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andfill disposal of hazardous wastes: a review of literature and known approaches

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LANDFILL DISPOSAL OF HAZARDOUS WASTES:

A REVIEW OF LITERATURE AND KNOWN APPROACHES

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1. Introduction

The landfill has been developed over a number of years as a means of disposing of various types of waste materials. However, due to the increasing quantities of hazardous waste sludges (most of which are generated by air and water pollution control processes), land disposal is becoming more widely used as a hazardous waste disposal technique, and as a receptor of larger waste volumes. In 1973, an effort was made by the TRW Systems Group, under EPA contract, to review the available information and summarize the state-of-the-art of hazardous waste land disposal.[1] This work was included in an broad effort to identify and analyze all treatment and disposal practices potentially applicable to hazardous wastes.

Since issuance of this pioneer study, sufficient additional information has surfaced to justify a new compendium. In this report, OSWMP has extracted the most useful information from the "TRW report" and added pertinent information from office files.

The information and data contained are for information and guidance purposes only. The report does not present regulations or guidelines for treatment or disposal. It is meant simply to be a digest of the most useful technical and economic information on the subject, known to the Office of Solid Waste Management Programs (OSWMP), EPA. Much of the information has been received from contractors and other outside sources and has been accepted largely on face value. OSWMP is therefore not in a position to confirm data presented, or to make definitive judgement on the adequacy of the operations and methods discussed.

This report has been prepared for those not intimately familiar with hazardous waste materials or disposal methods. It can serve as a starting point in addressing any situation or question involving hazardous waste land disposal. The report presents an overview of conventional sanitary landfilling, the chemical waste landfill, and alternatives to chemical waste landfill disposal. A discussion of research, development, and demonstration programs in the area of hazardous waste land disposal is presented. Finally, Appendix A presents a listing of hazardous waste materials and applicable pretreatment and land disposal methods. OSWMP anticipates revising this report periodically as additional information becomes available.

2. Background

Hazardous wastes have been defined as any "wastes or combinations of wastes which pose a substantial present or potential hazard to human health or living organisms because they are lethal, non-degradable, persistent in nature, can be biologically magnified, or otherwise cause, or tend to cause, detrimental cumulative effects."[2] The five general categories of hazardous wastes are: (1) toxic chemical, (2) radioactive, (3) flammable, (4) explosive, and (5) biological. There is overlap, of course. For example, flammable and explosive wastes may be toxic as well; however, in this case, the primary waste characteristics of concern are flammability and explosiveness, rather than toxicity. The same logic applies to many radioactive and some biological wastes as well. Most of the non-radioactive hazardous waste generated in this country (about 10 million tons annually) fall into the toxic chemical category. Most toxic wastes can be subcategorized as: (a) inorganic toxic metals, salts, acids or bases, and (b) synthetic organics.[2]

Some of the primary findings of EPA's Report to Congress on Hazardous Waste Disposal, which was mandated by Section 212 of the Solid Waste Disposal Act as amended, are that current hazardous waste management practices are generally unacceptable, and that public health and welfare are unnecessarily threatened by the uncontrolled discharge of such waste materials into the environment, especially upon the land.[2] It was also concluded that usage of the land for hazardous waste disposal is increasing due to the implementation of air and water pollution controls, and the limitation of disposal methods such as ocean dumping.

The Clean Air Act (as amended), the Federal Water Pollution Control Act (as amended), and the Marine Protection, Research, and Sanctuaries Act (as amended), are curtailing the discharge of hazardous pollutants into the Nation's air and water.[3,4,5] The basic objective of the latter is to prohibit the dumping of some materials, and strictly regulate the dumping of all materials (except dredge material controlled by Army Corps of Engineers).[30] Increasing volumes of sludges, slurries, and concentrated liquids will therefore find their way to land disposal sites.

Few economic incentives exist to encourage waste generators to utilize environmentally acceptable disposal methods (Figure 1). Current methods frequently result in contamination of groundwaters from leachates; surface waters from run-off and leachate; and air from evaporation, sublimation, or dust dispersal. For example, toxic heavy metals create a chronic hazard when deposited in the land environment. As a result of arsenic buried more than 30 years ago, several

NOTE: 1000 gallons = approximately 4.2 tons

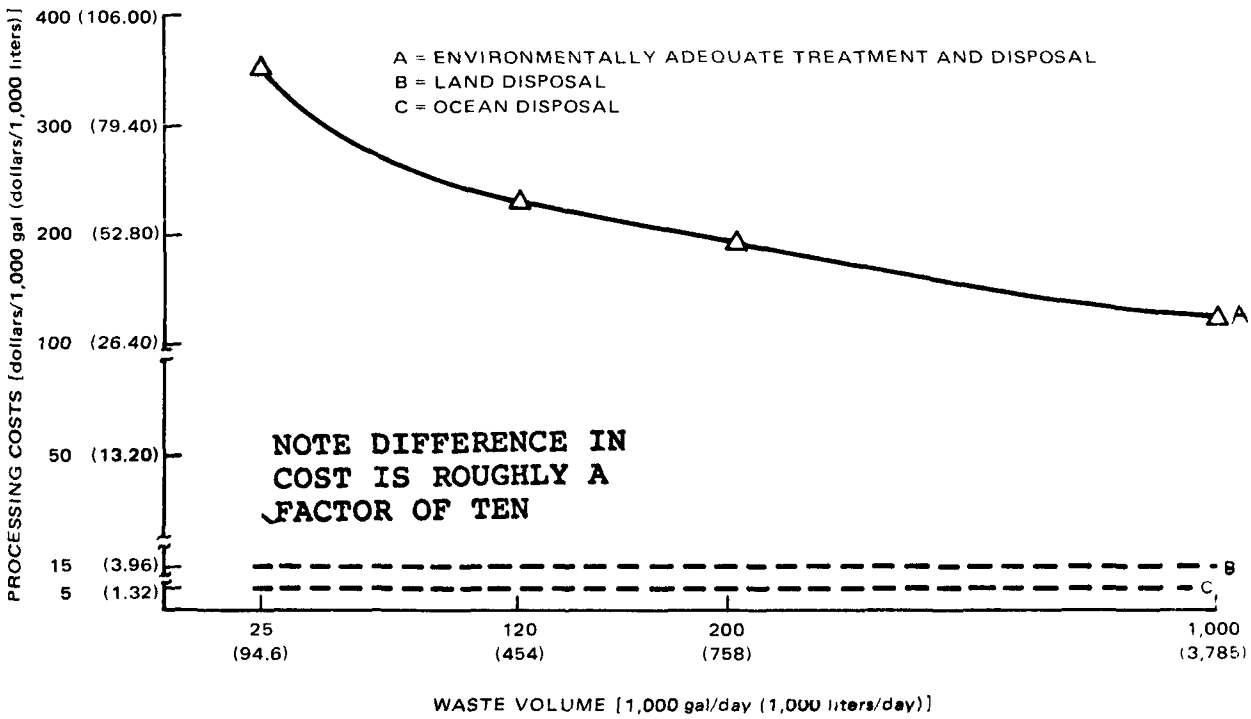

Figure 1. Costs for adequate treatment are significantly greater than ocean or land dumping. Source: Report to Congress. 2, p.13.

people in Perham, Minnesota, had to be hospitalized due to arsenic poisoning of drinking water from a groundwater supply source contaminated by leachate from the buried deposit.[2]

With the exception of radioactive and pesticide wastes, land-based hazardous waste treatment, storage, and disposal activities are essentially unregulated at the Federal level. The Atomic Energy Act of 1954, as amended (P.L. 703) and the Federal Insecticide, Fungicide, and Rodenticide Act, as amended (P.L. 92-516) do provide mechanisms for control of disposal of radioactive, and pesticide-containing wastes.[6,7] Hazardous waste legislation has been enacted in a few States, of which Oregon, California, New York, and Minnesota are examples. These programs are new and staffing levels are fairly low. The disposal of the majority of hazardous wastes generated in the U.S. is not regulated by the State of Federal Government. Of those few States with some type of hazardous waste management controls, less than half have acceptable treatment/disposal facilities within their boundaries. Due to the generally spotty nature of Federal, State, and local solid waste and land protection legislation, regulation and enforcement, there has been little pressure applied to generators of hazardous residues to force disposal by environmentally acceptable methods.

3. The Conventional Sanitary Landfill

Open dumping involves the deposition of wastes on the land with little or no regard for environmental and/or public health protection.[8] The preferable alternative for many wastes, such as municipal solid wastes, is the conventional sanitary landfill which may be defined as "a land disposal site employing an engineered method of disposing of solid wastes on land in a manner that minimizes environmental hazards by spreading the solid wastes in thin layers, compacting the solid wastes to the smallest practical volume, and applying cover material at the end of each operating day."[9] The potential for leachate generation exists even in a well-designed and operated sanitary landfill.[10] However, good site selection and design and careful attention to operating procedures minimizes this potential, and, in many instances prevents its occurrence. Other potential problems include escape of hazardous vapors and gases and possible explosive reactions within the fill. Thus, additional precautions over and above those taken during sanitary land-filling of municipal solid wastes are required for land disposal of many hazardous wastes. The conventional landfill might be used, however, in those instances where the wastes contain a hazardous substance but in a form which is not particularly hazardous, i.e., insoluble salts, or in a concentration so low as to be innocuous. Certain other wastes should probably never be land disposed because of extreme hazards posed by escape of even small quantities.

Because of the lack of effective controls, many hazardous wastes are currently being disposed of in dumps and conventional sanitary landfills. As an example, for several years a large municipal land disposal site in Delaware accepted both domestic and industrial wastes.[2] In 1968, this disposal site had to be closed because chemical and biological contaminants had leached into the groundwater. By 1974, two major groundwater supply fields which had provided water for about 40,000 households in the area were contaminated. The cleanup costs are expected to be over $10 million. Although this situation has not directly been linked to the hazardous nature of any of the industrial wastes constituents, this example serves to point up the potential problem caused by disposing of any wastes in an unacceptable land disposal site.

4. The Chemical Waste Landfill

Methods have been developed to modify the conventional sanitary landfill to make it acceptable for receipt of hazardous materials. Taken together, these modifications result in a "chemical waste landfill." In general terms, such operations provide complete long-term protection for the quality of surface and subsurface waters from hazardous waste deposited therein, and against hazards to public health and the environment. Such sites should be located or engineered to avoid direct hydraulic continuity with surface and subsurface waters. Generated leachates should be contained and subsurface flow into the disposal area eliminated. Monitoring wells should be established and a sampling and analysis program conducted. The location of the disposal site should be recorded in the appropriate local office of legal jurisdiction.[11] A special operating permit will most likely be required under the terms of future regulations. Of course, these requirements are also desirable in standard sanitary landfills. The primary difference involves the degree of concern and care which must be exercised where hazardous materials are involved. If there is potential for hazardous wastes to percolate or leach to groundwater, then the use of barriers and collection will be necessary. Due to potentially hazardous reactions, wastes must be segregated and records kept of disposal areas. Neutralization, chemical fixation, encapsulation, and other pretreatment techniques are often necessary. Because of the high concentrations of hazardous wastes, attenuation capacity may be reached relatively quickly. Leachate treatment may be more complex due to the wide variety of waste types and constituents. Due to volatility or for other reasons, hazardous materials may require immediate cover. Due to these reasons, land disposal of hazardous wastes normally requires a greater degree of care and sophistication in design and operation at a given site than would normally be necessary with municipal refuse.

a. Existing Industrial Waste Landfills

There have been some efforts made by the public and private sectors to dispose of hazardous wastes in an environmentally acceptable manner. Private companies operate six Class I (designated for hazardous wastes) landfill sites in the State of California. Five other California Class I sites are operated by local jurisdictions.[12]

According to recent California hazardous waste management criteria and standards, Class I disposal sites are "those at which complete protection is provided for all time for the quality of ground and surface waters from all wastes deposited therein and against hazard to public health and wildlife resources.[13] "There are nine criteria developed by California which must be met by Class I facilities (Table I).

Most other industrial waste landfill sites identified by OSWMP are those operated by the small private hazardous waste management industry. There are at least eight such sites, some of which appear to be operating environmentally sound facilities (Table II).[14] As an example, Chem-Trol Pollution Services, Inc., Model City, New York operates an industrial waste landfill which receives residues from its physical-chemical hazardous waste treatment plant. This plant receives a large variety of industrial wastes for treatment.[15] The Chem-Trol landfill consists of a series of clay-lined pits or cells into which solid sludges, chemically stabilized or solidified liquids, and slurries are deposited. A sump at the bottom of each cell recycles leachate to the treatment plant. A three-dimensional inventory is kept of wastes buried in each cell to facilitate reclamation at a future date, should economics permit. The company estimates this landfill can be utilized for the next 150 to 200 years.

A few large U.S. chemical companies also have landfill facilities which are reportedly capable of handling hazardous waste materials (Table III). The Union Carbide Corporation, for example, has operated a State licensed "chemical" landfill at their Institute, West Virginia, plant since 1965.[16] The initial system experienced drainage problems, and resulted in a re-engineered landfill which was completed in 1969. Wastes coming to the landfill are generated by the broad-range plant production mix of some 200 or more chemicals (mostly organic). According to the company, all leachate from the landfill is collected and treated either in the plant's five million-gallon per day activated sludge wastewater treatment system, or burned as a source of heat for steam generation. Biological sludge from the treatment of wastewater is dried in special beds, cycled back into the chemical landfill, and mixed with soil and incoming chemical waste sludge. Dried chemical sludges are introduced into the landfill on a one-to-one basis by "blending" with soil. Blending the wastes with earth reportedly reduces the gas and fire hazards sometimes associated with conventional landfill cell construction techniques. It also tends to hasten bio-oxidation of the chemical wastes. The landfill handles approximately 10 tons (20 cubic yards) per day of chemical

TABLE I

CALIFORNIA CLASS I SITE CRITERIA

(a) Geological conditions are naturally capable of preventing hydraulic continuity between liquids and gases emanating from the waste in the site and usable surface or groundwaters.

(b) Geological conditions are naturally capable of preventing lateral hydraulic continuity between liquids and gases emanating from wastes in the site and usable surface or ground waters, or the disposal area has been modified to achieve such capability.

(c) Underlying geological formations which contain rock fractures or fissures of questionable permeability must be permanently sealed to provide a competent barrier to the movement of liquids or gases from the disposal site to usable water.

(d) Inundation of disposal areas shall not occur until the site is closed in accordance with requirements of the regional board.

(e) Disposal areas shall not be subject to washout.

(f) Leachate and subsurface flow into the disposal area shall be contained within the site unless other disposition is made in accordance with requirements of the regional board.

(g) Sites shall not be located over zones of active faulting or where other forms of geological change would impair the competence of natural features or artificial barriers which prevent continuity with usable waters.

(h) Sites made suitable for use by man-made physical barriers shall not be located where improper operation or maintenance of such structures could permit the waste, leachate, or gases to contact usable ground or surface water.

(i) Sites which comply with a,b,c,e,f,g, and h but would be subject to inundation by a tide or a flood of greater than 100-year frequency may be considered by the regional board as a limited Class I disposal site.

Source: California State Water Resources Control Board, Disposal site design and operation information, Sacramento, March 1975. p. 19-21

Table II

Private Hazardous Waste Management Companies
(non-inclusive)

1. Rollins Environmental Services, Inc.
   3208 Concord Pike
   Wilmington, Delaware 19899

2. Chem-Trol Pollution Services, Inc.
   P.O. Box 200
   Model City, N.Y. 14107

3. Hyon Waste Treatment Services
   Chicago, Illinois 60617

4. Conservation Chemical Company
   Kansas City, Missouri

5. Nelson Chemical Company
   12345 Schaefer Highway
   Detroit, Michigan 48227

Table III

U.S. Companies With Chemical Waste Landfills
(non-inclusive)

1. Union Carbide Corporation
   Institute, West Virginia

2. Dow Chemical Company
   Midland, Michigan

3. American Cyanamid
   Willow Island, West Virginia

waste sludges, and 28 tons (33 cubic yards) per day of wastewater treatment plant sludges. The chemical wastes make up only three to six percent by volume (two to four percent by weight) of the total plant wastes, but are by far the most difficult and costly to manage. According to the company, the cost of "chemical" landfill disposal is $36.80 per ton ($9.27 per cubic yard), while the costs for disposing of municipal-type plant wastes (garbage, rubbish, metals, etc.) in a conventional sanitary landfill are $2.50 per ton ($0.63 per cubic yard).

The Union Carbide landfill has a two foot thick rolled-clay liner to keep leachate from entering adjacent groundwaters. A 20-year life (based on a 4,000-tons, or 12,000 cubic yards, per year waste disposal rate) has been projected for the landfill. An internal drainage system permits all-weather operation, and serves to collect the leachate for treatment. The basic operating procedures for hazardous waste disposal consists of strict segregation of in-plant wastes; deactivation before landfilling, where practical; continuous blending of wastes and soil, and daily earth cover. Union Carbide indicates that not all chemical wastes are degraded in the landfill. Some liquid flows out of the landfill as an "oil" layer into a contaminated water basin, where it is skimmed for residue fuel. Other waste leaves as dissolved chemicals in the leachate and goes to wastewater treatment.

The estimated costs for the expected 20-year life of the fill can be summarized as follows:

		1973 $
(a) Study and Design		$ 77,495
(b) Land Costs		100,000
(c) Capital Costs		250,000
(d) Operating Costs (20-year)		2,884,505
	Total	$3,312,000

Some foreign companies also operate industrial waste landfill facilities. The Bayer Chemical Company's main plant in Leverkusen, West Germany, for example, has a large (150-acre) specially designed landfill.[17] About 1,000 cubic meters (35,310 cubic feet) per day (about 5,000,000 metric tons, or 550,000 tons, per year) of solid waste are deposited in the landfill, which has a one meter thick clay bottom. Landfilling is done in 10-meter (33 feet) layers, which will lead ultimately to construction of a plateau 60 meters (197 feet) high. Estimated life is 70 years. Approximately 35 monitoring wells are located around the landfill. Wastes accepted at the landfill include organic sludge from biological wastewater treatment, slag from the plant's high temperature (1,200°C or 2,190°F) incinerator, insoluble salts from titanium dioxide production, and heavy metal hydroxide sludges precipitated from inorganic production wastewaters.

b. <u>Site Selection/Evaluation</u>

Chemical waste landfills should be sited to take advantage of geologic factors responsible for optimum attenuation of the wastes and any decomposition products, and designed to overcome the disadvantages posed by less favorable sites.[18] The factors to be considered in the selection of a site include: waste characteristics, topography, geology (rock type, geologic structure, weathering characteristics), hydrology (permeability, depth to water table, direction and rate of groundwater flow), climate, and composition of soils (which affect pH and sorptive capacity). Design factors to be considered include: waste preparation, construction of impermeable liners, leachate collection systems, and monitoring equipment. The objectives of an engineering design are to overcome the natural drawbacks of the site and to control and monitor the release of hazardous wastes into the environment.

In selecting and evaluating a chemical waste landfill site, some of the general criteria to be considered are as follows:[10]

(a) Chemical waste landfills ideally should be located in areas of low population density, low alternative land use value, and low groundwater contamination potential.

(b) All sites should be located away from flood plains, natural depressions, and excessive slopes.

(c) All sites should be fenced, or otherwise guarded to prevent public access.

(d) Wherever possible, sites should be located in areas of high clay content due to the low permeability and beneficial adsorptive properties of such soils.

(e) All sites should be within a relatively short distance of existing rail and highway transportation.

(f) Major waste generation should be nearby. Wastes transported to the site should not require transfer during shipment.

(g) All sites should be located an adequate distance from existing wells that serve as water supplies for human or animal consumption.

(h) Wherever possible, sites should have low rainfall and high evaporation rates.

(i) Records should be kept of the locations of various hazardous waste types within the landfill to permit future recovery if economics permit. This will help facilitate the analysis of causes if undesirable reactions or other problems develop within the site.

(j) Detailed site studies and waste characterization studies are necessary to estimate the long-term stability and leachability of the waste sludges in the specific site selected.

(k) The site should be located or designed to prevent any significant, predictable leaching or run-off from accidental spills occurring during waste delivery.

(l) The base of the landfill site should be a sufficient distance above the high water table to prevent leachate movement to aquifers. Waste leachability and soil attenuation and transmissivity characteristics are important in determining what is an acceptable distance. Evapotranspiration and precipitation characteristics are also important. The use of liners, encapsulation, detoxification, and/or solidification/fixation can be used in high water or poor soil areas to decrease groundwater deterioration potential.

(m) All sites should be located or designed so that no hydraulic surface or subsurface connection exists with standing or flowing surface water. The use of liners and/or encapsulation can prevent hydraulic connection.

(n) In arid regions where the cumulative precipitation is less than the evapotranspiration, water will not likely accumulate in the landfill or migrate through the soil. Under such conditions, leachate containment precautions (liners, etc.) will not be necessary unless the water table is high or large quantities of liquid wastes are disposed.

(o) Unless leachate generation or escape is prevented in some manner, such as by encapsulation, location in arid regions or naturally impermeable basins, or by immediate cover with an impermeable membrane to prevent infiltration, it will be necessary to line the basin with an impermeable membrane, collect the leachate in headers, and recycle it through the fill or pump it to an appropriate treatment facility.

(p) All liners, cover materials, and encapsulating materials must be tested or have known chemical resistance to the materials it will contain or might otherwise come in contact with. Ideally, such materials should have an effective life greater than the toxic life of the wastes they contain.

(q) Studies will be necessary to determine general site monitoring requirements. Hydro-geological monitoring will be required to detect routine and accidental releases of liquid effluents. A system of observation wells should be installed in aquifers around the site and concentrated in potential water and waste movement paths downgradient from the site. A monthly sampling frequently has been suggested by one source.[10] Downstream monitoring stations and a bimonthly sampling frequency were suggested for surface streams in the site vicinity.

c. Site Design and Preparation

Although the criteria used by the State of California, Union Carbide and Bayer vary, all have incorporated site design and preparation requirements considerably more stringent than those normally required for a standard sanitary landfill.

Liners. The use of liners is becoming more widespread, and is being incorporated even in some conventional sanitary landfills. When impervious basins are desired at a landfill site and the existing soil is not suitable, artificial liners are a potential solution to the problem. All prospective liners should be pretested for strength and compatibility with the expected wastes.

Due to relatively few applications and recent emergence of various liner materials, the long-term effects of different hazardous wastes in a landfill upon the liner's life cannot be determined in a definitive manner.

In addition, the use of liners for environmental protection may require collection and treatment of leachate if rainfall is significant.

Common types of liner materials include clay, rubber, asphalt, concrete and plastics such as Hypalon (a chlorinated polyethylene plastic) and PVC (polyvinyl chloride). The leachate collection process usually requires plastic pipes, risers, and pumps. Leachate treatment methods are not well defined but may require neutralization, biological treatment, evaporation or precipitation.

DuPont, the manufacturer, claims that 30 mil Hypalon sheeting is essentially impermeable to water.[19] The material is also said to resist tearing and puncturing, but may be readily patched if an accident occurs. Also, it is claimed that the liner resists aging, weather, ozone (a chief enemy of rubber), and a wide range of hydrocarbons and chemicals. It is reportedly not adversely affected by soil chemicals and microorganisms. The cost of rubber and Hypalon liners varies between $0.25 and $0.50 per square foot, while certain other plastic liners cost $0.15-$0.25 per square foot.[20] The plastic pipes and risers for leachate collection range between $3 and $7 per linear foot.[20]

At a recent NSWMA Congress in Chicago, the use of liners in landfills was discussed. One speaker discussed a sanitary landfill on Long Island which uses a 20-mil thick Hypalon liner with sand cover. The liner costs were $20,000 per-acre installed and the leachate collection system adds an additional $6,000 to $7,000 per-acre.[20]

To protect groundwater, a Pennsylvania firm has lined a 52-acre sanitary landfill with 1/2 inch thick asphalt covered with a one foot thick layer of sandy loam.[20] It is being developed in five-acre sections. The low point of the landfill is two feet above the groundwater level. The base is excavated, graded, and rolled. The asphalt is applied in several coats. Sandy loam is applied on top of the asphalt to protect the liner and allow a flow path for leachate. The depth of each 5-acre fill is 22 feet. Leachate is collected from a manhole at the low point of the fill. Laboratory tests have indicated that the asphalt liners resist normal leachate. Solvents cannot be accepted, however, since tests have indicated that dissolution of the asphalt will result. Lab tests indicate that the life of an asphalt liner is at least 50 years. Asphalt liner costs, including installation, vary between $6,000 and $12,000 per-arce. The higher cost applies when the sand cover must be trucked long distances. The asphalt used is a special flexible type, and not the normal paving grade. It is applied at the rate of 2 gallons per square yard. An estimated 65 gallons per minute of leachate is expected upon completion of this facility. A leachate treatment plant will be constructed, though process details are not currently available.

Another approach is to collect the landfill leachate and circulate it back through the wastes.[18] This reportedly recycles the successful flora and nutrients which may improve and speed waste degradation. Further research is needed regarding the interactions between appropriate types and concentrations of micro-organisms and different hazardous wastes.

The Hypalon liner was introduced commercially in 1951. Primary uses of Hypalon include the lining of pits, ponds, lagoons, and landfills.[19] At least two of the larger regional hazardous waste processing firms have begun using this material in their operations. Rollins Environmental Services, Inc.(RES), experienced holding basin failures using rubber liners and clay liners (8 to 12 inches thick), and have switched with apparent success to a concrete base with a Hypalon liner.[20] Rollins estimates that construction of a 500,000 gallon holding basin, square in cross-section and 9 feet deep in the center, costs approximately $19,000, including 4 to 8 inches of concrete. The Hypalon liner adds an additional 20-25 cents per square foot (or approximately $4,500) to the cost. Company officials indicated that initial difficulties were experienced with the adhesive used to bond the liner to the concrete.

The EPA-sponsored Kansas City Model Sanitary Landfill demonstration project is operated on a 46-acre site. The cost of installing an 18-inch clay liner was $54,500, or approximately $1,185 per-acre.[21] A summary of available cost data for the liner types discussed above is presented in Table IV.

The Lindenmaier-Precision Company of West Germany is promoting the use of polyurethane foam to seal landfills.[22] A top layer of the same foam material is used to cover the compressed waste, and a final earth cover is applied over the foam. Complete containment of the waste reportedly results. There is no infiltration of water into the landfill, and no contamination of air and water resources.

Table IV

Liner Costs

Liner Type	Cost/Acre (1973)
Clay (18 inch)	$1,185
Asphalt	$6,000 - $12,000
Rubber	$11,000 - $22,000
Hypalon	$11,000 - $22,000
Polyvinyl Chloride (PVC)	$ 4,840 - $ 9,680

Recent controlled research evaluated the stability of concrete, asphalt, rubber, and plastic in contact with selected acids and organic solvents (benzene, ethyl alcohol, acetone, chloroform).[18] The relative durability was found to be in the following decreasing order: (a) concrete, (b) plastic, (c) rubber, and (d) asphalt. Asphalt was the least suitable, according to the tests, reacting with all of the reagents tested and completely dissolving in benzene and chloroform.

pH Adjustment. The above study also investigated the effect of pH on soil attenuation capabilities.[18] A low pH, apart from inhibiting the growth of beneficial micro-organisms, reportedly increases the solubility of metals and affects the ion exchange and absorption properties of the colloidal fraction of soils. Clays are more effective absorbers of metals at higher pH's while most organics are more effectively absorbed under more acid conditions.

As a general principle, maintaining the soil pH at 7.0 to 8.0 is encouraged to reduce leaching potential of heavy metals and promote biological activity. The effectiveness and longevity of most liners is also improved.

Cover Materials. A sufficient supply of suitable cover material is a necessary item. Ideally, the cover material will minimize or eliminate infiltration of water, and prevent sublimation or evaporation of harmful pollutants into the air.

A recent EPA study indicated that a good cover for a chemical waste landfill in arid regions of the U. S. might consist of a one-foot layer of sand topped by a four-foot layer of silty loam or clay.[10] However, in other regions of the country, more stringent requirements may be necessary. If infiltration of water to the fill can be minimized sufficiently, very little leachate will form, and collection and treatment might not be necessary. It is apparent that landfilling wastes on a one-shot basis, as opposed to semi-continuously, has advantages since the site can immediately be sealed to infiltration, eliminating the need for leachate collection.

The importance of adequate cover materials is demonstrated by the following case history.[23] In early 1973, excess levels of hexachlorobenzene (HCB) were detected in slaughtered cattle from the Ascension Parish area of Louisiana. A quarantine was imposed on food animals in an area of over 100 square miles surrounding this area. Studies conducted by State and EPA Region VI personnel confirmed that the problem was associated with chlorinated hydrocarbon manufacture in the vicinity. The HCB transfer mechanism from manufacturing operations to cattle is believed to be sublimation from two dump sites receiving wastes from the manufacturing facilities. No cover was provided at the sites. To rectify the situation, land disposal of the HCB wastes has been halted and one of the dumps has been sealed with a sheet of 10-mil polyethylene covered with two feet of silty sand material dredged from river banks. The polyethylene sheet is separated from the wastes by a 1-2 foot layer of soil material. Air monitoring by State Department of Health officials indicates a marked decline in HCB concentrations over the dump site.

When a top liner is used at a landfill to provide a waterproof covering, care must be exercised to avoid potential gas problems. Gas venting mechanisms must be provided, since even minimal accumulations can cause ballooning and rupture. A recent journal article mentioned one instance where the application of a clay soil cover forced migrating methane gas into an adjacent farm, ruining crop production.[24]

The primary factors affecting the rate at which gas is produced in a landfill are:[21]

- Moisture - The greater the moisture, the greater the rate of decomposition.

- Temperature - Increased temperatures tend to increase bacterial productivity and resulting gas production.

- Amount of Organic Matter - Greater amounts of organic material increase the amount of substrate material from which the micro-organisms can produce gas.

- pH - A pH of 6.5-7.5 is optimum for methane gas production.

The possibility of recovering gases from sanitary landfill operations is beginning to be examined. The Solid and Hazardous Waste Research Laboratory, EPA, is planning a case study of the methane recovery method in effect at the Palos Verdes sanitary landfill operated by the Los Angeles County Sanitation Districts. The objectives of the study will be to determine: (1) whether such methods of methane recovery are feasible and, (2) how the economics and techniques of such methods might be exploited. Additional work is being sponsored by OSWMP and Pacific Gas and Electric (PG & E) at the Mountainview, California municipal landfill. This work will investigate gas withdrawal rates in relation to stability of gas quality over time. PG & E will build a facility to dehydrate the gas but plans for ultimate use have not been finalized.

Observation/Monitoring Wells. Prior to the deposition of hazardous wastes, observation and monitoring wells should be installed around the periphery of the site. Locations should be determined by the appropriate regulatory authorities based on the site topography and hydrogeological conditions. A recent OSWMP documented case history[2] illustrates the importance of monitoring wells. A company in the north central United States had utilized the same dump site for laboratory waste disposal since 1953. More than half of the waste dumped was arsenic. Although the monitoring wells around the site were superficial in nature, arsenic concentrations greater than 175 ppm were detected. The U.S. Public Health Service drinking water standard for arsenic is 0.05 ppm.[2] The dump site is located above a limestone bedrock aquifer which supplies about 70 percent of a nearby city's residents with drinking and crop irrigation water. Indications are that this water is in danger of being contaminated by arsenic seepage through the bedrock. Without monitoring wells, this waste transport would not have been detected, and serious illness could have resulted.

d. Waste Preparation

Many of the hazardous wastes disposed of in chemical waste landfills should be prepared or treated in some manner prior to deposition to lessen potential environmental and health effects. Methods of hazardous waste preparation for chemical landfill disposal include chemical stabilization (fixation), volume reduction, waste segregation, detoxification/degradation, and encapsulation.

Chemical Fixation. Chemical fixation of industrial waste materials has been developed by several companies, including: the Chemfix Division of Environmental Sciences, Inc., I. U. Conversion Systems, Inc., Dravo, Inc., and Chicago Fly Ash Company. Although the environmental adequacy of these processes has not been evaluated by OSWMP, the resulting solidified waste sludges are less likely to cause environmental damage than if the wastes were deposited on land as is. Long-term leaching and defixation potentials are not understood at this time. In all fixation systems, proprietary chemicals are mixed with the waste sludges, and the resulting mixture is pumped onto the land, where solidification occurs between a few days and a few weeks (depending upon the process). Some of these processes result in the formation of a matrix in which wastes are entrapped;

others claim that pollutants such as heavy metals are chemically bound in insoluble complexes. Processes such as these have been applied to many varied waste streams, including heavy metal sludges, oil refinery wastes, and lime/limestone wet scrubber sludges. Reduced leaching should result, but the permanence of the resulting structure and the absolute environmental adequacy of these techniques have not as yet been fully demonstrated. Typical costs quoted by one firm are in the range of 2-10¢ per gallon [25]; however, certain waste types involve much higher treatment costs.

Volume Reduction. Incineration is the most widely used hazardous waste volume reduction technique. Approximately 60 percent by weight of the hazardous waste generated in this country are organics[2] and can normally be destroyed and/or detoxified by incineration. The potential for use of incineration as a hazardous waste management technique is apparent. Many wastes can be completely destroyed; others leave small amounts of solid residues which may or may not be hazardous. In any case, they must be disposed of, usually on the land. Several of the larger regional hazardous waste processing firms use incineration in combination with land disposal. Emission control devices are usually required for hazardous waste incineration since combustion by-products may also be hazardous. More details regarding incineration can be found in the EPA report entitled, "Incineration in Hazardous Waste Management."[31]

Waste Segregation. Segregation by type and chemical characteristics of wastes is usually practiced to prevent undesirable reactions within the fill. A number of dangerous problems can develop from mixing. For example, acid wastes combined with cyanide-containing wastes produce extremely toxic hydrogen cyanide gas.[10] Segregation prior to disposal may allow the acquisition of sufficient quantities of particular waste types to realize economies of scale in design of treatment facilities for detoxification or recovery. Also, it may be possible to use acidic wastes to neutralize high pH wastes, or perhaps to use waste sulfides to precipitate toxic heavy metals.

Detoxification. Detoxification prior to landfill disposal can often be accomplished by thermal, chemical, or biological processes. Included in this category are such techniques as ion exchange, neutralization, oxidation-reduction, pyrolysis, incineration, activated sludge, aerated lagoons, waste stabilization ponds, and trickling filters.[2]

Degradation. Some chemical degradation methods being developed and/or utilized primarily for pesticides include hydrolysis, dechlorination, photolysis, and oxidation.[26] No single chemical procedure for degrading the entire spectrum of hazardous materials is effective. Hyrdolysis is the best method for destroying organophosphorous and carbamate pesticides. Chemical dechlorination can be used to degrade polychlorinated pesticides. Photolysis may be applied to partially degrade 2,4-D and 2,4,5-T. The use of strong oxidants offers still another approach to destroying some pesticides and herbicides. However, the water insolubility of many of the compounds, particularly the chlorinated pesticides, makes the use of strong oxidants in aqueous solution impractical. The above methods are usually more expensive than alternative pesticide disposal methods (e.g., incineration, biodegradation, etc.), and for the most part have not been demonstrated on a full-scale basis.

Economically, biological degradation of pesticides by soil incorporation may be a useful disposal method. Soil degradation requires that the soil micro-organisms not be inhibited, and be capable of metabolizing the waste components.[27] Also, the site must have minimum potential for pollution of groundwaters or via dust dispersal.

Encapsulation. Those wastes which are not amenable to detoxification may be encapsulated in some permanent material prior to disposal. Available materials include concrete, molten asphalt, and plastics (polyurethane, polyethylene). Leachable heavy metal wastes are examples of wastes which may require encapsulation prior to land disposal[28] In some cases, the resulting encapsulated wastes will require casting in drums prior to deposition in the landfill. The purpose of encapsulation is to limit the leachability of the potentially toxic materials contained therein by physically keeping water from contacting the hazardous materials or their containers.

A recent OSWMP study[28] provides some cost data regarding encapsulation of heavy metal sludges (20 percent solids by weight). For asphalt or polyethlene scrap encapsulation, it is assumed that still bottoms or other tar residues might be used at an average cost of one cent per pound. Off-standard polymers are available at the same price. It is further assumed that wastes are cast into used steel 55-gallon drums costing about $2 each. The study estimates the fixed capital expenditures for asphalt encapsulation of 115 cubic feet per day of chrome waste sludge at $21,000. The corresponding operating costs are $0.65/cubic foot of sludge encapsulated, and an additional $0.12/ft^3 of sludge landfilled.

In another process, dilute metal sulfide or hydroxide can be used as added water in mixing concrete, thus incorporating the wastes into the poured concrete. A portable cement mixer can be used to mix the cement and the water containing the insolubilized metal. The cement mixture is then cast into fiber drums, or used steel drums. It is estimated that cement encapsulation and burial on-site of volatile sludges cost about $.10/gallon of sludge. According to this report, cement is preferred over molten asphalt or plastics for metal sulfides or hydroxides since volatile heavy metal sludges may have high vapor pressures at the temperature of the molten asphalt or plastic polymers.

The Lindenmaier-Precision Company of West Germany has developed a unique encapsulation technique in which the waste sludge is placed in 55-gallon drums. An inch thick layer of polyurethane foam material is then sprayed completely over the drum's exterior, so that air and water can no longer reach this surface.[22] If the inside of the drum is not resistant to the sludge deposited therein, an inside liner of plastic or some other suitable material might be necessary. The polyurethane foam prevents rusting of the steel, thus eliminating deterioration of the capsule and ultimate release of the contents. Long-term testing of this approach is continuing under actual landfill conditions. Encapsulating a 55-gallon drum in polyurethane foam costs about $4 in Germany.

5. Alternatives to Chemical Waste Landfill Disposal

When considering any waste for disposal, the potential for resource recovery or reuse of hazardous constituents within the particular waste should be examined first. Where recovery or reuse is not technically possible or economically practical, and where land disposal does not appear environmentally acceptable, then other alternatives might be considered. Alternative techniques which have been practiced in the past include incineration, deep well injection, detonation, ocean disposal, and engineered storage. Several of these options have been, or will be, greatly curtailed as a result of recent environmental protection regulations.

The advantages of incineration as a means of detoxifying wastes and reducing volumes for land disposal were discussed in Section 4. However, a large proportion of the hazardous wastes can be destroyed in the sense that no solid residue remains for land disposal. Through use of the correct combinations of excess air, temperature, and dwell time, these organics are completely converted to gaseous products. Thus incineration is sometimes considered to be a "disposal" technique. Incineration can also create air and water pollution problems which require emission control facilities. Also, inorganic and heavy metal containing wastes generate residues which may also be hazardous and, in any event, will require disposal.

Deep well injection of liquid and semi-liquid hazardous wastes can pollute groundwaters unless great care is taken in site selection, construction, and operation of these wells. The EPA subsurface waste management policy opposes deep well injection unless all other surface disposal alternatives have been found to be less satisfactory.[30] Proof of environmental adequacy is a responsibility of the disposer. The difficulty in defining adequacy of well disposal lies in the fact that

Considerable quantities may be deposited and a number of years may elapse before problems (possibly very serious) develop.

The recent ocean dumping legislation mentioned in Section 2 was enacted to control the use of the ocean as a waste disposal sink. At present, persons wishing to discharge to the ocean must obtain permits from EPA (or the Army Corps of Engineers in the case of dredge spoils). It is EPA's intention that ocean dumping be strictly regulated where discharge might adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities.[31]

Detonation of hazardous wastes (explosives, munitions, etc.) results in air pollution problems and should not be carried out unless a severe explosion hazard is presented and no other means of deactivation can be found. Underground detonation of hazardous wastes is not generally practiced due to the absence of sufficient oxygen for combustion purposes.

In those few instances where a hazardous waste cannot be treated or disposed of adequately, the best alternative is engineered storage until adequate methods are developed. However, only a very small percentage of the total quantity of hazardous wastes generated in this country should require permanent storage. An engineered storage facility must provide for safe storage of hazardous wastes for long periods of time, and retrievability of the wastes at any time during this storage. Solidification of wastes prior to storage may be desirable to eliminate leakage. The storage facility should be routinely monitored and deteriorating drums or other containers replaced as required. Ultimately, the goal is to reclaim these wastes or transform them so they are acceptable in a permanent disposal facility.

6. Research, Development, and Demonstration

It is obvious that there are many things not known, or known imperfectly, and thus, there are many technical questions which need to be answered if hazardous wastes are to be properly controlled in a secured landfill. More work is required to fully answer such questions as:

(a) Which hazardous materials can be satisfactorily landfilled?

(b) How must a hazardous waste material be prepared before deposition in a landfill?

(c) How must the landfill site be prepared before deposition of the hazardous waste material?

(d) What monitoring requirements are necessary for effective landfill site operation?

(e) How might a landfill site be prepared for re-use at a future date?

(f) What are the requirements for long-term surveillance of such sites?

EPA, in cooperation with other governmental agencies and the private sector, is endeavoring to find answers.

The primary EPA program responsibility for land disposal of hazardous wastes resides in the Office of Solid Waste Management Programs (OSWMP). OSWMP has initiated a contract assessment of available physical, chemical, and biological treatment technology for potential application to detoxifying or recycling of hazardous wastes. Another significant contract is evaluating incineration as a means of destroying hazardous wastes. A series of test burns will be conducted in full-scale commercially available incinerators utilizing real world wastes. Other work is planned in the area of damage monitoring in existing dump sites which have a history of receiving hazardous wastes.

A rather major effort being conducted by OSWMP involves the development of a full-scale model hazardous waste land disposal demonstration project. Appropriate waste and site preparation procedures necessary to dispose of selected hazardous wastes will be included. Site selection, management, and operating procedures and problems will also be highlighted.

The Solid and Hazardous Waste Research Division of the Municipal Environmental Research Laboratory (Office of Research and Development), in support of OSWMP is conducting some much needed research in the following areas:

(a) Deep Well/Salt Mine Disposal Studies - A review is being made of the existing information on disposal and/or storage of hazardous wastes in deep wells, salt mines and hard rock mines. An assessment of the environmental adequacy of these techniques for different wastes is also being made.[32] These reports will draw together the known current information and present best current opinions by experts on design criteria and potential problems associated with subsurface disposal. Research, development and demonstration needs will be highlighted.

(b) Hexachlorobenzene (HCB) Research - Due primarily to the national concern which grew out of the aforementioned Louisiana HCB problem, SHWRD has initiated a research program addressing the leachability of HCB when landfilled, the effect of acids (generated by mixed municipal refuse) on HCB solubility, the sublimation of exposed HCB wastes at various conditions of temperature, humidity and moisture, the effect of various soil types and cover depths on HCB sublimation, and the effect of covering HCB-bearing wastes with plastic sheeting to prevent sublimation.

(c) Soil Transport Studies - There remains much to learn about the movement of hazardous wastes in the land environment. Laboratory-scale (soil column) investigations of transport mechanisms of specific hazardous wastes have been undertaken by SHWRD. This work is designed to prove that potentially dangerous leachates (or air emissions) can and do result from conventional sanitary landfilling of individual hazardous wastes. The resulting reports will include characteristics of the wastes and soils used, other pertinent experimental conditions, the data obtained including transmissions rates and attenuation coefficients, and analysis of the potential environmental impact in the real world. The latter will include an analysis of the potential transportation rate through various soils under given rainfall conditions.

A second study area will document on-site research into the transport mechanisms associated with actual instances of environmental degradation, or health hazard associated with hazardous waste disposal. The final report shall contain a summary and analysis of this in-depth investigation, and establish the connection and the pathway between the source and the effect.

(d) Chemical Stabilization/Fixation - As stated earlier, several companies have developed and are providing chemical fixation services. An evaluation of this technique is necessary to substantiate environmental claims made for the processes. SHWRD is conducting research to evaluate different approaches to the stabilization of hazardous wastes prior to ultimate disposal. One project will examine the fixation and solidification of waste sludges via the various commercial techniques now available. This approach is felt to be attractive for waste materials containing significant quantities of water, since the wastes can be agglomerated and solidified without the need for separating the bulk of the water from the solids. Other research involves the utilization of organic cements and coatings to obtain stabilized agglomerates having a waste solids content of greater than 90 percent. This latter technique is applied to heavy metal wastes which are essentially dry, and for which more effective stabilization may be achieved at a much higher waste loading.

In addition to the above EPA programs related to land disposal of hazardous wastes, other Federal agencies have pertinent programs. The Energy Research and Development Agency (ERDA) has authority over and conducts programs in all aspects of radioactive waste management, while the Department of Defense (DOD) is conducting a waste management program primarily devoted to items such as chemical and biological warfare agents, explosive/ordnance materials, and pesticides.

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APPENDIX

Landfill Disposal of Specific Materials

The attached Table 1 presents hazardous waste stream constituents for which landfill disposal is considered an acceptable waste disposal alternative. A brief summary of each applicable landfill disposal process is found in Table 2, including design and operating parameters where known. These processes are coded alphabetically in Table 1. Other equally acceptable or preferable treatment/disposal techniques are mentioned. By examining the disposal methods in Table 2, it is obvious that a great deal of additional detailed information on suitable operating parameters is needed. Some of the programs planned to help fill these knowledge gaps were presented in Section 6.

The material in these tables comes primarily from the TRW Systems, Inc. report entitled, Recommended Methods of Reduction, Neutralization, Recovery or Disposal of Hazardous Waste, which was performed as an adjunct study relative to the requirements of Section 212 of the Solid Waste Disposal Act of 1965, as amended. Additional material from OSWMP files was added where appropriate. Reference to these tables will provide the user with an indication of whether a material in question is landfillable and in many cases, some of the operating parameters and procedures required. These tables should be used in making preliminary investigations to indicate the overall practicality of the landfill approach to specific hazardous waste problems. In many cases, more detailed information can be obtained by referring to the TRW report or to the Hazardous Waste Management Division of OSWMP.

Although OSWMP is of the opinion that land disposal is acceptable for the named wastes, this table should not be construed as unqualified OSWMP endorsement, since detailed studies have not been performed with OSWMP monitoring to confirm the information. Specific criteria should be viewed as examples of criteria known to have been used with reported success and not hard and fast rules for universal land disposal of all materials containing the subject substance. In the end, any decision regarding the environmental adequacy and safety aspects of land disposal of a given waste material must depend on an overall analysis of the individual situation.

Because of the threat to public health and the potential for environmental damage, land disposal of hazardous waste materials must not be entered into lightly. Reference is made to the list of considerations in Section 4 which should be addressed in analyzing any hazardous waste landfill proposal.

It is OSWMP's plan to update these tables on a periodic basis as more information is gathered. In this regard, users of this information can be of assistance by notifying OSWMP of new information regarding landfill test results for various substances or waste materials.

Table 1-1

LAND DISPOSAL OF SPECIFIC MATERIALS

Hazardous Material	Recommended Disposal Method
1. Aluminum Fluoride	A
2. Aluminum Oxide	B
3. Ammonium Bifluoride	C
4. Ammonium Fluoride	C
5. Ammonium Perchlorate	D
6. Ammonium Persulfate	D
7. Antimony Pentafluoride	E
8. Antimony Pentasulfide	A
9. Antimony Sulfate	A
10. Antimony Trifluoride	E
11. Antimony Trisulfide	A
12. Barium Fluoride	F
13. Barium Nitrate	G
14. Barium Sulfide	G
15. Benzene Sulfonic Acid	H
16. Beryllium Carbonate	I
17. Beryllium Chloride	I
18. Beryllium Oxide	I
19. Beryllium (powder)	I
20. Beryllium Selenate	I
21. Boron Trifuluoride	J
22. Cacodylic Acid	K
23. Cadmium Fluoride	F
24. Calcium Arsenate	L
25. Calcium Arsenite	L
26. Calcium Fluoride	B
27. Calcium Hypochlorite	D
28. Calcium Phosphate	B
29. Chromic Acid (Liquids, Chromium Trioxide)	M
30. Chromic Fluoride	N
31. Chromic Sulfate	N
32. Cobalt Chloride	G
33. Copper Acetoarsenite	L
34. Copper Acetylide	X
35. Copper Arsenate	L
36. Copper Nitrate	O
37. Copper Sulfate	O
38. Diphenylamine (Phenylaniline)	P
39. Hypochlorite (Sodium)	D

Hazardous Material	Recommended Disposal Method
40. Lead	Q
41. Lead Arsenate	L
42. Lead Arsenite	L
43. Lead Oxide	R
44. Magnesium Arsenite	L
45. Magnesium Chlorate	D
46. Magnesium Oxide	B
47. Manganese	B
48. Manganese Arsenate	L
49. Manganese Chloride	S
50. Manganese Sulfate	S
51. Metallic Mixture of Powdered Magnesium and Aluminum	B
52. Nickel Antimonide	T
53. Nickel Arsenide	T
54. Nickel Selenide	T
55. Nitrochlorobenzene (dilute)	A
56. Potassium Arsenite	L
57. Potassium Bifluoride	C
58. Potassium Binoxalate	U
59. Potassium Fluoride	C
60. Potassium Oxalate	U
61. Potassium Permanganate	V
62. Selenium (powdered)	A
63. Silica	B
64. Sodium Arsenate	L
65. Sodium Arsenite	L
66. Sodium Bifluoride	C
67. Sodium Cacodylate	K
68. Sodium Carbonate Peroxide	D
69. Sodium Fluoride	C
70. Sodium Oxide	W
71. Sulfur	B
72. Tantalum	B
73. Thallium (dilute)	A
74. Thallium Sulfate (dilute)	A
75. Vanadium Pentoxide	B
76. Zinc Arsenate	L
77. Zinc Arsenite	L
78. Zinc Chlorate	D
79. Zinc Oxide	B

Table 2

Disposal Methods

A. Disposal in a chemical waste landfill.

B. Disposal in a sanitary landfill. Mixing of industrial process wastes and municipal wastes at such sites is not encouraged however.

C. Reaction of aqueous waste with an excess of lime, followed by lagooning, and either recovery or land disposal of the separated calcium fluoride.

D. Dissolve the material in water and add a large volume of concentrated reducing agent solution, and then acidify with H_2SO_4. When reduction is complete, soda ash is added to make the solution alkaline. Ammonia will be liberated and will require recovery. The alkaline liquid is decanted from any sludge formed, neutralized, diluted, and discharged. The sludge is landfilled.

E. The compound is dissolved in dilute HCl and saturated with H_2S. The precipitate (antimony sulfide) is filtered, washed, and dried. The filtrate is air stripped of dissolved H_2S and passed into an incineration device equipped with a lime scrubber. The stripped filtrate is reacted with excess lime, the precipitate (CaF - CaCl mixture) is disposed of by land burial.

F. Precipitation with soda ash or slaked lime. The resulting sludge should be sent to a chemical waste landfill.

G. Chemical reaction with water, caustic soda, and slaked lime, resulting in precipitation of the metal sludge, which may be landfilled.

H. Biological or chemical degradation of dilute streams using conventional waste water techniques; treatment with lime to precipitate out calcium benzene sulfonate which can be disposed in a chemical waste landfill.

I. Wastes should be converted into chemically inert oxides using incineration and particulate collection techniques. These oxides may be landfilled.

J. Chemical reaction with water to form boric acid, and fluorboric acid. The fluorboric acid is reacted with limestone forming boric acid and calcium fluoride. The boric acid may be discharged into a sanitary sewer system while the calcium fluoride may be recovered or landfilled.

K. Long-term storage in concrete vaults or weatherproof bins; small amounts may be disposed in a chemical waste landfill.

L. Long-term storage in large, weatherproof, and sift-proof storage bins or silos; small amounts may be disposed in a chemical waste landfill.

M. Chemical reduction of concentrated materials to chromium-III and precipitation by pH adjustment. Precipitates are normally disposed in a chemical waste landfill.

N. Alkaline precipitation of the heavy metal gel followed by effluent neutralization and discharge into a sanitary sewer system. The heavy metal may be disposed in a chemical waste landfill.

O. Copper wastes can be concentrated through the use of ion exchange, reverse osmosis, or evaporators to the point where copper can be electrolytically removed and sent to a reclaiming firm. If recovery is not feasible, the copper can be precipitated through the use of caustics and the sludges deposited in a chemical waste landfill.

P. Wastes may be incinerated, or disposed in a chemical waste landfill.

Q. Recycle using blast furnaces designed for primary lead processing to convert waste into lead ingots. Small quantities may be disposed in a chemical waste landfill.

R. Chemical conversion to the sulfide or carbonate followed by collection of the precipitate and lead recovery via smelting operations. Landfilling of the oxide is also an acceptable procedure.

S. Chemical conversion to the oxide followed by landfilling, or conversion to the sulfate for use in fertilizer.

T. Encapsulation followed by disposal in a chemical waste landfill.

U. Ignite to convert it to a carbonate. The carbonates (non-toxic) may be sent to a landfill.

V. Chemical reduction in a basic media, resulting in manganese dioxide formation. The material may be collected and placed in a landfill.

W. Chemical neutralization followed by solids separation with deposit of solids into a chemical waste landfill.

X. Detonation (on an interim basis until a fully satisfactory technique is developed); the copper salts liberated may be disposed of in a chemical waste landfill.

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