown in Table 2.

Nitrogen is of concern when it is present in high concentrations. Excesses can cause environmental and health problems. Nitrogen inputs should equal nitrogen removals in order to maintain acceptable levels of nitrates in runoff and groundwaters. Nitrogen is often the RLC in land treatment systems.

Although not hazardous, other constituents must be considered in designing the system. Excessive amounts of phosphorus, inorganic acids, bases, salts, and halide may cause problems in the land treatment processes or may cause some loss of environmental quality through contamination of groundwater or surface water. Each such constituent should be evaluated and considered when determining acceptable waste loading rates.

The basic design objective is to develop a system where the soil, waste, and site conditions interact to yield the desired degradation and/or deactivation of the hazardous waste constituents. Allowable application rates are calculated by determining key waste constituents that are limiting because of their interaction with the soil, climate, and other site conditions. After each potentially problem-causing constituent is considered, a comparison is made to select the one that is most limiting. When the limiting constituents and the allowable loading rates have been determined, the required land area, applications per season, and facility life can be determined.

A monitoring program is an essential component of facility design and management. This essential program should include provisions to assure that the waste input does not change significantly, that degradation and treatment is taking place, that unacceptable levels of toxic constituents and contaminants are not leaving the facility or building up in the system to levels that restrict proper treatment, and that soil conditions (pH, moisture, etc.) are satisfactory.

Closure of the facility is also an important consideration in design and operation. This process begins when the last load of waste has been accepted. The type of final closure chosen will greatly influence the level of degradation required. Three closure procedures are available:

- To stabilize the site with vegetation and use soil conservation methods that will prevent any problems to human health or the environment.
- To remove the contaminated material to a hazardous waste treatment or disposal facility.
- To cap the treatment area as required for a landfill to control infiltration and erosion.

If the hazardous waste land treatment facility has been properly designed, successful operation hinges on a single factor: management. Improper management is probably the most frequent cause of problems at land treatment facilities. Proper management involves assuring that (1) applications rates are not exceeded, (2) berms, ponds, waterways, etc. are properly maintained, (3) required cultivation, liming, and fertilization are practiced, (4) proper monitoring is conducted, and (5) other activities required for proper operation are carried out.

Land treatment is an old concept that offers an acceptable alternative for managing hazardous wastes. Properly designed and managed systems can treat selected hazardous wastes efficiently and economically. The technique has suffered from an image that includes surface dumping and a misunderstanding of its potential when properly applied. Land treatment deserves adequate consideration as a hazardous waste treatment alternative.

Mine Storage

One option for the disposal of hazardous waste is storage within underground mines. The hazardous waste, which has been solidified, is packed in drums and transported down the mine shaft and placed in prepared rooms. The disposal area is divided into several sections, each receiving specific wastes that are compatible with each other. As a room within the mine is filled, it is sealed off. If the mine is properly selected, the atmosphere is very dry and the drums have an indefinite life unless they are corroded from the inside. One advantage of this method is that the waste can be received at a later date if necessary. Figure 4 illustrates a conceptual waste handling system.

Salt, potash, and gypsum deposits have been identified as having the highest potential for waste storage. Worked out portions of existing or inactive mines would be most appropriate since the cost of developing the site would be minimized. Salt deposits have many advantages. First of all, as shown in figure 5, they are widely distributed throughout the United States. Many are located in close proximity to major industrial areas where the majority of hazardous wastes are produced.

Thus, the transportation of hazardous wastes over long distances and the risk associated with it are minimized. These deposits often have large volumes of underground openings available. Salt has good structural properties including high compressive strength (comparable to concrete) and plasticity. It is typically well isolated from aquifers by adjacent deposits that are both thick and impervious as is the salt itself. Most salt deposits occur in areas of low seismic risk and large geologic stability. Chemically, salt is compatible with nearly all hazardous compounds.

Although mine depositories for low level radioactive wastes have been used in the United States, underground mines have not been used for hazardous waste. An exemplary situation does exist in Herfa-Newrode, Germany. Kali & Salz A.G. has developed a worked-out section of a potassium salt mine for the depository of more than 700 compounds. In 7 years over 240,000 tonnes of solid waste have been deposited in the mine. Currently, 35-40,000 tonnes are deposited annually.

The disposal area has a cover of impervious rock salt approximately 170m thick that segregates it from an upper aquifer and a 100m thick layer below that serves as a barrier to the lower strata. In order to prepare the mine for waste depositing, the rooms are cleaned of waste rock, made higher, and the roof bolted.

A negotiation between Kali & Salz and the waste producers takes place before any waste is accepted at the mine. Free flowing waste, any waste that produces a gas that when mixed with air will ignite, radio-active waste, waste that will self-combust, or waste that produces dangerous gases are not accepted. The German mining and environmental authorities must approve the storage. No processing of the waste takes place at the mine. The producer must process the waste so that it is not free flowing. The waste arrives at the mine in one of three basic types of containers, i.e. 55-gallon steel drums, fiber drums, and plastic-lined paper bags. The mine has been separated into 19 different storage categories. Compatible wastes are stored together. The waste is moved from the unloading area and down the shaft on pallets. Pallets are carried by truck to the disposal site, then unloaded and stacked with a fork lift. They are normally stacked 2-3 drums high. After an area has been filled with drums, a brick wall is constructed across the face of the room. The main purpose of this wall is to assist the ventilation system.

The disposal practice is controlled in several ways. A manifest system is used to assure the producers and the environmental authorities that the waste has arrived at the mine. Each waste is coded according to its producer and location in the mine. An air monitoring system is used to assure safety of the mines. In 1980, the cost of disposal, not including transportation to the mine, was 148 DM/tonne (approximately $80/ton). The major expense is the preparation of the rooms. The disposal program employs a total of 25 people for one shift per day.

Deep Well Disposal

Deep well waste disposal involves the injection of liquid waste into subsurface geologic formations by means of wells. The technique is based on the concept that liquid wastes can be injected into and contained by geologic strata not having other actual or potential uses of a more beneficial nature. Thus, long-term isolation of the waste material from man's usable environment is accomplished. This practice has been used extensively by the petroleum industry to dispose of brine produced during oil recovery. Since the 1950's there has been a steady increase in the use of wells for the disposal of other types of industrial waste. Over 250 wells injecting approximately 130 different chemical compounds are now in operation. Deep weel disposal is not without controversy. Proponents argue that it is a safe economical method to dispose of a diverse variety of wastes, while opponents are concerned with groundwater pollution, and further utilization of the aquifer. Some states have limitations on the types of wastes which can be injected, for example, chlorinated hydrocarbons.

The geologic formation is the key factor in deep well injection. Figure 6 presents a generalized map of these areas in the United States with potentially suitable geologic conditions. Specific factors that must be considered for an underground reservoir are: (1) uniformity, (2) large areal extent, (3) substantial thickness, (4) high porosity and permeability, (5) low pressure, (6) a salaquifer (an aquifer containing brackish water, salt water or brine), (7) separation from fresh water horizons, (8) adequate overlying and underlying aquicludes, (9) no poorly plugged wells into the reservoir, and (1) compatibility between the mineralogy and fluids of the reservoir and the injected waste. Those injection wells that have created environmental problems have been located in unsuitable geologic settings, or have been poorly engineered and installed for the geologic conditions present.

Good engineering and construction of an injection well are critical to its success. The first concern in planning, construction, and operation is the protection of potable waters and minerals of economic value. The second concern is the possibility of corrosion of the tubular goods and cementary materials used in well construction. If a casing string or the cement sheath behind the casing is materially damaged, then uncontrolled movement of the injection fluid into zones that contain potable water or minerals will occur.

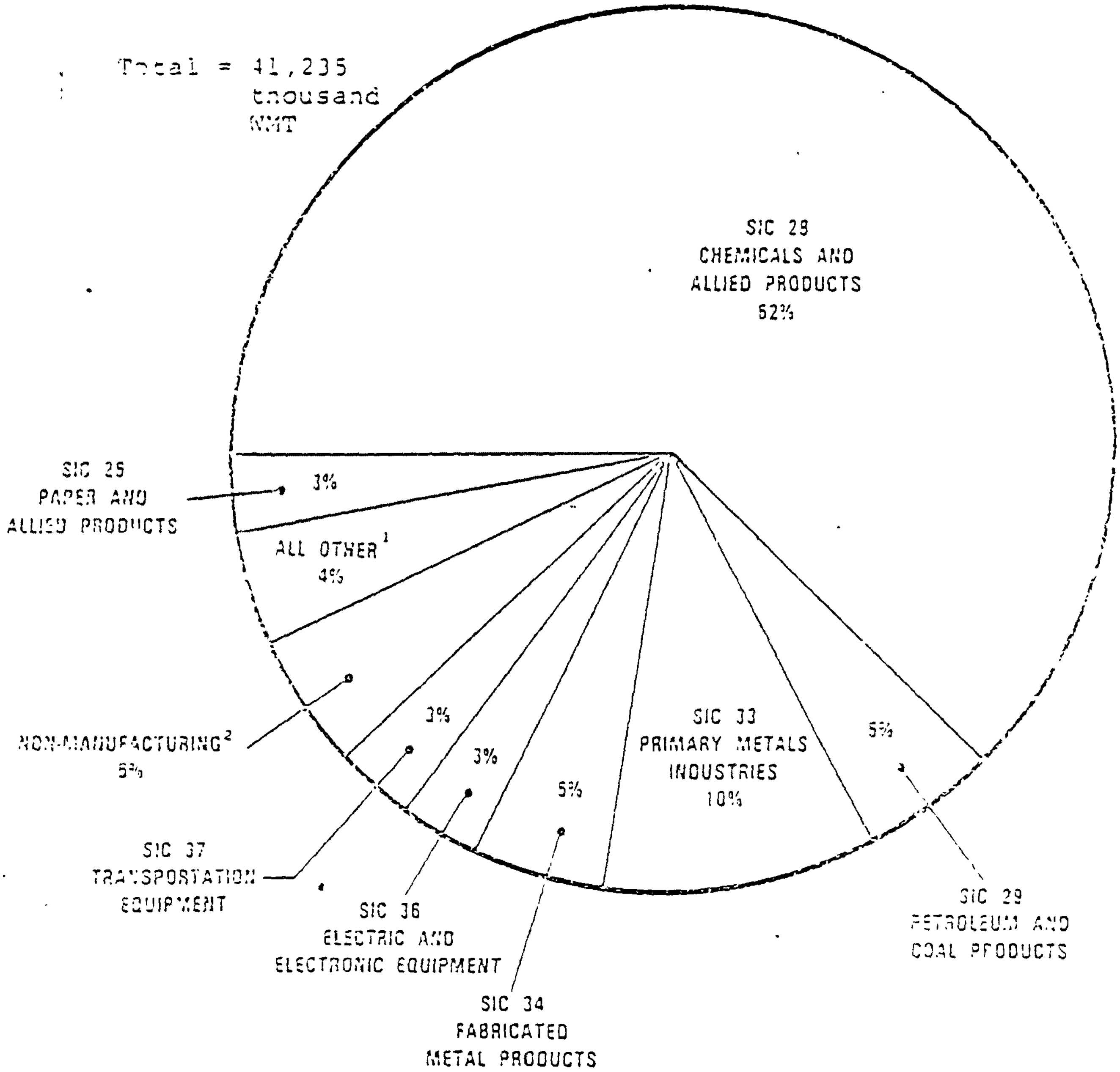
Once the geologic conditions are understood, the design of the tubing string, which serves to conduct the injected material to the injection face, is made. The tubing string should be constructed of a material which has the mechanical properties for the depth of the well, has adequate flow characteristics, and is compatible with the injection fluid. The tubing string is placed within the casing. The casing is cemented into place. The cement system should be planned to be compatible with the injected fluid. External casing packers and string packers at the injection zone to protect the casing and cement are additional safety features.

The completion technique often used is equipping the tubing with a packer set in the casing above the disposal zone. (See figure 7.) The packer provides a seal to isolate the annulus space above the packer from the waste fluids. The annulus space is filled with an inert liquid and placed under pressure. Thus, if there is a failure of the tubing, packer, or casing, the annulus pressure will change and serve as an alarm.

Often the injection liquid must be treated before injection to remove solids that might plug the system. In some cases the liquid must receive chemical treatment to make the liquid compatible with the aquifer.

Figure 1

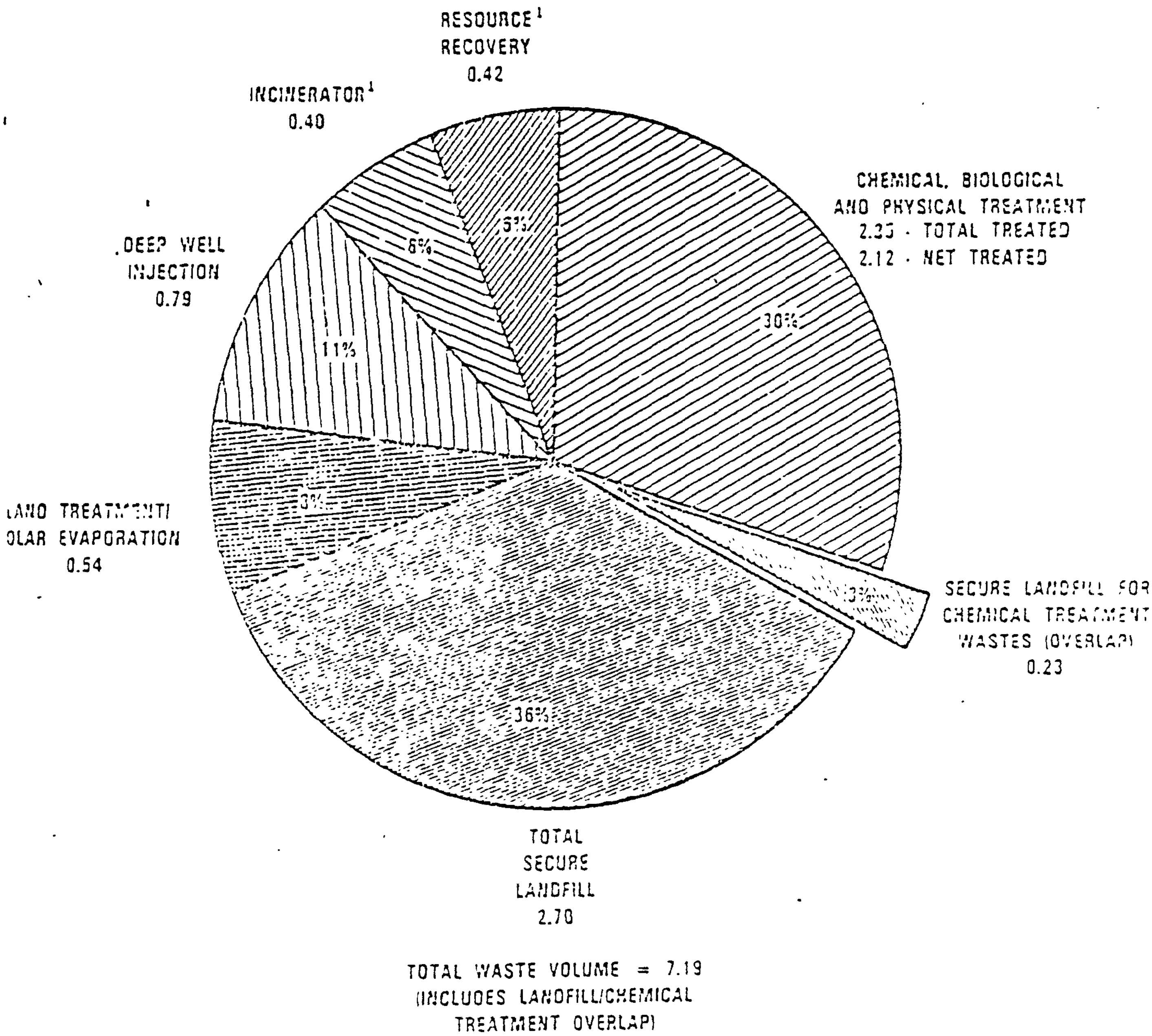
Percentage of 1980 Hazardous Waste Generation
by Standard Industrial Classification (SIC) Code



Source: Hazardous Waste Generation and Commercial Hazardous Waste Management Capacity - An Assessment. U.S. Environmental Protection Agency Publication SW-894, Washington, D.C. 1980.

Figure 2

Estimated Hazardous Waste Volumes Treated/Disposed by Commercial Off-Site Facilities by Waste Management Options
1980
(Millions of Wet Metric Tons)



Source: Hazardous Waste Generation and Commercial Hazardous Waste Management Capacity - An Assessment. U.S. Environmental Protection Agency Publication SW-894, Washington, D.C. 1980.

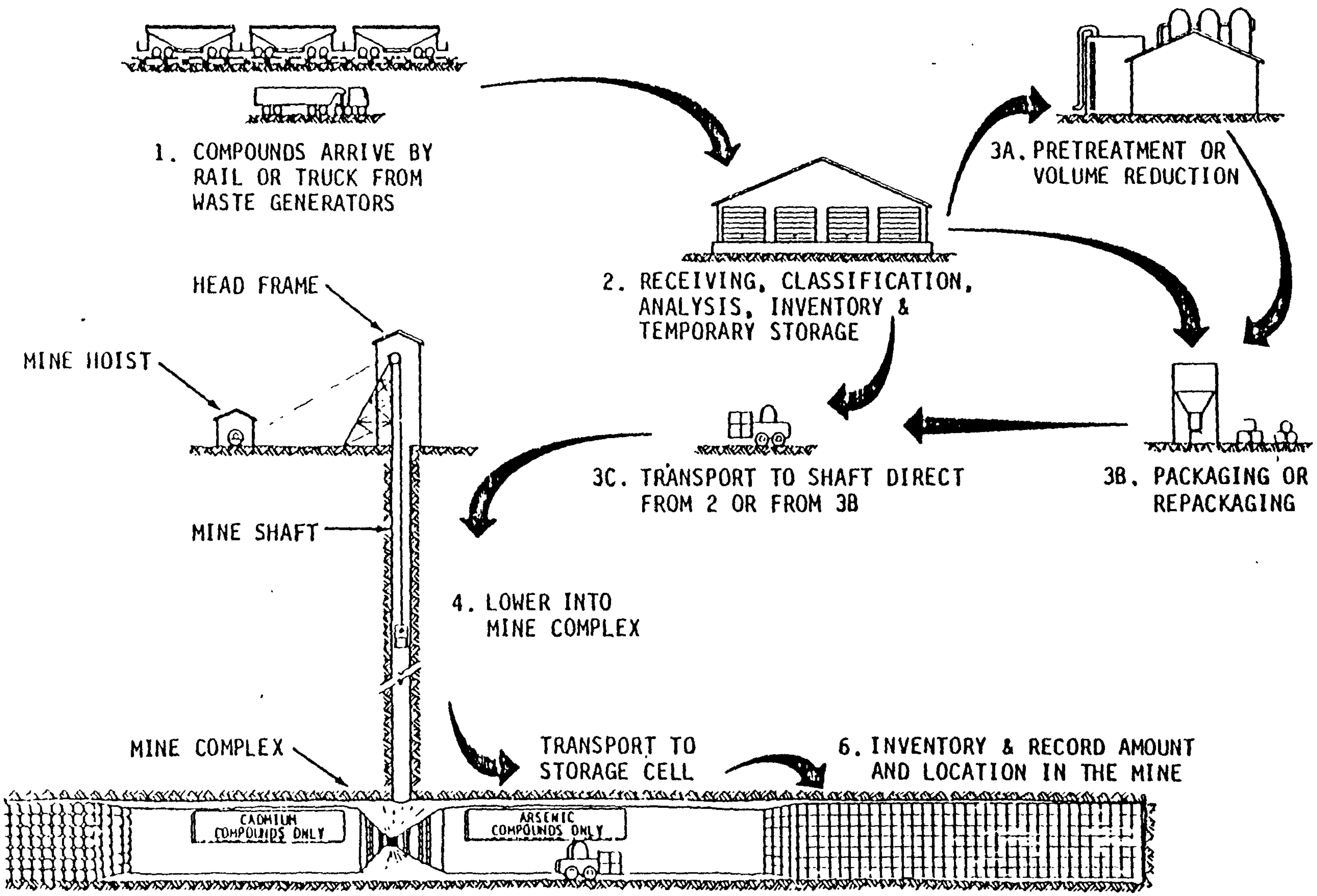


Figure 4. Waste Handling Flow Chart for Disposal of Hazardous Waste in a Mine.

Source: Evaluation of Hazardous Waste Emplacement in Mined Openings. USEPA publication EPA 600/2-75-040, Cincinnati, Ohio, 1975.

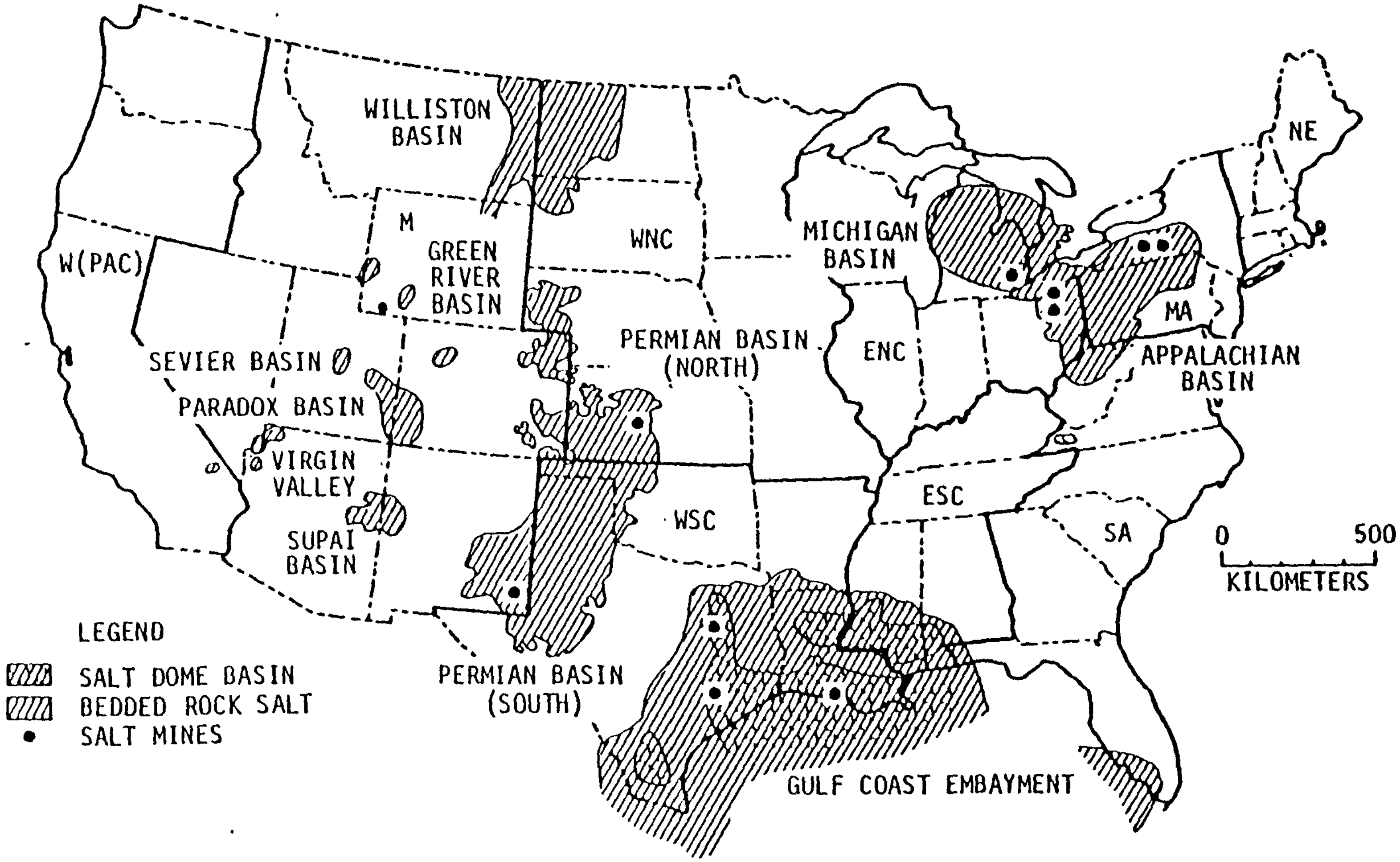


Figure 5. Major United States Salt Deposits and Mines.

Source: Evaluation of Hazardous Waste Emplacement in Mined Openings. USEPA publication EPA 600/2-75-040, Cincinnati, Ohio, 1975.

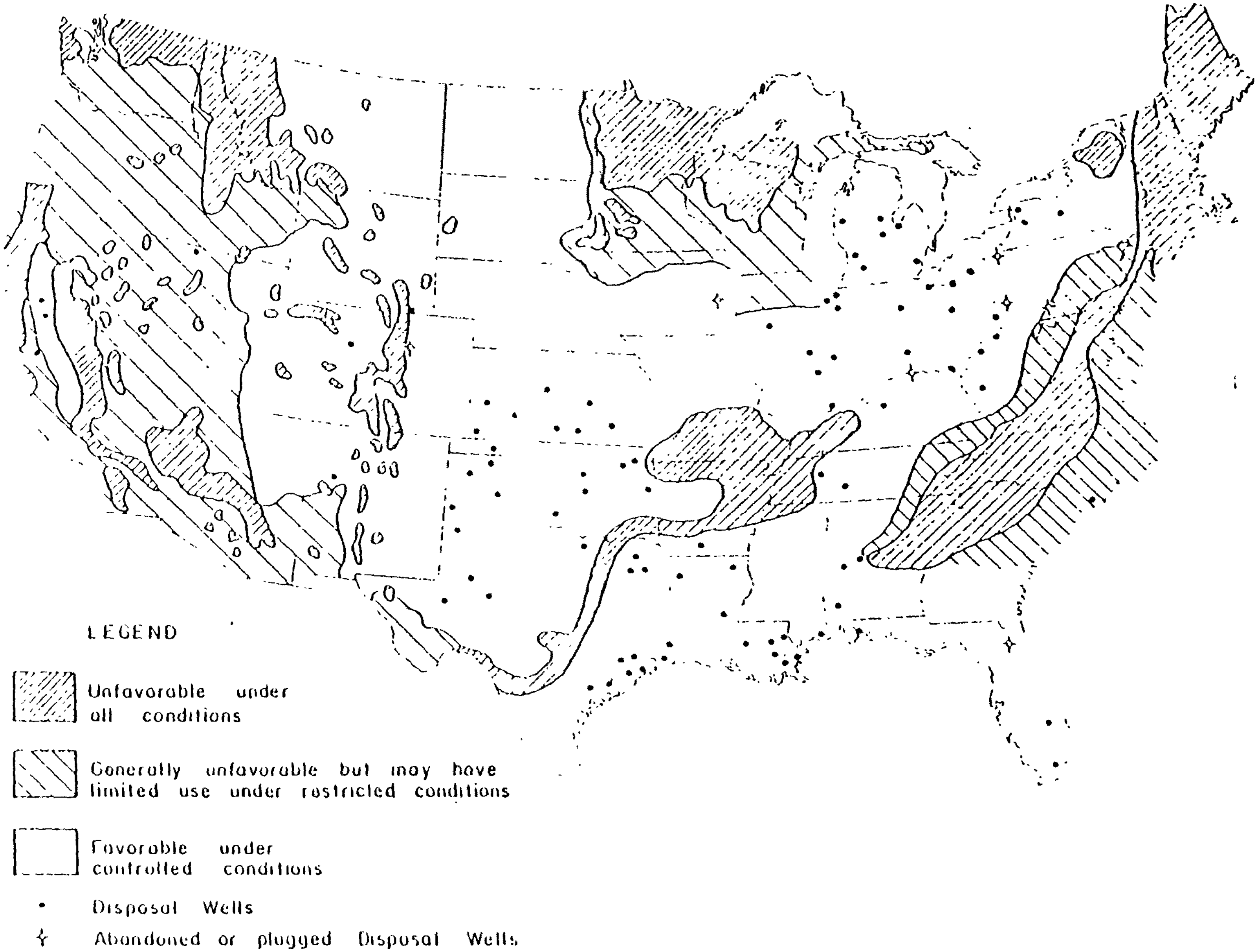


Figure 6. Site suitability for deep-well injection of industrial waste

Source: Review and Assessment of Deep-Well Injection of Hazardous Waste. EPA 600/2-77-029a, Cincinnati, Ohio, 1977.

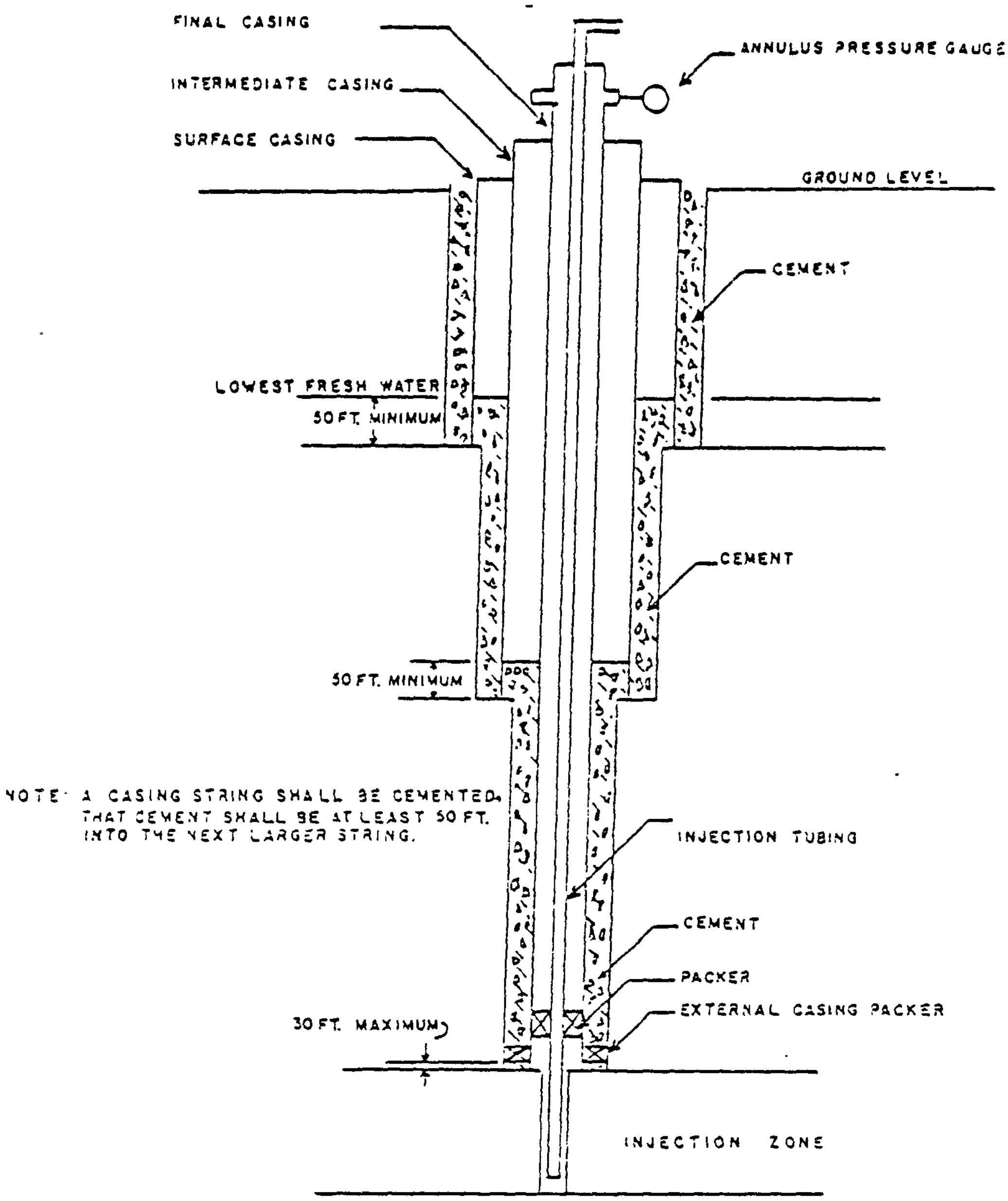


Figure 7. Completion of Waste Injection Well

Source: Review and Assessment of Deep-Well Injection of Hazardous Waste. USEPA publication EPA 600/2-77-029a, Cincinnati, Ohio, 1977.

TABLE 1. PRESENT AND PROJECTED ECONOMIC CONSIDERATIONS FOR WASTE STABILIZATION/ SOLIDIFICATION SYSTEMS

Type of treatment system	Major materials required	Unit cost of material	Amount of material required to treat 100 lbs of raw waste	Cost of material required to treat 100 lbs of raw waste	Trends in price	Equipment costs	Energy use
Cement-based	Portland Cement	$0.03/lb	100 lb	$ 3.00	Stable	Low	Low
Pozzolanic	Lime Flyash	$0.03/lb	100 lb	$ 3.00	Stable	Low	Low
Thermoplastic (bitumen-based)	Bitumen Drums	$0.05/lb $27/drum	100 lb 0.8 drum	$18.60	Bitumen prices are rising rapidly because of oil prices	Very High	High
Organic polymer (polyester system)	Polymer Catalyst Drums	$0.45/lb $1.11/lb $17/drum	43 lb of polyester-catalyst mix	$27.70	Price could rise rapidly due to oil shortage	Very High	High
Self-cementing	Gypsum (from waste)	**	10 lb	**	Stable	Moderate	Moderate
Glassification/ mineral synthesis	Feldspar	$0.03/lb	Varies	--	Stable	High	Very High

* Based on the full cost of $91/ton.
** Negligible but energy cost for calcining are appreciable.

TABLE 2. CURRENTLY ACCEPTED CUMULATIVE SOIL LOADING LIMITS FOR SELECTED METALS

METAL	LOADING LIMIT IN SOIL		
	ppm	kg/ha·15 cm	lb/acre·6 in.
Arsenic	500	1120	1000
Cobalt	500	1120	1000
Chromium	1000	2240	2000
Nickel	100	220	200
Lead	1000	2240	2000
Zinc	500	1120	1000

SOURCE: U.S. EPA 1980, Hazardous Waste Land Treatment, SW-874.