CHAPTER 11

Hazardous Wastes

To the general public, the subject of hazardous wastes carried different meanings from its onset in the mid-twentieth century to the 1990s. At the beginning, a "hazardous" waste was simply one that would result in danger to any person or structure with which it came into contact. As more widespread understanding grew, a "hazardous waste" was considered one that was "toxic" to microorganisms that were present in domestic wastes and generally used to treat them biologically. And, finally, most environmental workers became acutely aware that certain hazardous wastes would also be toxic to the soil and water environments that they ultimately entered when almost unaltered in form composition.

It is difficult to put exact dates to when these definitions became general knowledge. Certainly the periods of their existence overlapped greatly and certainly some scientists—especially those educated in the environmental science area—understood all of these "effects" right from the beginning. However, little was done by anyone to ameliorate the adverse effects on the environment until late in the century. The reasons for the "lack of action" on treatment of hazardous waste were largely driven by industrial secrecy and economics. Action finally began when enough catastrophes occurred and industrial secrets and cover-ups were revealed.

Definitions

Generators of waste materials can ascertain whether their waste is hazardous either by referring to a published list or by complying with the U.S. Environmental Protection Agency (EPA) definition of hazardous waste. The EPA defines the characteristics of a hazardous waste in terms of ignitability, corrosivity, reactivity, and extractive procedure toxicity. These are mentioned by Nemerow (1983, Table 1) and discussed briefly in the following four sections of this chapter.

Many hazardous wastes contain toxic materials that can be classed in more than one category. In these cases, the waste will be grouped in the category of major

significance. The reader must understand, however, that certain constituents of a waste may also be important and from another category.

The legal U.S. definition of a hazardous waste is extremely complicated and even controversial. At the time this book was written, an interested person was urged to refer to the EPA Regulations for Identifying Hazardous Wastes—40-CFR261, 45-FR33119, May 19, 1980, and revised July 1, 1983, and amended on 10 occasions from then until July 25, 1985.

The reader can ascertain the status of a certain waste by referring to the following four figures published by the Bureau of National Affairs, In. Washington, D.C. 20037. The waste must first receive a legal definition of a Resource Conservation Recovery Act (RCRA) solid waste (Figure 11.1). It can then be classified as "hazardous" and handled as such by referring to Figure 11.2. Regulations covering hazardous wastes are

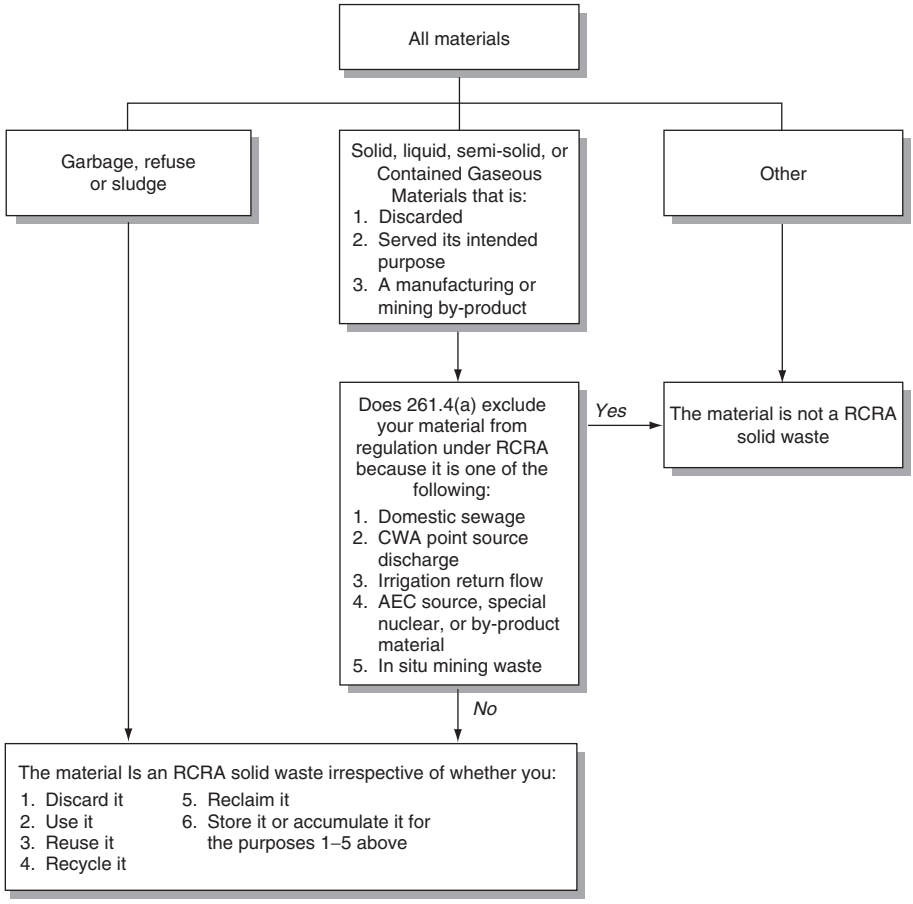


FIGURE 11.1. Definition of a solid waste.

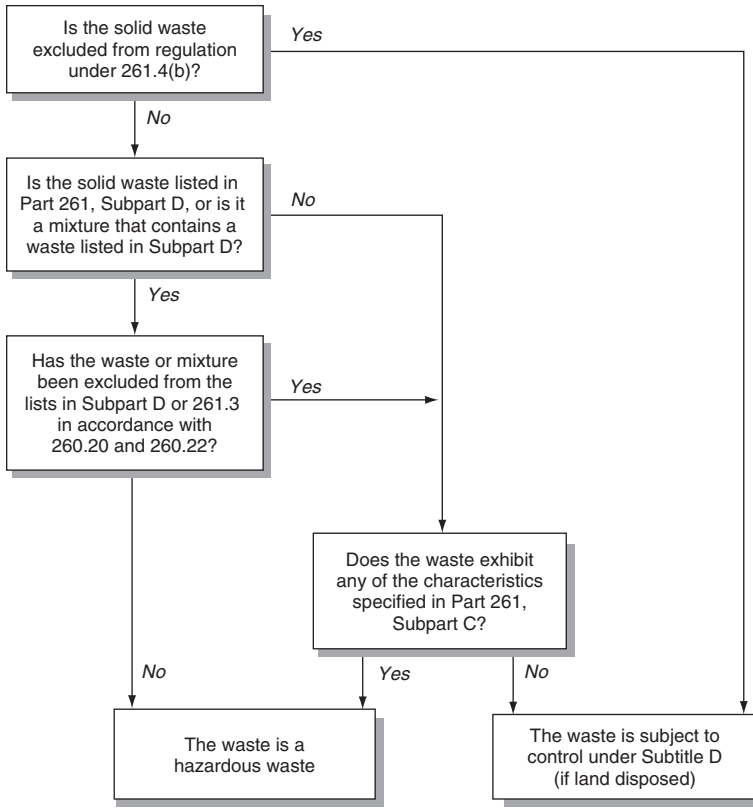


FIGURE 11.2. Definition of a hazardous waste.

shown in Figure 11.3 and for those subject to control under Subtitle C of EPA regulations in Figure 11.4.

Dangers

Once a decision has been made to manufacture a potentially toxic chemical or product, the door is open to catastrophic release of either to the environment. Careful control must be maintained by the industrial manufacturer and product users from the very beginning. The dangers of toxic wastes being released to the environment are real and originate from three sources: (1) production of the toxic chemical, (2) use of the toxic chemical in subsequent manufacturing of a product, and (3) release of a toxic product (or other chemical) from the use or wastage of the product. In addition, there is always the potential hazard of escape of any of these toxic materials during transportation from any location to another for use or disposal. In reality, all of these dangerous emissions or releases of toxic material to the environment occur accidentally. No one

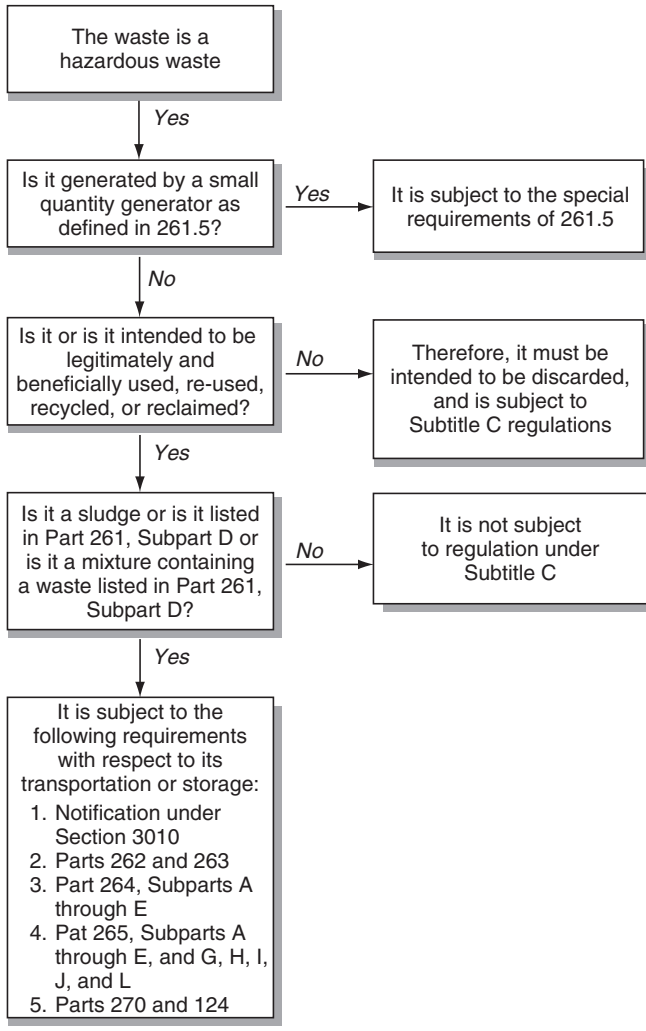


FIGURE 11.3. Special provisions for certain hazardous waste. (Amended by 48 FR 14153, April 1, 1983.)

intends to cause these catastrophes, but accidents occur frequently enough to be considered a usual occurrence no matter how infrequently they happen. The only reasonable prevention—other than nonuse of hazardous materials—is to design fail-safe devices to operate when the accidents occur.

Scope of Problems and Costs of Solutions

Pearce (1983, 57) reports that in the industrialized nations, at least by far the largest proportion of hazardous waste generated is recycled or reclaimed by industry. He gives

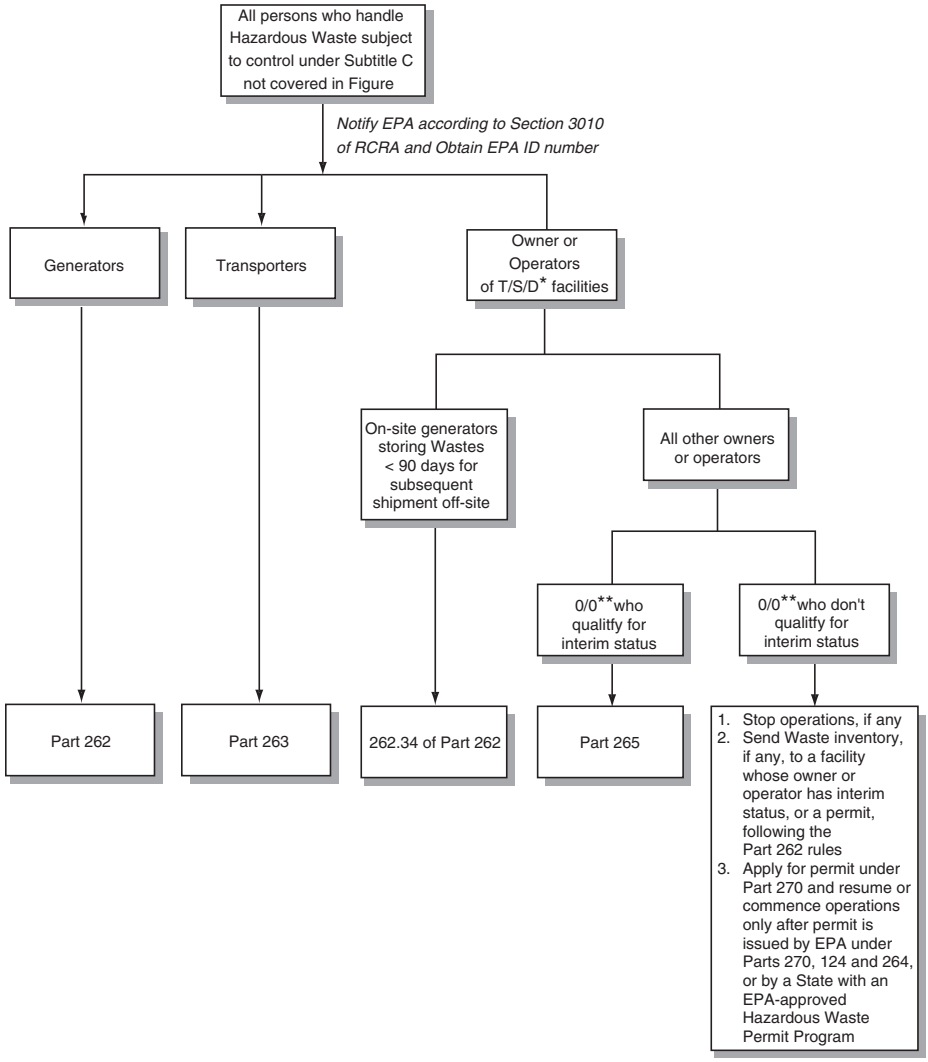


FIGURE 11.4. Regulations for hazardous waste not covered in diagram 3. (Amended by 48 FR 14153. April 1, 1983)
*T/S/D, for Treatment, Storage or Disposal
**0/0, for Owners or Operators

as an example Great Britain, where about 10 million tons per year are recovered by industry, whereas only 3.4 million tons are rejected for disposal.

The EPA (1980) determined that costs of hazardous waste disposal were major factors in attaining final solutions to the problem. Although costs vary widely, the EPA gave ranges for various treatments, as shown in Table 11.1.

Another EPA (March 1985) rough general cost comparison for hazardous waste treatment gives the following:

TABLE 11.1
Cost of Hazardous Waste Disposal Practices

Technology	*$/Metric Ton*
Land spreading	2–25
Surface impoundment	14–180
Chemical fixation	5–500
Secure chemical landfill	50–400
Incineration (land based)	75–2,000

Source: U.S. EPA (1980).

Type of Waste	*Type or Form of Waste*	*Price 1981, $/Metric Ton*
Management		
Landfill	Drummed	168–240
	Bulk	55–83
Deep-well injection	Oily wastewater	16–40
	Toxic rinse water	132–164
	Cyanides/heavy metals, and highly toxic waste	66–791
Land	Liquids	53–237
Incineration	Solids and highly toxic liquids	395–791

Effects on Environment

Hazardous wastes pollute the air, water, and land drastically. They often affect human beings directly and most certainly indirectly. The deterioration of the environment is extensive and often irreversible, or reversible at heavy cost in both money and people-power. Effects are caused by wastes that burn, corrode, react violently, are toxic, and are acutely hazardous to the health and welfare of society.

It is becoming increasingly evident that traces of hazardous chemicals, including suspected carcinogens, are getting into the food chain via surface-water and groundwater supplies. People are exposed through drinking water, air, and food such as fish originating in rivers and lakes. Toxic pollutants find their way into surface-water supplies from waste-treatment plants, coal burning, refuse incineration, and atmospheric fallout. An example of this dangerous effect is that occurring in the U.S. Great Lakes basin (Great Lakes Study 3, 1985) in which 1,065 hazardous or potentially hazardous substances were identified in the lakes, with the highest concentration at the southern edges. Besides the recreational and commercial fishing in these lakes, many large cities, such as Syracuse, New York, take in raw water from them (Lake Ontario) for drinking-water purposes. Drinking water must now be carefully examined and analyzed for potentially hazardous chemicals.

Philosophies of Solutions

Problems caused by hazardous wastes must be solved by (1) not producing them in the first place, (2) collecting and reusing every bit of them in some other product that does

affect the environment, or (3) destroying them in ways that either there will be nothing left or their residues will be compatible with and harmless to the environment.

Any of these solutions costs money to instigate and requires ingenuity and research to implement. They cannot usually be solved in ways heretofore practiced by municipalities and industries in rather conventional manners.

One of the major objectives of this book is to explore potentially feasible means of solving what is now a major problem for society: disposal of our hazardous wastes. Developed countries such as the United States, Germany, France, and so on tend to locate chemical plants that use or produce hazardous chemicals in less developed countries in order to minimize production and distribution costs. A lesson rapidly being learned by developed countries is that these lower production costs cannot be gleaned at the expense of the local environment. Hazards from these plants in developing countries are just as dangerous and intolerable as they are in developed nations. It was originally thought possible by developed nations to export environmental damage—and acceptable to lesser developed countries in order to gain economic compensation. The Bhopal incident accentuates the fact that this kind of thinking on anyone's part no longer exists.

Varied Types of Industrial Hazardous Wastes

In 1974, the EPA listed 15 major industries that discharge wastes containing hazardous substances. It indicated the specific hazardous materials in each waste (Table 11.2).

In addition to private section industries, the U.S. Navy has voiced concern over its contribution to the hazardous waste problem (LaPue 1996). The Navy spent $3.2 million to scrape up and dispose of 7,900 yd^3 of soil deposited between the years 1943 and 1975, contaminated with "everything from mercury in torpedoes to lead paint and since-banned

TABLE 11.2
Hazardous Waste Industries

Industry	*Hazardous Substances*
1. Mining and metallurgy	As, Cd, Cr, Cu, Cn, Pb, Hg, Se, Zn
2. Paint and dye	Cd, Cr, Cu, Cn, Pb, Hg, organics, Se
3. Pesticide	As, C1-hydrocarbons, Cn, Pb, Hg, organics, Zn
4. Electrical and electronic	Cu, C1-hydrocarbons, Cn, Pb, Hg, Se
5. Printing and duplicating	As, Cr, Cu, Pb, organics, Se
6. Electroplating-metal finishing	Cd, Cr, Cn, Cu, Zn
7. Chemical manufacturing	C1-hydrocarbons, Cr, Cu, Pb, Hg, organics
8. Explosives	As, Cu, Pb, Hg
9. Rubber and plastics	C1-hydrocarbons, Cn, Hg, organics, Zn
10. Battery	Cd, Pb, Ag, Zn
11. Pharmaceutical	As, Hg, organics
12. Textile	Cr, Cu, organics
13. Petroleum and coal	As, C1-hydrocarbons, Pb
14. Pulp and paper	Hg, organics
15. Leather	Cr, organics

fluids from torpedoes." Between 15,000 and 110,000 gallons of drummed waste were drained at the site of the Navy yard in San Diego, California, before it was paved, along with about 10,000 gallons of transformer fluid laden with polychlorinated biphenyl (PCB). The Navy expects to excavate and remove 1.5 to 6 ft of soil underneath the asphalt pavement, with special precautions taken to prevent dust and airborne contamination associated with the removal procedures.

Sundaresan et al. (1983, 70) group industries producing toxic and hazardous wastes into two categories:

1. Conventional solid wastes generated in large quantities and stored near the factory such as phosphatic fertilizers and thermal power plants.
2. Other semisolid and solid residues including liquid wastes resulting from the organic and inorganic chemical industries. These wastes are not voluminous, but some are highly toxic and potentially hazardous.

Yakowitz (1988) presents a list of 14 types of hazardous wastes (Table 11.3). It appears to be the most comprehensive breakdown of specific general characteristics available at the time.

TABLE 11.3
List of Hazardous Characteristics

Code Number	*Characteristics*
H1[a]	Explosive An explosive substance is a solid or liquid substance (or mixture of substances) that is in itself capable by chemical reaction of producing gas at such a temperature and pressure and at such a speed as to cause damage to the surroundings.
H2[a]	Oxidizing Substances that, while in themselves are not necessarily combustible, may, generally by yielding oxygen, cause or contribute to the combustion of other materials. (Organic substances that contain the bivalent-0-0-structure are thermally unstable substances that may undergo exothermic self-accelerating decomposition.)
H3[a]	Inflammable The word "flammable" has the same meaning as "inflammable." Inflammable liquids are liquids, or mixtures of liquids, or liquids containing solids in solution or suspension (e.g., paints, varnishes, lacquers, etc., but not including substances otherwise classified on account of their dangerous characteristics) that give off an inflammable vapor at temperatures of not more than 60.5˚C, closed-cup test, or not more than 65.6˚C, open-cup test. (Since the results of open-cup tests and of closed-cup tests are not strictly comparable and even individual results by the same test are often variable, regulations varying from the above figures to make allowances for such differences would be within the spirit of this definition.) Inflammable solids are solids, other than those classed as explosives, that under conditions encountered are readily combustible, or may cause or contribute to fire through friction.

TABLE 11.3 *(continued)*

H4[b]	Irritating Noncorrosive substances and preparations that, through immediate, prolonged, or repeated contact with the skin or mucous membrane, can cause inflammation.
H5[b]	Harmful Substances and preparations that if they are inhaled or ingested or if they penetrate the skin, may involve limited health risks.
H6[a]	Toxic Substances and preparations, that, if they are inhaled or ingested or if they penetrate the skin, may involve serious, acute, or chronic health risks and even death.
H7[b]	Carcinogenic Substances and preparations that, if they are inhaled or ingested or if they penetrate the skin, may induce cancer in people or increase the incidence.
H8[a]	Corrosive Substances that, by chemical action, will cause severe damage when in contact with living tissue, or, in the case of leakage, will materially damage, or even destroy, other items or a means of transport; they may also cause other hazards.
H9[a]	Infectious Substances containing viable microorganisms or their toxins, which are known, or suspected, to cause disease in animals or humans.
H10[a]	Liberation of flammable gases in contact with water Substances that, by interaction with water, are liable to become spontaneously inflammable or to give off inflammable gases in dangerous quantities.
H11	Liberation of corrosive fumes in contact with air or water.
H12	Liberation of toxic gases in contact with air or water.
H13	Capable, by any means, after disposal, of yielding another material, e.g., leachate, which possesses any of the characteristics listed above.
H14	Ecotoxic Substances which, if released, present or may present immediate or delayed adverse impacts to the environment by means of bioaccumulation and/or toxic effects upon biotic systems.

[a]Definition from *Transport of Dangerous Goods*, Recommendations of the United Nations Committee of Experts on the Transport of Dangerous Goods, Third Revised Edition, United Nations, New York, 1985.
[b]Definition from Article 2 of the European Communities Council Directive of 18 September 1979 amending for the sixth time Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging, and labeling of dangerous substances (Directive 79/831/EEC.)
[c]Guidance with regard to this characteristic may be obtained by consulting the lists of known and strongly suspected carcinogens published periodically by the International Agency for Research on Cancer.

Source: Adapted from Yakowitz (1988).

The American Chemical Society (ACS) is especially concerned with the various types of hazardous wastes. It published a list of the types of these wastes of concern to its members (ACS 1984) (Table 11.4).

TABLE 11.4
RCRA-Regulated Hazardous Wastes

Waste Group Generated	*% of Establishments Generating*
Spent solvents—halogenated and nonhalogenated[a]	51.0
Ignitable wastes[a]	43.4
Corrosive wastes[a]	33.4
Spilled, discarded, or off-specification commercial chemical products or manufacturing chemical intermediates	28.8
EO toxic wastes[a]	27.8
Electroplating and coating wastewater treatment sludges and cyanide-bearing solutions and sludges	16.4
Statutory hazardous wastes (i.e., not listed or regulated as hazardous wastes by EPA or state)	12.2
Listed industry wastes from specific sources	10.2
Acutely hazardous wastes	10.2
Reactive wastes[a]	7.1

Note: The list, taken from an EPA survey, provides estimates of the percentage of generators producing specific types of RCRA-regulated hazardous wastes during 1981. The sum of the total exceeds 100% because a generator may have produced more than one type of waste, and a given waste stream may have been a mixture that consequently was reported under multiple characteristics.
[a]These waste groups include wastes that, while not specifically listed in EPA's list of hazardous wastes, exhibit one of the hazardous characteristics, such as high flammability, high or low pH levels, toxicity, and volatility or violent reactive tendencies with other substances.

Ignitable Hazardous Wastes

The EPA (1980) classifies these hazardous wastes in four categories:

1. A liquid that has a flash point less than 60˚C (140˚F); exemption—aqueous solution with less than 24% alcohol
2. A waste that is not a liquid but is capable under standard temperature and pressure of causing fire through friction, absorption of moisture, or spontaneous chemical changes, and, when ignited, burns so vigorously and persistently that it creates a hazard
3. An ignitable compressed gas
4. An oxidizer

From these definitions, such ignitable hazardous wastes can originate from all three physical states: gases, liquids, and solids.

Waste Oils

Waste oils not only are objectionable aesthetically in any of the three environments (air, water, or land) but also are classified as toxic or hazardous because they are ignitable. Burning by itself is a hazard to health and property. Further, the products of combustion can also be toxic to breathing. For all these reasons, oils must be treated and ultimately disposed of so as to prevent toxicity in any environment.

Automotive crankcase used waste oil constitutes a large proportion of waste oils. Collection, recovery, and re-purification of waste oils represents the ideal solution to disposal problems. However, economics must justify such methods. When oil prices rise, justification for recovery is also improved. For evaluating recovery of waste oils, the physicochemical analysis of average waste oils is necessary. A typical analysis is given in Table 11.5. The main obstacle to recovery is that of collection. The use of strategically located collection stations where individuals and garages can bring their oils will enhance recovery. Other deterrents to recovery include additives in the oils, environmental laws on reprocessing, and removal of tax incentive laws for reuse of waste oils.

Other possibilities for treatment include (1) mixing waste oils with lighter new fuel oil for burning in power plants, and (2) incorporating them with municipal solid wastes and tree and bush cuttings or beach littoral collections for composting. No data are currently available on either of these methods.

Spent Oil Emulsions

Spent oil emulsions originate mainly from metal fabricating and power plants where mixtures of oils and waters are used to cool moving parts. Because these oils are contaminated with water and grit or cuttings, they can be centrifuged or skimmed for concentration before transportation away from the site of origin. Lubricating oils can also be heated, coagulant added, and centrifuged before reuse in the same plant.

Other Oily Wastes

Other waste oils originate from ship discharges, either accidental or planned. Oil water mixtures from bilges are usually discharged to the sea when the bilge water level gets too high. Sometimes bilge water is coagulated and filtered before discarding the water. In that case, a residual sludge remains to be disposed of. In proper proportions, and with good

TABLE 11.5
Typical Automotive Oil Waste Composition

Variable	*Value*
Gravity, °API	24.6
Viscosity at 100°F	53.3 Centistokes
Viscosity at 210°C	9.18 Centistokes
Flash point	215°F (C.O.C. Flash)
Water (by distillation)	4.4% volume
BS&W	0.6 by volume
Sulfur	0.34 weight %
Ash, sulfated	1.81 weight %
Lead	1.11 weight %
Calcium	0.17 weight %
Zinc	0.08 weight %
Phosphorus	0.09 weight %
Barium	568 ppm
Iron	356 ppm
Vanadium	5 ppm

premixing and feeding devices, it may be burned in special furnaces, even aboard ship. Usually, it is held in a collection tank and pumped out at an onshore station. Such stations can handle larger quantities of oily sludges more effectively and economically. Furnaces or incinerators can be designed specifically to burn these wastes. One company, Haz-Mat Response Technologies, has developed a product to clean up hazardous waste spills (Findle 1996). The product is a mixture of hydrocarbon polymers called "Rubberizer." The product absorbs and transforms petroleum products and solvents into a rubber-like and essentially inert material. This makes the spill cleanup easier because the hardened material can be lifted easily out of the water or other surfaces such as roads and airport runways. The hardened matter can be buried or placed safely in a sanitary landfill.

Onshore oil sludge storage tanks can also be used to receive tank-cleaning wastes. These wastes are usually more dilute, containing mixtures of condensed steam and oil.

Power stations, both stationary and moving, generally use centrifugation to purify their fuel oil before burning, to remove the last traces of water. The latter contaminant may reduce boiler efficiency. It is possible to use these or other standby centrifuges to recover oil from tank cleanings or even bilge waters. The recovered oil could be burned in the power plant's boiler or re-purified, if necessary and and sold or reused for lubricating purposes.

Oily Shipboard Waste or Refinery Sludges

Waste oils can be mixed with soils and decomposed by naturally adapted soil bacteria. Dotson et al. (1974) report that bacteria of the genus *Pseudomonas* grew most rapidly in a soil–oil mixture. These bacteria continued to grow until this food source was exhausted. Despite this finding, Dotson et al. (1974) blame lack of information on full-scale studies as the reason for not using this disposal method. A mixed population such as that of soils is more efficient than a single species or genus. Petroleum hydrocarbons vary in susceptibility to decomposition. High molecular weight, viscosity, and crystallinity are properties that inhibit biological oxidation and decomposition. Straight-chain medium molecular weight hydrocarbons such as kerosene and light motor oils oxidize readily, whereas aromatic types are more resistant. Some evidence of oil decomposition in soil is provided by the oxidation of the asphalt coatings of underground pipes and the disappearances of oil leakages in lakes and shore areas attributed to microbial assimilation.

Corrosive Hazardous Wastes

The EPA (1980) considers corrosive any wastes falling into either of the following two classes:

1. An aqueous waste that has a pH of either 2 or less or 12.5 or more
2. A liquid that corrodes steel at a rate greater than 6.35 mm (0.25 in.) per year at 55˚C

These corrosive wastes could be either very acid or very alkaline and thereby hazardous to any environment into which they are emitted.

Acid Wastes

Acid wastes may be discharged by any plant manufacturing materials, apparel, and chemicals. Most important and hazardous are those coming from chemical plants such as those

producing dyes, explosives, pharmaceuticals, and silicone resins. The major ones are dilute wastes from hydrochloric, sulfuric, and sometimes nitric acid. Regardless of the degree of acidity or the origin of acid wastes, the main method of treatment is neutralization.

Alkaline Wastes

Alkaline wastes are considered corrosive at pH values greater than 12.5 and, hence, are classified as hazardous. As such, they must be treated properly before release to the environment. Like acidic wastes, they too must be neutralized, as described in Chapter 3.

Reactive Industrial Wastes

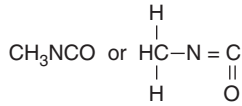
The EPA (1980) rather broadly defines reactive wastes into eight distinct categories:

1. Normally unstable, readily undergoes violent change without detonating.
2. Reacts violently with water.
3. Forms potentially explosive mixtures with water.
4. When mixed with water, generates toxic gases, vapors, or fumes in dangerous quantities.
5. Cyanide- or sulfide-bearing waste when exposed to pH conditions between 2 and 12.5 can generate toxic gases, vapors, or fumes in dangerous quantities.
6. Capable of detonation or explosive decomposition or reaction at standard temperature or pressure.
7. Forbidden explosives, class A or class B explosives.

Wastes Containing Cyanides and Isocyanides

Wastes containing cyanides and isocyanides are generally recognized by the public as being very "reactive," and thereby are classified as hazardous. They are classified as generating toxic gases, vapors, or fumes in dangerous quantities. They are used and released from many chemical industries and metal-plating plants. These compounds aid in solubility and plating of protective metals or machined parts varying from typewriters to silverware. They also can serve as a basic starting chemical for nitrogenous fertilizers. However, when they are allowed to reach the environment without treatment and in sufficient concentration, they are deadly.

Other chemicals containing cyanides are also used and occasionally released to the environment. Such a situation occurred accidentally at Bhopal, India, in December 1984, when a tank of methylisocyanate (MIC) leaked the gas and killed more than 2,000 persons. MIC has a formula of



and is reported by Sax (1979) to be highly dangerous when exposed to heat, flame, or oxidizers. It is highly irritating to the skin, eyes, and mucous membranes, can cause pulmonary edema, and can be absorbed via the skin. This chemical is an important starting compound for the manufacturing of nitrogenous fertilizers. Because it exists as a liquid and boils at the relatively low temperature of 39.1˚C, it must be kept quiescent and cool until used or oxidized to degrade the cyanide.

Sulfide Residues
Sulfide residues or sludges may result from the natural or artificial precipitation of sulfur-bearing wastes from a variety of chemical wastes such as sulfur dyes from textile plants or acid sludges from oil refinery processing.

Oil Refinery Sludges
Spent caustic wastes from catalytic polymerization and alkylate washers in oil refineries contain considerable amounts of sulfides. Acidification of these caustic wastes (with H_2SO_4) removes some of the objectionable compounds. The acid sludges may be used as a source of fuel or to produce byproducts such as oils, tars, asphalts, resins, fatty acids, and chemicals. Some refineries recover sulfuric acid from the acid sludges for their own use. Without reuse or recovery, these acid sludges still contain high amounts of precipitated sulfides, which, in turn, could be released to the environment if the pH or other conditions caused leaching of the sludge.

Trihalomethanes
Organic compounds reaching drinking-water supplies mainly from waste-cleaning solutions contain toxic chemicals such as trichloroethylene, tetrachloroethylene, methyl chloride, vinyl chloride, and carbon tetrachloride. These chemicals are all relatively volatile—reverting from the liquid to the gaseous state readily—and can be removed from the water supply by either granular activated carbon adsorption or air stripping.

Halogenated methane or ethane compounds are highly reactive and unstable and can release toxic gases. They are, therefore, considered hazardous. Such compounds can be released in their manufacture in the petrochemical industry or in the resulting solvent used in dry-cleaning establishments.

Major methods of treatment include prevention of their release by collection tanks for accidental overflow spills and rejects. Most of these compounds are colorless liquids with ethereal odors, relatively low boiling points, and high vapor pressures, and very irritating to the conjunctiva and hence dangerous to the health of humans and animals.

EP Toxic Industrial Wastes

Toxicity to humans and animals as described in this chapter can affect different organs of the body. For example, carcinogenic toxicity causes cancer in living cells and tissues, while genotoxicity causes genetic damage to these same cells and tissues. On the other hand, neurotoxicity causes toxic effects only on the nervous system, nephrotoxicity on the kidneys, and hepatoxicity on the liver. It is not the object of this book to discuss

details of toxicity, but only to point out that there are various types and each may be caused by many different chemicals at different concentrations for different periods of exposure.

The EPA (1980) considers a solid waste toxic if, when extracted by the EP method (Nemerow 1983, p. 116), the leachate contains ions of constituents 100 times or more the Primary Drinking Water Standard. If the wastes contain less than 0.5% filterable solids, then the filtrate is considered exact.

Mercury-Containing Wastes

Caustic chlorine plants use mercury cells and waste mercury. Sundaresan et al. (1983) report a plant producing 60 tons of alkali per day and discharges 1,400 m^3 of wastewater with a pH of about 11 and from 3 to 5 mg/liter of mercury. Brine sludges are also reported to contain from 18 to 20 mg Hg/L. Leaching of mercury into water supplies with subsequent biomagnification causes serious diseases of the nervous system of humans eating fish from such waters.

Mercury, a toxic chemical, is also a naturally occurring element on Earth. However, about 10,000 tons of it are extracted from HgS, cinnabar ore, in the United States each year. About half is released directly into the environment through the discharge of industrial wastes.

The accumulation of mercury in predatory fish, such as tuna and swordfish, constitutes a major danger to humans eating the fish. Many catastrophes, such as that in Minimata Bay, Japan, have resulted in death from eating fish contaminated with mercury. Other industries besides the chlor-alkaline plants discharging mercury-laden wastes are electric wire and equipment and paper processing.

Treatment of mercurous wastes by industry primarily involves recovery within the plant and better housekeeping practices to eliminate wastes.

Metal-Containing Sludge

Many types of industrial- and municipal-originated sludges contain metals that constitute a hazard to the environment receiving them.

Municipalities contribute two main sludge-type wastes that contain metals: (1) wastewater (sewage) sludge, and (2) refuse solids or sludge. The concentrations of metals in both depend on the types of industries within the collection system and the habits and practices of these plants and people in the district.

Domestic-sewage sludge often contains various amounts of heavy metals. The latter originates in wastes discharged mainly from small electroplating shops and garages located within municipal limits. Quantities are difficult to control even though many cities have enacted ordinances limiting allowable concentrations of metallic ions. Generally, no more than 1 ppm of copper, cyanide, or chromium, and 2–5 ppm of zinc or nickel should be allowed in sewage plant influents. If the quantities exceed these values, concentrations in the sludges resulting from sedimentation or biological treatment contain excessive amounts of metals, which hinder anaerobic digestion processes.

Chemical precipitation at elevated pH values aids in the removal of heavy metals by precipitation of the hydroxide or carbonate. Refer to Chapter 6 for treatment details.

Other Inorganic Wastes

In general, the presence and removal of inorganic/dissolved minerals from wastewaters have been given relatively little attention by environmental engineers. But, with the passage of the TOSCA legislation of 1976 and RCRA legislation of 1976, these minerals, which are deemed toxic, and the type and concentration are given serious consideration for treatment and removal.

Chlorides, phosphates, nitrates, sulfates, and certain metals are examples of the more common and significant inorganic dissolved solids. Among the methods employed mainly for removing inorganic matter from wastes are (1) evaporation, (2) dialysis, (3) ion exchange, (4) algae, (5) reverse osmosis, (6) chemical precipitation, and (7) certain oxidation-reduction reactions (see Chapter 7 for more detailed descriptions).

Pickling Liquors

Before applying the final finish to steel products, the manufacturer must remove dirt, grease, and especially iron oxide scale, which accumulates on the metal before and during fabrication. Normally this is carried out by plunging the steel material into dilute sulfuric acid (~20% by weight). The process, known in the trade as "pickling," produces a hazardous waste called *pickling liquor* containing primarily ferrous sulfate.

Galvanizing and Metal-Plating Wastes

A good description of the origin, characteristics, and treatment of these wastes in can be found in Chapters 5 and 6 (Nemerow and Agardy 1998). After metals have been fabricated into the appropriate sizes and shapes to meet customer specifications, they are finished to final product requirements. Finishing is accomplished by stripping, removing undesirable oxides, cleaning, and plating. In plating, the metal to be plated acts as the cathode while the plating chemical metal in solution acts as the anode. The overall liquid wastes are relatively small in volume but are extremely toxic, as confirmed by the EP toxicity test. Most significant toxic metals are chromium, zinc, copper, nickel, and tin. Acids, cyanides, alkaline cleaners, grease, and oil are also found in these wastes and must be considered when planning treatment of metals.

The management policy in the United States for eliminating this type of hazardous waste has been waste minimization. This subject is treated elsewhere (Nemerow 1995). Duke (1994) evaluates the effectiveness of minimization of waste technologies in the San Francisco Bay area. Out of 52 actions, he reports that 25 are treatments, 13 are maintenance or housekeeping, and the remaining 14 are process changes. He concludes that minimization of hazardous wastes "has not fully penetrated the industry" (Duke 1994).

Graphic and Photographic Waste Liquors

Wastewater from large-scale film-developing and printing operation contains "spent" solutions of developer and fixer, which carry thiosulfates and silver. The solutions are usually alkaline with various amounts and types of organic reducing agents along with

the silver. The silver metal is toxic in certain concentrations and, therefore, qualifies this waste as a toxic one.

Treatment to eliminate toxicity involves removal and recovery of valuable silver metal. Three methods are generally used for silver recovery: metallic replacement, electrolysis, and precipitation.

Salts

Salts are generally considered nontoxic primarily because in most water resources such as lakes, streams, and groundwater, their concentration is still relatively low. However, salt concentrations of more than 2,000–3,000 ppm are generally toxic to plants. Salts gradually build up in receiving waters, especially those being reused for irrigating croplands where rainfall is low. Here, salts may never flush out of the root zone of crops. Where drainage from these croplands is hampered by underlying clay layers, salt pockets in the groundwater will build up.

Citing figures by the United Nations Food and Agricultural Organization (FAO), Earthscan reported that "about 120 million hectares (300 million acres)—half of the world's irrigated land—suffer from reduction of crop yields due to salinization" (Raloff 1984).

One way of controlling the toxicity of salts in groundwater caused by continual reuse of irrigation waters with inadequate land drainage is planting of alfalfa or in certain cases grasses. Alfalfa is an extremely thirsty and deep-rooted perennial. It will soak up the high-salt water table and cause it to fall below the normal crop root level. After a number of seasons or years, the original crops of barley or wheat can be replanted without danger of salt toxicity. In the meantime, the alfalfa or grasses can be harvested for other uses.

When certain industries such as pickle processing and textile finishing discharge heavily salted wastes, they may increase the salt concentration in receiving waters to toxic levels. In such cases, these wastes should be segregated and concentrated further by solar evaporation or membrane filtration, and the salt then recovered and reused by industry.

Without improved salt removal from industrial wastewaters, our water resources will eventually become salt toxic. When and if that occurs, civilization as we know it will begin to deteriorate and dry up.

A possible solution is to develop more salt-tolerant crops as foods. Raeburn (1985) described plants known as *halophytes* that grow like weeds along seacoasts and estuaries. One of them, salicornia, a plant that grows to a foot or two in height, looks like a bunch of green pencils. The plant produces oil high in polyunsaturates at a greater yield than soybeans, a high-protein food product, and a principal source of vegetable oil. They also found that two varieties of another crop, atriplex, yield as much animal feed as alfalfa and can be harvested several times a year. They report much work progressing on developing hybrid strains of salt-tolerant wheat, rice, barley, and tomatoes.

Phosphatic Fertilizer Sludges and Ore Extraction Wastes

Wastes from the phosphate industry arise from (1) mining the rock, and (2) processing the rock to elemental phosphorous and other pure chemicals. In mining, the main wastes originate from the washer plant when the rock is separated from the water solution, as well as from the flotators, where phosphate particles are separated from the

impurities retained on the screens. In processing the phosphate, the major source of waterborne waste is the condenser water bleed-off from the reduction furnace.

The wastes are high in volume and contain fine clays and colloidal slimes, as well as some resinous oil from the flotators. Both mining and processing wastes contain small concentrations of radon emitted from uranium rock associated with the phosphate rock. Flotation wastes contain some resinous oils. Mining slimes also contain other heavy metals. Toxic constituents are classed as radioactivity, oils, and heavy metals.

The major hazard of these sludges comes from leaching of the toxic contaminants into water supplies or exposing humans to radioactivity from reused gypsum as building material.

Krishnan et al. (1996) report on the use of an environmentally balanced industrial complex for handling this phosphogypsum sludge and, thereby, realizing an overall savings of 42% in real production costs.

Ore Extraction Wastes

Copper, lead, and zinc can be extracted from their ores and concentrated to obtain pure metals. In copper processing, about 4 tons of concentrated ore produces 1 ton of pure copper metal. Slag, which develops as a waste from metal smelting, contains silicon, iron, and magnesium, as well as 6–8% zinc, 0.5% manganese, 0.4% copper, and 1.7% sulfur. Reused spent acid from the electrolyte is occasionally wasted and contains small amounts of toxic metals considered hazardous to the environment.

Power Plants

The operation of steam power plants generally involves the generation of heat from coal, oil, or uranium fuel to produce steam with exceptionally pure water. The steam is used to drive turbines, which, in turn, are coupled to generators.

Toxicity of residuals arising from the production of electricity in the aforementioned manner originates in the following:

1. Hot concentrated water salines from boiler and evaporator blow-down. These may include various metals and hexavalent chromium used as a corrosion inhibitor. These are hazardous.
2. Acid and alkaline chemical solutions used in cleaning power-plant equipment. These are hazardous.
3. Acid water drainage from coal storage and ash ponds. These also are hazardous.
4. Leakage or discharge of nuclear-fired power-plant cooling waters. These are hazardous.
5. Fuel (nuclear) reprocessing plant wastes. These are also hazardous.

Nitrogenous Fertilizers

In all nitrogenous fertilizers, ammonia is the basis and by far the most significant compound in wastewaters. In the fertilizer effluents from the production of ammonium phosphates, a considerable amount of fluorine gas is driven off or elemental and fluorosilicious acid fluoride is found in the condensates. This element and traces of arsenic are the main hazardous wastes. They are toxic.

The principal method of treatment of the toxic components has been storage of the wastewaters in lagoons, from which they are equalized and proportioned to discharge over longer periods, coagulation of the fluoride with lime and/or alum-polyelectrolytes, or recovery of the fluorine directly as fluorosilicious acid.

Wood-Preserving Wastes

Almost all of the 400 U.S. wood-preserving plants use pressure processes to preserve wood (for long-term exposure to soil, water, and air) with either creosote or pentachlorophenol or both. Air-dried timber is first steamed at about 20 psi for up to 12 hours while the condensate is continuously removed. Following evacuation and raising the pressure with air to 30–90 psi, the retort is filled with the creosote or pentachlorophenol oil. When all the air has been expelled by the preservative, pressure is maintained at about 200 psi for 2–8 hours. Entrapped air and preservative bubble out after the pressure is released. The preservative escaping is recovered and returned to a storage tank for reuse. Excess oil is removed by a vacuum before steaming. This condensate is the source of the major portion of toxic waste (Figure 11.5).

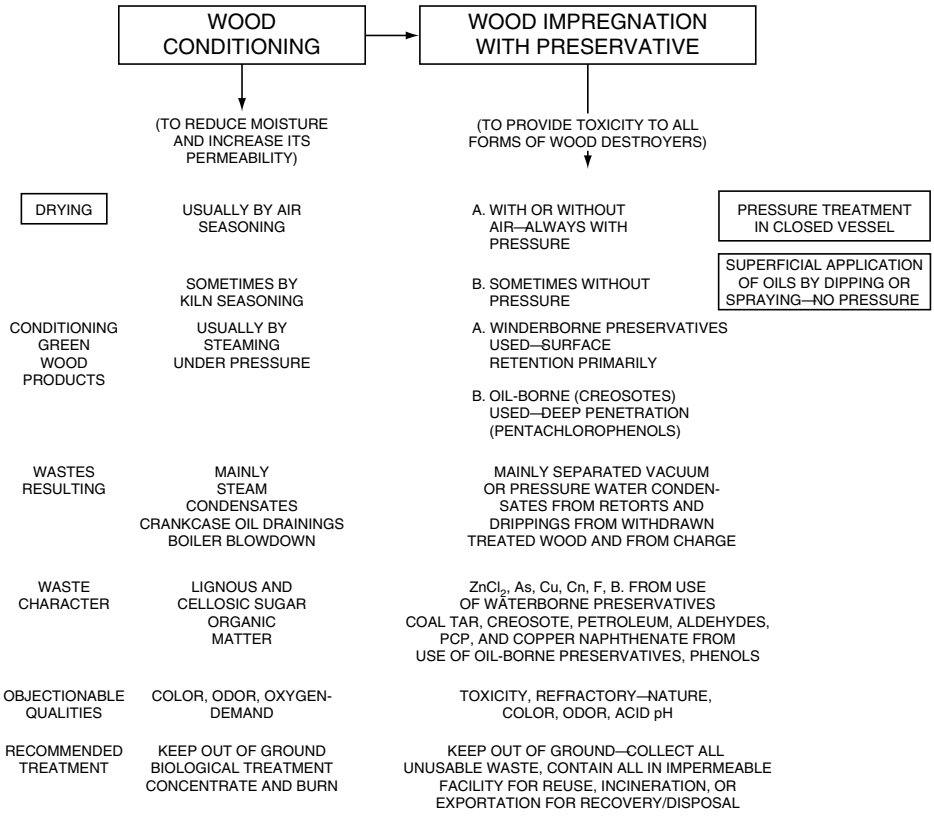


FIGURE 11.5. Wood-preserving processes.

Acute Hazardous Industrial Wastes

The category of acute hazardous industrial wastes includes industrial wastes that are a danger to humans and animals in very small concentrations when released into the environment. They affect the health of all living beings in an insidious manner, usually invisible and undetectable without sophisticated sampling and measuring equipment. Such wastes include radioactive, biological, and asbestos-laden air and water.

Radioactive Wastes

Major origins of radioactive wastes are from the use of nuclear energy by power plants and hospitals. Natural fallout from nuclear explosions is also an ever present possibility and has occurred in the past. In power plants, radioactive wastes can be released in contaminated cooling waters, leaks and subsequent wash-downs. In addition, fuel elements need reprocessing to renew the uranium rods periodically. Acid reprocessing wastes containing high levels of radioactivity can be released either at the power plant site or at designated national reprocessing sites. For example, a tank filled with radioactive gas ruptured at a uranium reprocessing plant on January 4, 1986, in Gore, Oklahoma. The container was being heated at the time ("Worker killed, dozens hurt" 1986) when it burst, releasing about 14,000 lb of slightly radioactive uranium hexafluoride gas, which breaks down into toxic hydrogen fluoride and low-level radioactive uranyl fluoride particles. One person died of acid burns and 14 were hospitalized for skin and respiratory system exposure.

American homes contaminated with radon gas could be causing as many as 30,000 lung cancer deaths per year. The gas rises to the land surface from any source of uranium and can travel horizontally for miles before penetrating cracks in house foundations. If the air within the building is not exchanged continually with outside air, the radon concentration can build up to dangerous levels.

Because these wastes cause genetic changes, usually in the form of some type of cancer in humans and animals coming in contact with them, proper disposal is mandatory. Generally, they are either concentrated and contained or diluted and dispersed. In the United States, the plans are for using the former method on all high-level radioactive wastes and burying them in governmentally selected and monitored, safe, deep underground sites. Low-level radioactive wastes are retained until safe levels of radioactivity are reached or are diluted with other wastes and discharged to sewers or streams.

Radioactive wastes may be released to the air, land, or water environments from many varied sources. Some of these include hospitals, power plants, and various industrial laboratories. Its ultimate site for disposal determines—in many cases—the hazard to the environment.

One unusual source of radioactive contamination occurred in several loads of steel construction bars shipped to Arizona from a Mexican plant. The steel was contaminated with Cobalt 60, a human-made radioactive material produced in nuclear reactors. It is also used to treat cancer tumors and in gauging devices. In this case (*Miami Herald* 1984), the steel bars were already in place in several construction sites in Arizona when the radioactivity was discovered. Some bars contained up to 350 millirems/hr; the permissible dosage for U.S. workers in the nuclear industry is 5,000 millirems/yr.

As another step in using underground burial of these wastes, the Department of Energy (1986) named 12 areas in seven states as prime candidates for the nation's second nuclear waste dump, tentatively scheduled for operation shortly after the year 2000. The sites proposed are given in Box 11.1.

Three sites in Nevada, Texas, and Washington State were chosen for the first nuclear waste depository scheduled for construction beginning in about 1996. Important criteria besides the political and social acceptability of these disposal sites are sufficient bedrock formations, ability to withstand earthquakes, and the proper composition to prevent contamination and subsequent escape of groundwater.

As of 1986, about 10,000 metric tons of spent fuel from 98 nuclear power generators is stored in water pools near the reactors.

The nuclear industry is still protected from excess environmental liability by the Price-Anderson Act of 1957. This legislation was intended to spur investment in commercial nuclear power. In recent years, there has been public pressure not to renew this act (Welch 1986). The main argument against the provisions of the act is that it also encouraged recklessness and negligence that may lead to catastrophic disasters.

Under the provisions of the Nuclear Waste Policy Act of 1982, the Public Service Electric and Gas (PSE&G) Company of New Jersey, along with other operations of nuclear plants, has signed fuel-disposal contracts for its nuclear plants with the U.S. Department of Energy. These contracts require the federal government to ultimately take title and provide necessary services to transport, package, and place the spent fuel in underground repositories (Public Service Electric and Gas Co. 1984). Utilities are required to pay a fee of 1 mill per kilowatt-hour of nuclear energy produced to fund the disposal program.

BOX 11.1. Seven Proposed Waste Storage Sites

1. Georgia: Lamar, Monroe, and Upison counties, 214 square miles.
2. Maine: Hancock, Penobscot, and Washington counties, 52 square miles; Androscoggin, Cumberland, and Oxford counties, 385 square miles.
3. Minnesota: Marshall, Pennington, Polk, and Red Lake counties, 300 square miles; Norman and Polk counties, 113 square miles; Benton, Mille Lacs, Morrison, and Sherburne counties, 397 square miles.
4. New Hampshire: Cheshire, Hillsborough, Merrimack, and Sullivan counties, 78 square miles.
5. North Carolina: Franklin, Johnson, and Wake counties, 142 square miles; Buncombe, Haywood, and Madison counties, 105 square miles.
6. Virginia: Bedford, 209 square miles; Halifax and Pittsylvania counties, 307 square miles.
7. Wisconsin: Langlade, Menominee, Marathon, Oconto, Portage, and Shawano counties, 1,094 square miles.

In the case of an "all-out" nuclear war or an accidental drop of a nuclear bomb, the environment (at the least) would become a gross hazard to all living beings. Chemist John Birks (paper presented at A.C.S. meeting, Miami Beach, May 1985) calculated that approximately 200 million tons of chemical-laden smoke would pour into the atmosphere after a widescale nuclear exchange. This smoke, Birks says, would include carcinogenic asbestos fibers released from burning ceiling tiles and asphalt shingles, large amounts of poisonous COs, NOs, and CH_4 from forest fires, and millions of tons of noxious chemicals from the combustion of rubber, plastics, petroleum products, and industrial chemicals.

Biological Wastes

Wastes from decomposing organic foods or bodies of humans or animals represent a hazard to people who make contact with them. The dangers are largely biological, that is, the diseases associated with decomposing organic matter. The infectious diseases can be carried by flies, mosquitoes, and rodents. Nemerow (1984) lists many diseases by these carriers. My main concern in this text is hazardous wastes of a biological nature contributed in hospital wastes. Also of concern since the 1980s are substances that interfere with reproduction (genotoxins). Certain hazardous chemicals can cause low sperm counts, structural sperm abnormalities, testicular cancer, and birth defects (Castleman 1985). Some examples of these chemicals include the following:

Dibromochloropropane (DBCP): temporarily sterilized all men who handled it during manufacturing

Dioxin: severe reproductive deformities in mice and monkeys

birth defects in Vietnamese children whose mothers were exposed to Agent Orange

disease to American soldiers serving in Vietnam exposed to Agent Orange

2, 4, 5T: high rates of miscarriage in women near sprayed areas

DBCP, Kepone, and Dioxin: sterility and other genotoxic effects in mice and rodents and probably humans

Ten antibiotics including penicillin and tetracycline: suppress sperm production temporarily

Tagamet (stress-related drug): reduced sperm counts by 43%

In addition, radioactivity and x-rays have been known to cause both sterility and structural abnormalities in sperm.

Hospital Wastes

Although wastes from hospitals include domestic, contaminated, and special wastes, we are concerned primarily with the pathological waste component. This biological waste is hazardous because of contamination with pathogens. Tubercular lungs are particularly hazardous because of the potential for airborne release of pathogens. The organism *Mycobacterium tuberculosis* has been found especially prevalent and dangerous in these wastes, as have bacteria of *Pasteurella, Brucella,* and *Psittacosis*

groups as well as certain viruses. Surgical and autopsy wastes contain pathogens and present dangers if not handled properly. Other contaminated wastes may also be classed as hazardous because they contain blood, pus, and sputum, which can infect the air with microbiological agents. Some wastes also are contain radioactive, such as C14, Cr51, AU198, I151, Fe50, P32, and Na24. These must be segregated and handled as radioactive. Pathological and contaminated wastes usually comprise less than 10% of the total hospital wastes.

Incineration is the safest method of disposal of these hazardous hospital wastes (Nemerow 1984). However, because this is costly unless done collectively and often includes dangers and malpractices, such systems must be designed and operated with care. Separation of these wastes from other hospital wastes, transportation, and storage must precede proper incineration.

An incidence of improper practice serves to illustrate some of the problems involved with disposing of hospital hazardous wastes ("Incinerator belches foul smoke" 1985). A malodorous pall hung over an area of northwest Dade County, Florida. The source of the odor was Metro Waste Services, Inc., where leak-proof metal containers of infectious hospital waste were trucked in over a gravel path, hauled up a concrete ramp, and fed into a smoky incinerator that even its owner admits is a rust-eaten "piece of junk." The state and county officials have cited the operator, claiming it was not burning the waste completely and that contaminated runoff was seeping into the ground. The two major concerns—even when the incinerator was repaired—were (1) the smoke itself, when it hangs close to the ground and penetrates the building and surrounding area, is obnoxious, and (2) the potential that live organisms could exist in both the smoke and drainage from the stored waste. This situation is typical of many incinerator operators who attempt to burn these wastes on a small scale.

Although high-temperature incineration is conceded by most environmentalists to be the preferred method of hospital waste disposal, inefficient or incomplete combustion of halogenated plastics, bactericides, and hazardous pharmaceuticals may yield toxic dioxin, HCl, and chlorine gas. Doyle et al. (1985) claim that alkaline scrubbing systems can effectively neutralize and remove acid gas and toxic air contaminants. Hospital wastes contain about 20–30% plastics (contrasted with about 5% for municipal wastes) and generally average 7,500–10,000 Btu/lb of heating value (compared to 5,000 Btu/lb municipal refuse). There are many hazardous materials in these wastes that must be considered when incinerating them. Infectious components (~10% of the total) can usually be destroyed completely by proper incineration. However, burning does not destroy inorganic constituents like mercury, some cytotoxic agents used in chemotherapy, and antineoplastic agents. Although dioxin and hydrochloric acid are the major toxic components following incineration, furans and PCBs are also present. Hospital incinerators are usually relatively inefficient in that they operate at lower temperatures and contain shorter stacks than larger commercial or industrial ones.

In addition to hospitals, laboratories, doctor and dentist offices, and small medical treatment centers contribute potentially infectious wastes. These include needles, syringes, gauze, dressing gowns, intravenous tubings, and used blood-storage bags. As

of 1988, 31 states had laws requiring hospitals, at least, to disinfect (steam-sterilize or incinerate) such waste before they bury it in landfills. However, both methods have limitations and, hence, may not be satisfactory. Further, tracing illegally dumped wastes of these types is very difficult. More illegally dumped medical wastes occur today because of the banning of small and scattered amounts in conventional landfills, and burning is costly. However, some companies are working on small disinfection units for individual medical waste suppliers and on incinerators capable of burning these wastes without creating air contamination from gases resulting from plastic burning.

Electron beam treatment has been proposed ("First plant in U.S." 1996) to treat medical waste (as well as domestic sewage and biologically and toxic-contaminated soil). The treatment comprises exposing ("zapping") wastes with electrons accelerated (by about 8 million V) under high-voltage electricity. The electrons that hit the viruses in the "zapper" disrupt atoms and molecules, rendering both bacteria and organics nontoxic immediately. Estimated costs include 7–9 cents/lb for beam treatment plus the cost of residuals disposal in landfills.

Biological Wastes and Other Contaminants

There were 4,742 reports of *Salmonella* sp. infection in Illinois, Michigan, Indiana, Wisconsin, and Iowa according to the Illinois State Inspector General's office during April 1985. At least three deaths were also linked to the outbreak. Salmonella is an infection of the gastrointestinal tract that usually causes cramps, vomiting, diarrhea, and fever. It causes death in 1 of every 1,000 cases, and the ones most at risk are the elderly and children. It is usually caused by contaminated food; in the aforementioned situation, it was traced to contaminated milk from Hillfarm Dairy in suburban Melrose Park, Illinois. Normally, most dairies use pasteurization, a high-temperature heating process, to kill Salmonella and other bacteria. Among the hypotheses put forward to explain the Illinois outbreak were (1) incomplete pasteurization, (2) contamination introduced after pasteurization, (3) heat-resistant Salmonella bacterium, and (4) sabotage.

Viruses growing in polluted waters have been proven to be hazardous to human health even though not ingested directly in drinking water. For example, eating uncooked or even poorly cooked shellfish represents a clear risk ("Eating raw shellfish" 1986) of gastrointestinal tract illness and hepatitis A infection from eating raw or steamed clams and oysters contaminated with viruses or bacteria apparently originating in polluted water. A study reported in the *New England Journal of Medicine* documents 103 outbreaks, in which 1,017 people became ill during 8 months in 1982, and concluded that the illness usually was associated with raw clams or oysters but that there was an "unexpected high attack rate" among people who ate steamed clams that had not been cooked sufficiently.

Nausea, vomiting, diarrhea, or abdominal cramps were the principal ill effects. Closing polluted waters to taking of shellfish is the most effective preventative of this health hazard, but often closing occurs too late to prevent all illnesses. In addition, many shellfish lovers resist ample cooking required to kill viruses.

Asbestos-Laden Wastes

Asbestos is a mineral fiber that has historically been used for insulating and fireproofing in a wide variety of industrial and construction materials and equipment. Asbestos dust can also originate in municipal refuse from discarded auto-brake linings and from demolition wastes. In 1989 the EPA proposed a ban on the use of asbestos in its most common applications, but this was struck down by the courts. Sax (1979) gives excellent examples of uses of asbestos, adapted in Table 11.6.

Asbestos is a health hazard when the microscopic fibers are inhaled or ingested. Exposure can result in asbestosis (a respiratory disease), lung cancer, or mesothelioma (cancer of the lining of the chest or abdominal cavities). Exposure is severely aggravated by smoking. The primary victims of asbestos exposure were World War II shipyard workers who handled large amounts of loose asbestos insulation.

Such practices have been corrected, and protective measures have been implemented. Worker protection is achieved by using inhalation masks, work-zone air monitoring, high-efficiency particulate filters, and moisture-laden air systems during product manufacturing, building demolition, or removal of asbestos-containing building materials.

Treatment of wastes primarily has been by sedimentation and/or filtration of the fibers and landfill disposal. I report using chemical coagulation treatment in Chapter 6 with iron salts or polyelectrolytes followed by filtration to remove better than 99.8% of fibers from water containing 12×10^6 fibers/liter. Disposal of asbestos waste employs landfilling using wet-type operations that eliminate dust.

Asbestos waste is not a listed RCRA waste, but there are many restrictions on its handling and disposal. Asbestos is a hazardous air pollutant under NESHAPS. The Asbestos Hazard Emergency Response Act (AHERA) of 1986 requires the EPA to address the transportation and disposal of asbestos; this has not yet happened. Asbestos is a hazardous substance under the Comprehensive Environmental Response,

TABLE 11.6
Sources of Asbestos Wastes

Hazardous Sources of Asbestos Usage	*Nonhazardous Sources of Asbestos Usage*
1. Thermal lagging and delagging (special risk from "blue" asbestos mainly from steel and power plants)	1. Fillers combined with other ingredients, mainly in linoleum, floor tiles, rubber paints, plastics, adhesives, roofing, and motor assemblies.
2. Furnace insulation, mainly from heavy industry	2. Grinding in assembly of brake and clutch parts
3. Heat and sound insulation, mainly from locomotive, railroad car, boiler, chemical plants, and gas works manufacturing	3. Asbestos washers and gaskets
4. Asbestos-cement sheets and boards of insulation, mainly from building trade plants	

Source: Adapted from Sax (1979).

Compensation, and Liability Act (CERCLA). Thus, generators of asbestos wastes to landfills are subject to CERCLA liability. Finally, a number of states regulate asbestos as hazardous waste or as an air pollutant. These regulations may go beyond federal rules.

Toxic Industrial Wastes

Although hazardous materials are those that are included in all hazard classes, toxic materials are those that cause toxic effects. Therefore, all toxic materials are hazardous, but not all hazardous materials are classed as toxic. These definitions are also verified in this book. While Chapter 11 deals with hazardous materials, it also describes toxic materials and their treatment. Special treatments of toxic materials may also be found in the following section.

Several of the newer chemical industrial plants manufacture organic chemicals for sale to producers of other products discharge some of these wastes to the environment. Many are extremely toxic to aquatic life, animal life, or humans in very small quantities. Most of these chemicals were either unheard of or seldom used 10 to 20 years ago. Few of them were measurable in small concentrations with laboratory scientific equipment until the last 10 years. Even now the long-term potential toxic effects of many of these modern chemicals are unknown. In the following section, I discuss the production effects and treatment of such chemicals as those that are contained in organic-laden wastes, as well as pesticides, pharmaceuticals, and laboratory chemicals.

Organic-Laden Wastes

Chemical plants containing organic chemicals such as PCBs, phenol, formaldehyde, spent solvents, halogens, organic sulfurs and nitrogens, paints and varnish residues, organic acids, dyes and pigments, and explosive and defoliant chemicals are considered in this section. They are so diverse as to defy classification except that they are all organic and potentially toxic.

PCB-Laden Oil/PCB-Containing Wastes

Polychlorinated byphenols originate in transformers and power capacitors, hydraulic fluids, diffusion pump oil, heat transfer applications, plasticizers for many flexible products including printing plates, and numerous other products. The major properties of heat resistance without decomposition and nonflammability are hard to duplicate in other substitute chemicals. Despite this, their use has been banned in the United States for all but transformers and high-voltage capacitors.

Reclass 50, a mobile operation conducted by a two-person crew, can bring a high-voltage transformer from 60,000 to less than 50 ppm faster than any other system (Graham 1985). In this process, the unit is put through three soaking steps over a period of 7–15 months, depending on the transformer size, PCB concentration, and operating temperature. Except for a short period, the transformer remains in service. First, the original askarel is drained and replaced with two flushings of TF-1, a proprietary material, which in turn is replaced with a final soak of silicone. The last step is filling with Carbide's silicone dielectric fluid, which will be used for the remainder of the transformer's service life.

PCBs are oily, colorless organic liquids in the same chemical family as the pesticide DDT. They have been linked to birth defects, reproductive failures, liver problems, skin lesions, cancer, and tumors.

Before 1972 PCBs were used in all nondrying microscopic immersion oils because they possess great stability, and optical properties are still said to be unmatched today.

Cargille (1983), whose company makes PCB-containing chemicals, recommends that customers send used and unused chemicals back to Cargille for reuse. However, a new labeling regulation of the EPA "forcing disposal" hindered this solution.

Fox and Merrick (1983) met PCB-discharge standards of 1.0 ppb by the following three operations and then conventional wastewater treatment:

1. Eliminating discharge into the storm and sanitary sewer system by source control.
2. Rerouting PCB-contaminated wastewater to the existing combined industrial–sanitary conventional treatment plant.
3. Flushing contaminated systems and storing PCB-contaminated oil and debris in tanks before disposal.

Treatment of PCBs has occured primarily by banning their production or use. Where found, they must be recovered and incinerated, pyrolyzed, or reused.

Sunohio developed a PCBX process that chemically destroys PCBs in transformer mineral oil. It is described in some detail in Figure 11.6.

Following the Fullers Earth Dual Filters shown in Figure 11.6, the treated fluid flows through a fourth-stage filter, a vacuum degasser, and a final fifth-stage submicron filter. As the treated fluid flows through the sequence of filters, all the spent reagent and reaction byproducts are removed, yielding a clean reusable fluid with a PCB concentration of less than 2 ppm. The reaction byproducts, spent reagents, and exhausted filter mediums are collected in approved containers, solidified, and disposed of in an appropriate landfill.

According to Sunohio, because PCBX treatment reclassifies transformers and allows for continued use of the oil, capital expenditures are avoided. Faulted transformers can be rebuilt after PCBX treatment instead of disposing of them. PCB oil leaks and spills, which often result in high cleanup costs, operation disruption, extremely adverse public relations, and potential EPA fines, can all be avoided by proper PCB treatment.

Another method of detoxifying PCB wastes—especially those of sludges such as collected in lake or river bottoms—is the fluidized bed combustion process. American Toxic Waste Disposal, Inc., of Waukegan, Illinois, uses this system for the PCB muds dredged from Lake Michigan (*The Amicus Journal* 1985). It involves grinding the sediments into fine particles and forcing hot air ($1,200^{\circ}$ F) through them on a perforated plate of bed until the PCBs vaporize. A cyclone separator and scrubbers then isolate the PCB gases, which are converted to liquid form. Then the PCBs can be either incinerated or adsorbed in activated carbon filters for later disposal in a relatively smaller space than that required for the untreated waste muds. One study, however, found it required

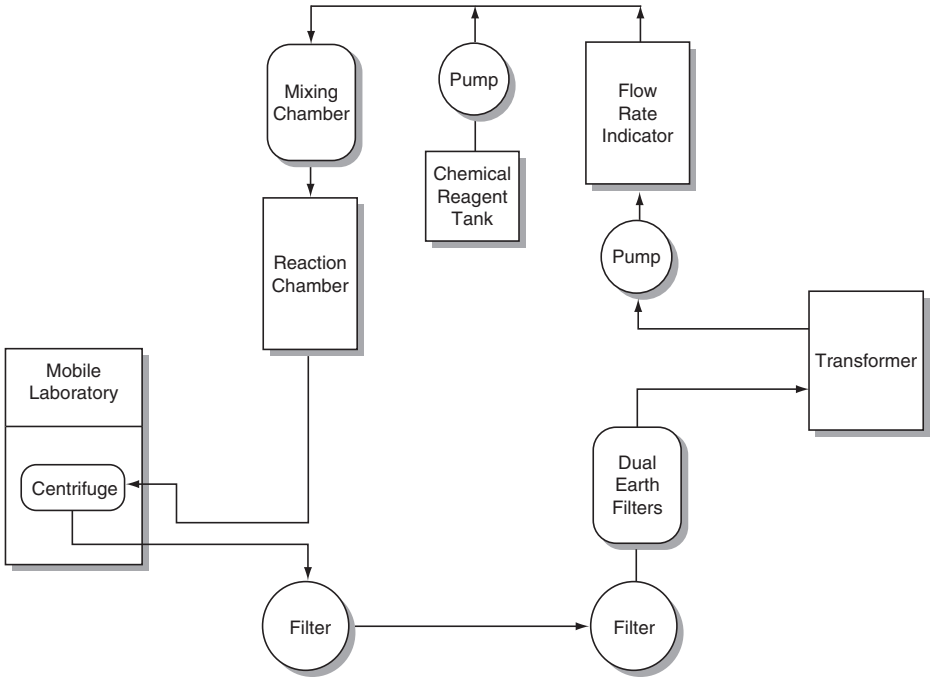


FIGURE 11.6. Mobile PCBX unit.

two-thirds of a barrel of fuel oil to burn each cubic yard of sediment. This represents a significant cost to the reclaimer/disposer.

Phenols and Formaldehydes

Phenol is an acutely toxic chemical containing the benzene ring (C6 H5 OH). In acute poisoning, the main effect is on the central nervous system. Also, absorption from skin contact of phenol may be very rapid and death results from collapse within 30 minutes to several hours. In industry phenols are mainly used or produced in integrated steel mills, synthetic textile mills, and resin (plastic) manufacturing. As early as 1943 (Ohio River Pollution Control-Supplement D), it was acknowledged by technicians that phenol was detrimental to public water supplies in very low concentrations. In higher concentrations, phenols were known to be detrimental to fish life; in fish phenol produces paralysis of the neuromuscular mechanism and hemolyses of the blood.

Phenol and formalin are used as starting chemicals for manufacturing the phenolic-derived resins. The phenolics and formalin, together with catalysts, are fed into an insulated and heated reaction tank. After reacting, draining following water evaporation, and cooling, the resin is used for product manufacturing.

Cooling waters, condensates, and blow-down wastes result in about 7 lb of wastewater per 100 lb of resin. These wastes usually contain high phenol contents (>1,000

ppm) and high biochemical oxygen demand (BOD) (>10,000 ppm). Treatment has been by phenol extraction, lagooning, thermal incineration, and sometimes discharge (and dilution) into municipal sewage systems.

Phenolic wastes, though bactericidal, have been degraded biologically under the proper environmental conditions usually involving bacterial adaptation periods. For example, Zoltek (1984) took groundwater already contaminated with phenols and terpenes allegedly from a nearby plant, which treats wool with coal tar creosote, and contracted for pumping it to the sewage treatment plant. His laboratory results showed the positive action of municipal sewage in degrading these compounds during biological treatment.

Spent Solvents

Organic solvents are used in many chemical industries for assisting in production. Dry-cleaning and paint industries are typical major users of solvents. Solvents used in paint, lacquer, and varnish manufacturing include ketones, aromatics, aliphatics, alcohols, glycol ethers, glycol esters ethers, glycols, glycol esters, terpines, and so on. The solvents aid in keeping pigments dissolved and are eventually evaporated either during the manufacturing process or during product use. Waste solvents discharged following condensation are potentially toxic to receiving waters.

Solvents of the chloromethanes are found in the widespread dry-cleaning industry establishments, as well as in dewaxing of oils, refrigerant preparation, and medicine formulation. Most are made by chlorinating methane in the presence of oxygen and high velocities under a temperature of about 700°F with product recirculation for heating. The exact product obtained can be varied somewhat to satisfy market demand. Where these chemicals are used in sufficient quantities to warrant environmental concerns, they must be collected and treated (usually by an outside contractor) and not discharged untreated to the local air, ground, or water. Treatment is usually by concentration by adsorption and/or incineration.

Dedert (1985) offered a "Supersorbon" process to recover solvents. Hazardous solvents are recovered from the contaminated air in various chemical plants by drawing the air through activated carbon and regenerating the carbon by back-flushing with steam and subsequent decanting off the condensed water, as shown in Figure 11.7. Solvents recovered are toluene, naphtha, lactol spirits, and similar blends of aromatic, aliphatic, and paraffinic hydrocarbon solvents. Acetates, alcohols, ketones, and chlorinated hydrocarbons can be recovered with added steps such as distillation and chemical drying. Claims are made of more than 90% yield of solvent. Some operational data indicate that 2–4 lb of steam, 0.07–0.20 of electricity, and 3–5 gallons of cooling water are required per pound of solvent. In addition, from 1 to 2 lb of activated carbon must be replaced for each ton of recovered solvent.

Another source of solvent turpentine originates from the manufacturing of naval stores. In this industry, shredded wood chips, usually pine, are located in a battery of extractors into which live steam and another solvent—usually naphtha—permeate and added and maintained at about 80 psig (pounds per square inch gage). Most of the naphtha is separated from the turpentine pine oil and rosin in a concentrating evaporator. Some turpentine escapes condensation and/or lost during purification of pine oil and rosin residues.

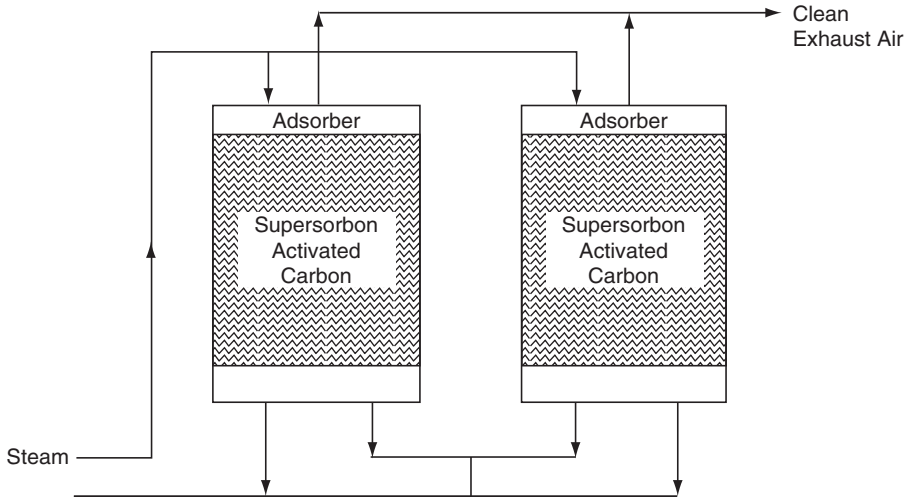


FIGURE 11.7. Supersorbon solvent recovery.

Still another source of solvents such as xylene, benzene, toluene naphthalene, acetylene, ethylene, propylene, and butene is the petrochemical industry. These solvent chemicals are actually derived from coal, oil, or natural gas and are precursors of finished products such as rubber, plastics, and fibers.

By distilling, compressing, fractionating, and reforming natural gas, petroleum, and coal under a variety of specific operating conditions (such as time, temperature, and pressure), these organic chemicals (solvents) are obtained. Inadvertently, some solvent is lost to the environment during the conversion or in the use of them to produce final useful products. Most of these solvents are known to be toxic, and usually carcinogenic, in certain concentrations.

Organic Wastes Containing Halogens, Sulfur, and Nitrogen

A variety of chemical and manufacturing industries produce wastes containing organic halogens, sulfur, and nitrogen. Sometimes they are discharged with other contaminants and difficult to separate, such as the explosives manufacturing plants that produce TNT wastes, and highly acid and colored textile-finishing plants that may use sulfur or azo dyes and produce wastes which are colored alkaline and replete with suspended and colloidal solids. Organic halogens are also produced by disinfection with halogen, usually chlorine, or organic waste residues. For example, chlorobenzene, an important intermediate for sulfur colors and a solvent used to make other products such as aniline, phenol, and chloronitrobenzene, among others, is produced by passing dry chlorine through benzene in iron vessels using ferric chloride as a catalyst and keeping the reaction at 140°F. The same compound could be produced with less efficiency as a result of disinfection of benzene-containing wastewater. In both cases, some chlorobenzene would be wasted into the environment and contribute to toxicity of the medium.

Special Treatments for Hazardous Wastes

In this section, I report, describe, and evaluate the many types of treatment systems being used or suggested for counteracting the negative impact of hazardous wastes on the environment. Although the conventional physical, chemical, and biological systems are covered, I do not go into basics very deeply, as this information can be found elsewhere (Nemerow 1987). On the other hand, I cover more extensively newer more sophisticated treatments that are directed specifically at handling hazardous wastes. For example, waste solidification, regional exchanges, plasmolysis, and recovery and reuse are explained with greater care because of their implications in hazardous wastes filed. Examples are given of treatment of specific hazardous wastes by appropriate methods whenever possible.

General Treatment

Hazardous wastes are incompatible not only with the environment, but also with other more common wastes of industry. Because of the direct and insidious dangers of hazardous wastes, they must be considered separately as infringements upon our normal industrial practices and upon every citizen's right to live and use environmental amenities. Those industrial wastes that burn, corrode, over-react, or are toxic are considered hazardous and are given special priority in treatment preference and type.

Pearce (1983, 57) stated that of the 3.4 million tons of hazardous wastes produced by industry in the United Kingdom, slightly less than 80% is landfilled, while less than 12% is disposed of in the ocean, 3% incinerated, and the remaining 5–6% is treated in other ways.

The EPA (1980) determined that only 10% of the treatment methods used for hazardous wastes are "acceptable." These are detailed in Table 11.7. Van Noordwyk et al. (1980) classified hazardous wastes by quantity generated and disposal method used. Organic chemicals (SIC 2861, 2865, and 2869) were categorized as shown in Table 11.8.

TABLE 11.7
Hazardous Waste Disposal in United States, circa 1980

Disposal Method	*Percent of Total*
Acceptable	
Controlled incineration	6
Secure landfills	2
Recovered	2
Unacceptable	
Unlined surface impoundments	48
Land disposal	30
Uncontrolled incineration	10
Other	2

Source: U.S. EPA (1980).

TABLE 11.8
Organic Chemical Treatment

Method of Treatment	*Quantities On Site*[a]	*(M's/yr) Off Site*
Landfill	483,000	113,000
Incineration	2,250,000	51,000
Controlled	699,000	—
Uncontrolled	1,550,000	—
Deep well	6,540,000	—
Biological treatment or lagoons	565,000	—
Recovery	267,000	
Total	10,100,000	164,000

[a]1977 data, basis.

Nemerow (1984) reported that large quantities of commercial hazardous wastes are collected and treated in the ways presented in Table 11.9. In a National Research Council staff digest (Reducing Hazardous Waste Generation 1985), reported that the RCRA law of 1976 defines as hazardous certain wastes because they may (1) cause or significantly contribute to an increase in mortality or an increase in serious irreversible or incapacitating reversible illness; or (b) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed. It arrived at four general principles that should govern efforts to reduce the generation of hazardous waste.

1. No single approach to encouraging waste reduction will be most effective in all circumstances.
2. Reductions in the generation of hazardous industrial wastes can be expected to occur through a series of loosely defined and overlapping phases. It is desirable to reduce the generation of hazardous wastes.

TABLE 11.9
Commercial Hazardous Waste Disposal Methods

Waste Management	*Capacity Wet, 1,000 Tons per Year, (1981)*	*Volume Received Wet, 1,000 Tons*
Landfill	37,372	1,965
Land treatment and solar evaporation	1,400	282
Chemical treatment	1,305	734
Deep-well injection	1,095	475
Resource (recovery)	341	83
Incineration	102	80
Total handled by nine commercial waste—treatment firms	41,615	3,610

3. The costs of alternative methods of waste disposal should reflect the social costs of protecting public health and the environment.
4. Regulation will continue to play a crucial and central role in the overall waste-management effort, but future waste reduction is more likely to be fostered by nonregulatory methods, such as information dissemination programs and economic incentives.

There are many processes in various stages of development for treating and destroying all types of hazardous wastes. The processes are compiled from response to two national solicitations for new hazardous waste treatment ideas, from several literature reviews, and through contact with experts in the field (Office of Policy, Planning and Evaluation 1985). These processes are summarized in Table 11.10.

Torricelli (1985) informs us that the Office of Technology Assessment cited 26 systems or products that could effectively and permanently destroy toxic sites. Among these, he chose to bring out four: chemical detoxification, biodegradation, encapsulation, and supercritical water oxidation.

Segregation

Segregation involves the removal of hazardous industrial wastes from other process wastes for subsequent special handling. Segregated hazardous waste can either be treated by the industrial plant at its own facility or be picked up by a service company for transporting to a central specially designed treatment plant for hazardous waste.

In the late 1970s, Rollins Environmental Services located in Logan Township, New Jersey, was generally conceded to be the largest waste-processing plant in New Jersey (Civil Engineering 1979). Rollins required information about the nature of the waste so the company can segregate and label wastes for pickup at its plant site. If wastes are not segregated and instead mixed, serious problems could occur. For example, a mixture of chlorinated hydrocarbons and metal sludge waste will corrode clay or plastic liners in landfills (because of the chlorinated hydrocarbons) or release metals to the atmosphere if incinerated (because of heavy metals in sludge).

Location of Facilities

The problem of gaining acceptance for a site for any sort of treatment, including storage, has always been a difficult one for conventional waste treatment. The situation becomes even more sensitive and one faces public objections even at the mere mention of "toxic" or "hazardous" waste. An ideal site where no people live but which is situated near suppliers does not exist in reality. Any site will take a great deal of time, patience, and tact in gaining its acceptance for use as a location for storing, treating, and/or disposing of hazardous waste.

Treatment Required-Risk Evaluation

The type and extent of hazardous waste treatment required for protection of the environment is related to the amount of risk one is prepared to accept. An acceptable

TABLE 11.10
Emerging Alternative Technologies, circa 1985 (From Assessment of Incineration)

Technology and Description	*Suitable Wastes*	*Capacity per Unit of Time*	*Cost per Unit of Waste*	*Environmental Data*	*Commercial Status*
Wet air oxidation: —Process of oxidizing organic compounds in water at temperatures of 350–650°F	Very dilute organic and inorganic aqueous waste except highly refractory organics	10 gal/min	5–10 cents a gallon for 10-gallon system Costs for larger system not available	Limited data available EPA currently evaluating a unit on cyanide, sulfides, and nonhalogenated waste	Technology currently available Widespread use expected in next 2 years on aqueous waste
Molten glass incineration: —High temperature in furnace (2,300°F) destroys organic waste streams —Combustion gases pass through ceramic filters —Glass slag encapsulates inorganic residues	Any combustible waste Degree of halogenation not a consideration Scrubbers required for HCL	Existing glass manufacturing process 100–21,000 lb/hr	Cost figures not available	Data not available Testing needed Ceramic tiles and residue encapsulation in slag indicate minimal impact	Not reported
Supercritical water: —Inorganics, insoluble in supercritical water, are removed from waste streams —Organics rapidly oxidized	Aqueous waste streams with high levels of inorganics and toxic organics Treatment of highly halogenated material not yet demonstrated	Currently treats 1,000–2,000 gal/day	Cost figures not available	Bench-scale test on various wastes indicates DREs of 98.5–99.8%	Commercial scale units will be available in 1–3 years

High-temperature electric reactor: —Two companies: Thagard Research Huber Corporation —Vertical reactor heated by electrodes implanted in walls to pyrolize organic wastes	Process initially designed for solid waste Also suitable for liquid refractory waste streams	75–125 lbs of solids per hour No figures available for liquids, but it is assumed throughput would be less	Cost information not available Huber claims cost comparable to conventional incineration	DREs far in excess of the 99.99% RCRA requirement	Mid-summer 1985
Molten salt reactor: —Burning and scrubbing (900˚C) oxidize carbons of organic matter to carbon dioxide and water —Byproducts (phosphorus, arsenic, sulfur, halogens) retained in melt as inorganic salt	Designed for solid and liquid waste Especially applicable to highly toxic and halogenated combustible waste with low percentage of ash	Pilot-scale facility processes 80–200 lb/hr	Cost data not available	No emissions; organic salts are the only byproduct DREs for organics, pesticides, and chemical warfare agents 99.99–99.99999%	Currently available for commercial use but none operating on that scale to date
Plasma arc: —Uses high temperature of plasma (50,000˚F) to destroy hazardous waste —All hardware in 45-ft mobile trailer	Highly toxic liquid waste streams Degree of halogenation not a consideration	600 lb/hr in commercially sized unit	Cost data not available	Current demonstration in New York State will provide data on DREs and emissions	Commercial scale unit to be operating in 1–3 years

risk depends not only on the cost of protection involved, but also on who will be required to pay for the environmental protection. Such risk analysis becomes simpler if the cost is borne directly by the one who will benefit from the treatment protection. In matters pertaining to hazardous waste treatment, however, it is more likely that industry will be required to pay for protecting an environment and its users that are far removed from the industry itself. Economists refer to such situations as "external dis-economies."

Even when governments are forced to grant funds for such expenditures to protect certain people specifically involved, they are somewhat reluctant to do so. Beneficiaries of governmental actions and expenditures on hazardous waste are difficult to identify and the effects are difficult to quantify.

For years the most acceptable practice of risk analysis and evaluation has been the use of cost–benefit relationships. That is, there must be a dollar benefit for every dollar spent to protect the environment from the adverse effects of hazardous wastes. With these wastes, costs are not only huge, but also difficult to predict reliably. Benefits are even more troublesome to quantify because they usually relate to human health, the quality of life, and even a value of human life itself. Costs and benefits often can be manipulated by the person or group presenting the case for or against remedial action depending on personal goals.

One device reported by Douglas Ginsburg (Shabecoff 1985), administrator for information and regulator affairs at the Office of Management and Budget, is to "try to guide and question and kibitz the process to get as much risk reduction as possible for the expenditure." This procedure is laudatory but is still highly subjective and will vary from one person to another and one case to another. What is needed is a dependable consistent objective method. Perhaps it might be better to state publicly that we will seek the maximum risk prevention that the public will buy, or that any environmental risk is too great to accept where hazardous wastes and people are involved. We have almost done this where the operation of nuclear power plants is concerned.

However, as Shabecoff (1985) points out, "There is no consensus on what society is willing to pay to avoid risk." For example, a life saved has been valued at various amounts ranging from $400,000 to $7.5 million. Much lower life values have been set where many lives are involved. For example, each life lost in the Bhopal accident has been valued at only $30,000 by a preliminary offer of settlement.

The administrator of the EPA (1985), Lee Thomas, was quoted as suggesting that "we are a long way from the point at which decisions can or should be made by mechanistic application of any acceptable risk or cost 'criterion.'" However, your author still believes that the public would benefit more from an established, open, scientific process for risk evaluation even if it was not perfect and always open to some debate. At least its parameters would be known and its values could be seen and evaluated by both violators and recipients of hazardous waste effects.

Dr. Steven Kelman of Harvard University believes that "we should hold the government responsible not for a risk-free society, but for a higher standard of behavior than people hold themselves" (Shabecoff 1985). This is probably because each person's chance of death or disease is less than that of government, which represent more people.

Unfortunately, governments seldom make decisions and laws in a vacuum and are usually influenced largely by individuals and their lobbyists. Therefore, government's decisions may appear to benefit certain individuals or groups rather than society as a whole. This fact is yet another reason and argument for objective risk–benefit procedures rather than subjective ones.

Land Treatment

The use of vacant land as a receptacle for hazardous waste is recommended only when the land can be upgraded from its previous use and when no additional adverse environmental consequence results. Qualifying lands should be far away from underground water supplies and residential communities where odors percolate or contact with hazardous gases, liquids, or drying solids might take place. Because these ideal conditions seldom are found, we suggest underlying the entire land area with an impermeable membrane to prevent leachate from entering the water supply. Leachate should be collected and treated, especially for heavy metals and toxic organics such as those originating from pesticides.

Land reuse for parking facilities and one-storied warehouse or parks are examples of upgraded uses following proper disposal of hazardous wastes.

Whenever possible, hazardous wastes—usually after some form of pretreatment—are returned to lands that are compatible with the residues. For example, many lands are low lying and unusable in their present condition. Such lands could be used as receptacles for such wastes. Sundaresan et al. (United Nations Environmental Protection 1983) states that DDT wastes are neutralized with lime and the lime sludge dumped in low-lying areas of land.

The Japanese are mixing solid wastes, excavated earth, gravel, and sludge, as well as ash from incineration plants to form a source of new land ("Land-poor but trash rich" 1986). They haul the mixture to Tokyo Bay where it is placed and has already served as real estate for Haneda Airport and Tokyo Disneyland, an oil terminal port, a power plant, an apartment complex with 4,500 units, an industrial park, and even a sewage-treatment plant. Of course, the competition for space has caused obstacles with other users of the bay. Shellfish have been reported to have been killed by the change in habitat caused by the newly created land, but the pressures upon their society for "living room" have dictated reuse of solid wastes and a change in the environment.

Thermal Treatment

Heating hazardous wastes to some elevated temperature can cause changes in the physical, chemical, and biological nature of some wastes and render them innocuous. This treatment is not to be confused with complete burning in the presence of excess air, as in incineration (Figure 11.8).

Perhaps one of the most promising and used thermal process is pyrolysis, which involves burning residue at about 900°C in the absence of air. The process has been used in the chemical industry and is often called "destruction distillation." It has been used for treating municipal refuse with the production of several byproducts

such as light oil, gas, ammonium sulfate, and tar, as well as solid waste residue. The gas energy is usually more than ample to supply the heat for pyrolysis. Whether pyrolysis of a hazardous waste will be effective in destroying the toxicity has not been fully resolved.

Should an industrial hazardous waste be organic and easily decomposable at relatively low (<900˚C) temperatures and yielding nontoxic products, pyrolysis may be a reasonably effective treatment process.

One form of thermal treatment is called "plasma technology." It developed from knowledge obtained from space-flight research, which required superelevated laboratory temperature to simulate spaceship nosecone reentry conditions. Electrical energy (high voltage) is converted with high (85–90%) efficiency to heat energy. One such process of plasma technology developed by SKF Steel Company (Herlitz 1983) recovers iron, zinc, and lead from steel mill bag-house dust. Without previous sintering, Herlitz reported that the fine material is pneumatically injected with coal powder into the lower part of a coke-filled shaft furnace provided with plasma generators where the material is injected. The oxides are instantaneously reduced, and liquid and gaseous metals are formed. The gases are extracted in a normal condenser. One such plant to produce 97% liquid iron, zinc, and lead from 80,000 tons of this dust per year was commissioned in Sweden in mid-1984. The process appears feasible for other solid wastes containing otherwise hazardous waste metals.

Another form of thermal treatment described by Worthy (1982) in the pilot-plant stage is the "molten salt process." He described a reactor tank that contains a constantly moving bed of molten sodium carbonate. The movement is maintained by a constant

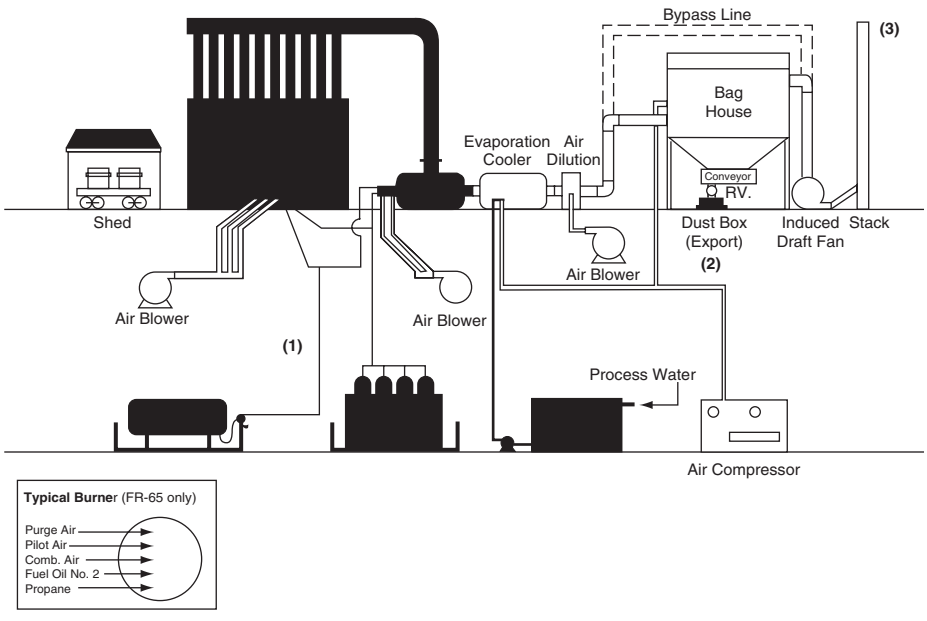


FIGURE 11.8. Thermal decontamination process flow diagram.

supply of wastes and air being fed beneath the melt surface, which is maintained at temperatures of between 750˚C and 1,000˚C. Destruction efficiencies are reported from bench-scale studies to be more than 99.99% for several organic hazardous wastes including toxic chemicals used in warfare, pesticides, and PCBs. This process is being developed by Rockwell International.

Worthy (1982) also reveals that the Thagard Research Corporation has reported developing a high-temperature fluid wall-type reactor. It consists of a tubular core of porous refractory carbon, which is externally heated by carbon electrodes to give off ample radiant energy.

This energy activates reactants (wastes) that descend through the tube. Radiant energy provides rapid and immediate heating of the contaminating reactants. Gas of an inert type (usually nitrogen) circulates around the porous core, which reduces contact of the reactants with the wall and prolongs the life of the core. Temperatures above 2,200˚C are reported in the reactor.

Worthy (1982) reported developing a fluidized bed turbulence to promote combustion of hazardous organic contaminants. It is based on the principle that in supercritical water (374˚C and 218 atmospheres), certain insoluble organic compounds become highly soluble and complex organics are converted to low-molecular-weight compounds. When these resultant products are reacted with oxygen, hydrogen, and carbon, they are rapidly oxidized, and halogen, phosphorous, sulfur, and metals form insoluble salts and settle out. A nonhazardous stream of supercritical water (500˚C and 252 atmospheres) is used directly for process heat or indirectly to drive turbines for generating power. In bench-scale studies, such toxic organics as chlorobenzenes, DDT, and PCB, as well as chlorinated ethanes have been destroyed.

ENELCO/Von Roll Environmental Elements Corporation (1984) uses a process of thermal destruction for disposing of industrial wastes. It is essentially a modernization of older incineration systems under highly controlled conditions. Control of the waste-combustion process involves accounting for the waste heat content and oxidation rate of each waste and then scheduling the mixing and feed rate of the waste so that the combustion heat release is reasonably constant. Pumpable waste is injected by its system at a predetermined rate resulting in a constant release of heat. Batch-fed waste, injected at predetermined regular intervals, releases additional heat, and because of the nature of the batch-feed process, this heat release will not be constant. Of the 23 Von Roll industrial waste disposal plants in operation, four are regional hazardous waste disposal plants. One serves Nyborg, Denmark, and can handle more than 60,000 metric tons of solvent, chemical byproducts, resins, paint and varnish residues, waste oil, plastics, halogenated hydrocarbons, and inorganic sludges and wastewaters totaling 1,200 metric tons/wk. The waste can be fed directly in steel drums. Kiln discharges of molten slag and flue gases generate steam to provide most of the heating requirements of the town of Nyborg. Recoverable materials are sold.

DuPont Company has provided a hazardous waste service since 1975 by thermal decontamination. It uses a furnace temperature of 600–750˚C and is claimed by DuPont to be the largest furnace in the world. Three sources of residual waste form this process (Figure 11.8) and include residual furnace noncombustibles (carted away to a smelter), bag-house solids to landfills, and stack gases discharged to upper air.

Incineration

Incineration is a high-temperature burning process whereby combustible wastes are reduced to inert residues (ashes). Incineration provides an economical nuisance-free clean method of ultimately disposing of municipal refuse. However, gases and residual ashes remain potential sources of pollution. In addition, when hazardous chemicals or materials are also incinerated, their combustion products must be evaluated to ensure that toxicity has been removed by the burning.

Incineration takes place in a furnace consisting of an enclosed refractory-lined structure equipped with grates and supplied with excess amounts of air in which the burning takes place (see Chapter 9 for more details). Temperatures in the furnace approximate 1,750˚F. The combustion chamber is an enclosed refractory-lined structure, sometimes combined with the furnace, in which more complete burning of residual fly-ash material and gaseous materials occurs. Following this is a "subsidence chamber," a large insulated chamber allowing the combustion gases to expand and reduce their velocity during which particles can settle prior to gas emission to the chimney (stack).

Fly-ash should be prevented from reaching outside air environment by settling and/or filtration and sometimes scrubbers. This collected ash can be combined with the residual grate-ash for final landfill or reuse in making other materials, such as bricks or cement blocks. The amount of residual ash depends primarily on the composition of the original hazardous waste, exit gas velocity, and fly-ash removal systems. Some of the fly-ash may contain unburned organic matter and must be tested further for residual toxicity before ultimate discharge. If residual toxicity remains, furnace temperatures may have to be increased, gas velocities reduced, or detention time increased in the combustion chamber, or all three used to reduce the discharge of toxic materials.

Final capital costs and operating costs may be relatively high as compared to other techniques. Therefore, design and operating conditions must be carefully controlled. Generally, we recommend both laboratory and pilot-plant experimental burning to obtain proper design and operating procedures.

For coastal producers of toxic wastes, land incinerators may be dangerous to inhabitants of those areas. In these cases, incineration on ships on the ocean can serve to eliminate potential land air pollution.

Waste Management Company (Chicago, Illinois) has converted a cargo ship, the *Vulcanus,* to an ocean-going incinerator. The company proposes to burn 3.6 million gallons of highly toxic PCB wastes on the high seas in the Gulf of Mexico.

Ship incineration has been purported to disperse acid wastes directly into the ocean, thereby avoiding costly scrubbing. Water, carbon dioxide, and vaporous hydrochloric acid falls out into the ocean within a short distance from the ship. Safe collection and transportation of these toxic wastes to the ship could be a major problem. Any accident involving the incinerator ship during its travel to the burning site could result in major environmental damage.

LeRoy (1983) reports incinerator capacity in France for burning 260,000 tons of hazardous waste per year including phenolated water, hydrocarbons, and chlorinated waste. He acknowledges relatively high costs for incineration of these wastes because of (1) technological complexity, (2) operating difficulties, and (3) the need to purify gas and smoke.

Freeman (1981) limits hazardous waste incinerators to two types: liquid injection and rotary kiln systems. In the former, liquid wastes are fed along with support fuel and air for combustion into the incinerator, which is maintained at 820–1,600˚C. Similar temperatures are also used in the latter rotary kilns, which handle large volumes of both solid and liquid wastes. Selection of the proper type of incineration and for the proper reasons is imperative. Freeman (1981) presents tables of advantages and disadvantages of the two types of incinerators (summarized in Table 11.11).

Noland (1984) demonstrated that a "transportable" incineration system could be disassembled, transported approximately 1,000 miles, be reassembled, and fully operational within 2 weeks. He reports destruction of "pink-water" explosive plant waste by incineration of more than 99.99% (based on primary kiln ash analyses), no detectable explosive wastes in the stack gas, and stack emissions were in compliance with all federal and state regulations (including SO_2, HCl, nitrogen oxides [NOx] CO, and particulates).

TABLE 11.11
Incineration

Rotary Kiln Liquid Injection	
Advantages	*Disadvantages*
Can be used for a wide variety of both liquids and solids (mixed or separate)	High capital costs for installation especially when using low feed rates
No problem when melt occurs	Careful operation in order not to damage refractory
Drums or bulk containers with various feeds are used	Airborne gases or particles may exit prior to complete oxidation
Good mixing and air for solids	Spherical or cylindrical solids may pass through faster and avoid complete burning
Continuous ash removal does not interfere with burning	Excess air required due to leaks, which lowers fuel efficiency
No moving parts in kiln.	If drying grates are used prior to kiln they may become plugged with heat
Wet scrubber can be added	High particulate loadings
Rotational speed of kiln can be varied to control residence time in burning	Relatively low thermal efficiency
No preheating, mixing needed	Liquid must be able to be atomized
Can be operated at very high temperatures of 1,400˚C to ensure destruction of toxic chemicals	Liquid must be heated sufficiently or supplemental fuel added
Able to handle a broad range of liquids.	Must be capable of complete combustion without flames hitting refractory
No ash removal needed from incinerator bottom	Liquid waste may clog burner nozzles
Can handle small amounts of liquids	Requires sophisticated instrumentation
Responds fast to waste temperature changes	
Almost no moving parts	
Low maintenance	

Source: Adapted from Freeman 1981

The EPA concluded (1985) that (1) incineration, whether at sea or on land, is a valuable and environmentally sound treatment option for destroying liquid hazardous wastes, particularly when compared to land disposal options now available, and (2) there is no clear preference for ocean or land incineration in terms of risks to human health and the environment.

Incineration at sea represents a potential solution to counteract the objections of people because of environmental land pollution. On November 27, 1985, the EPA gave tentative approval to a hazardous waste burning trail aboard ship at sea (Taylor 1985; Shabecoff 1985). The test of burning about 700,000 gallons of PCBs and perhaps dioxin took place in the spring of 1986 aboard a Chemical Waste Management ship in the Atlantic Ocean, 140 miles east of the mouth of Delaware Bay. The company provided $60 million in financial guarantees to cover a possible accident during the test burn. The entire test burn cost about $1.8 million. The wastes will be transported by railroad from a landfill in Emile, Alabama, and loaded aboard the ship in Philadelphia. Therefore, the hazards of storage and transportation described in the section "Other Oily Wastes" (earlier in this chapter) prevail also in this potential method of disposal.

Cheremisinoff (1988) recommends that "high temperature processes for specific applications should be particularly considered where available land is scarce, stringent requirements for land disposal exist, destruction of toxic materials is required, or the potential exists for energy recovery. He lists seven potential advantages and considerations of high-temperature processes: (1) maximum volume reduction, which reduces ultimate disposal requirements; (2) detoxification, which destroys or reduces toxics; (3) energy recovery from combustion of waste products; (4) costs, which are generally higher than for other disposal alternates (these are hardly advantages of high-temperature treatment but seem valid); (5) operating problems create high-maintenance requirements (once again, not an advantage but an important consideration); (6) personnel required are highly skilled and experienced; and (7) environmental impacts can result if air and solid effluents are not included in the treatment scheme.

The IIT Research Institute offers a new hazardous waste treatment process that essentially uses high temperature as the treatment vehicle. It is accomplished by inserting tubular electrodes into organic-laden landfills. Radiofrequency energy charges the electrodes to heat the soil to 200–1,000°F. The vaporized hazardous pollutants are collected in the same tubular pipes and evacuated to a separate vapor treatment system.

In August 1996 the U.S. Army (Mims 1996) began the systematic incineration of hazardous chemical weapons containing nerve and blister agents. The Army claims this is a "safe and secure way" of eliminating some 30,000 tons of weapon agents. The incineration activity at the Tooele, Utah, plant was expected to take several years.

At Tooele, where the weapons are stored in 208 earth-covered concrete bunkers, 1,500 leaks have been reported since 1967 (Nemerow 1974). The 6,000 tons of chemical weapons at Tooele were left over from the World War II–era stockpile and include nerve gas, sarin, three kinds of mustard agents, five kinds of nerve agents, and the blister agent lewisite. The incinerator used to destroy these hazardous wastes contains automated equipment that punches holes in the weapons, drains the chemicals, and sends/transports them to five furnaces where they are incinerated at 2,700°F. Problems

with this type of disposal arise from the potential of releasing cancer-causing dioxin (formed during the incineration process), as well as accidental breakdown in the plant, which would release toxic chemicals to the environment and surrounding population.

The release to the atmosphere of hydrocarbons, particularly chlorinated and fluoridated hydrocarbons from chemical plants, petrochemical plants, and oil refineries, continues to be a problem. At present there is no "practical" way to measure these emissions except through mass balance calculations, which are less than precise. Thermatrix, Inc., of San Jose, California, has been installing its flameless thermal oxidation technology at plants throughout the United States and in Europe and Asia. Installations include petroleum, chemical/petrochemical, pharmaceutical, and pulp and paper industries, as well as PCB cleanup. Units have also been employed in soil and groundwater remediation applications. This technology ("Make polluters pay" 1995; Agardy and Wilcox 1990), evolving from early investigations into oil shale recovery, has proven to be a "complete solution technology" in that no measurable residuals appear in the effluent stream. Typical destruction removal efficiencies exceed 99.99%, with di minimis formation of nitrogen oxides (NOx), carbon monoxide, and products of incomplete combustion (PICs), partially as a result of the thermal destruction taking place at temperatures generally below 1,800°F. In addition, NOx emissions rarely exceed 2 ppm. Not only has this technology demonstrated wide-scale applicability, but it uses considerably less energy than other typically employed incinerator technologies and, depending on the Btu content of the waste stream, can and does have a heat-recovery capability. Figures 11.9 and 11.10 show unit/assembly schematics, while Figures 11.11 and 11.12 show typical system installations.

Chemical, Physical, and Biological Treatments

Chemical, physical, and biological treatments are designed purposely to render the industrial hazardous wastes free from toxic chemicals and materials.

Chemical treatment aims at removing smaller elements of toxic nature, generally dissolved or colloidal solids. In cases where removal of toxic dissolved organic solids is the objective, chemicals used are powerful oxidizing agents such as chlorine, potassium dichromate, or ozone. The oxidation proceeds rapidly, depending on the concentration of organic matter and amount and contact time of oxidant used. End products are usually harmless gases such as carbon dioxide, nitrogen, and water. This type of treatment is costly because of the continuous consumption of oxidizing chemicals and detention time involved. The advantage of using this process and especially chlorination is that any harmful bacteria and/or viruses present are also killed. Photolysis is another form of chemical oxidation that destroys organic matter to carbon dioxide and water. Certain heavy metal oxides, notably zinc oxide and titanium dioxide, are photocatalytic and, in the presence of dissolved oxygen matter and beach sand, when irradiated, will decompose the organics by about 75% in 3 days.

Chemical treatment aimed at removing the larger colloidal solids is known as *chemical coagulation*. This is a process of destabilizing the colloids, aggregating them, and binding them for ease of sedimentation. It involves the use of chemical flocs, which absorb, entrap, or otherwise coalesce suspended matter that is too finely divided or

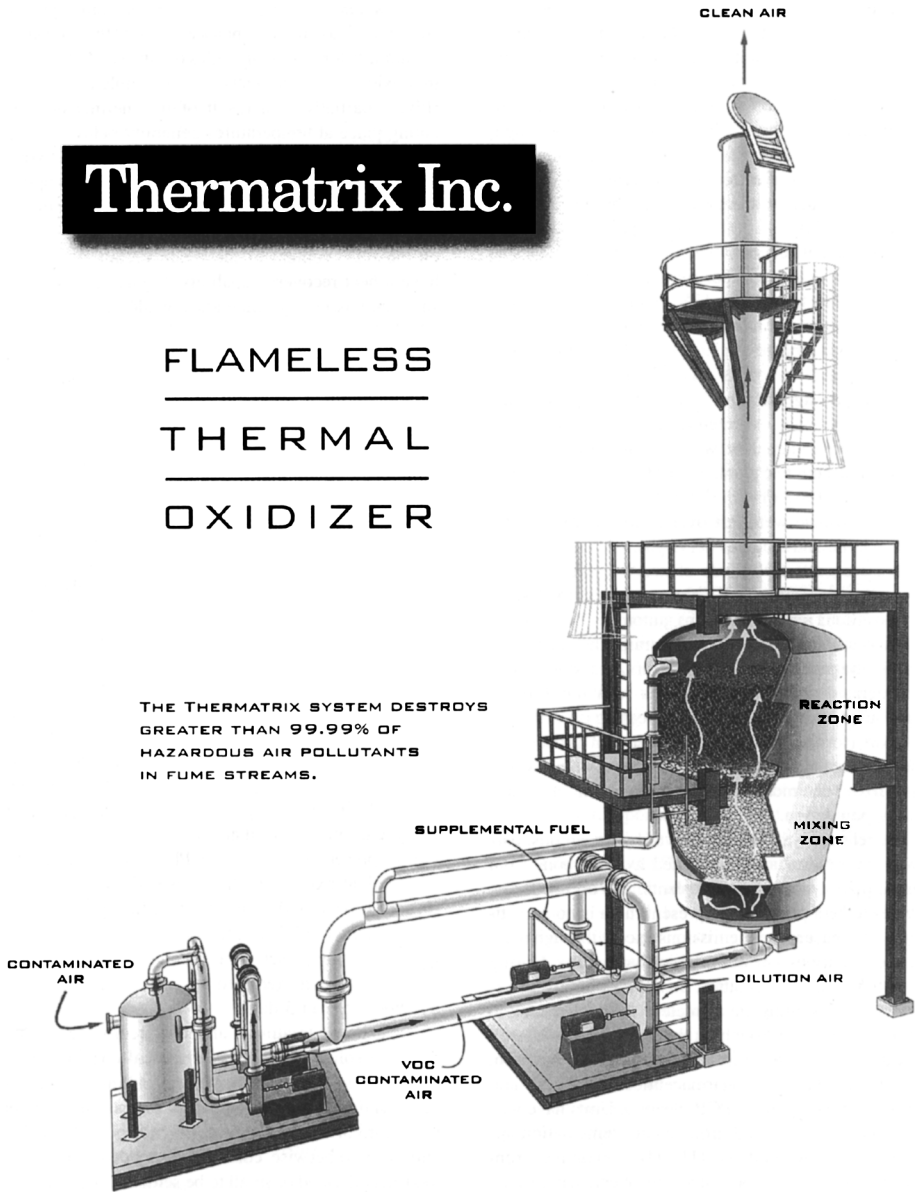


FIGURE 11.9. Flameless thermal oxidizer. Used with permission from John Wiley and Sons.

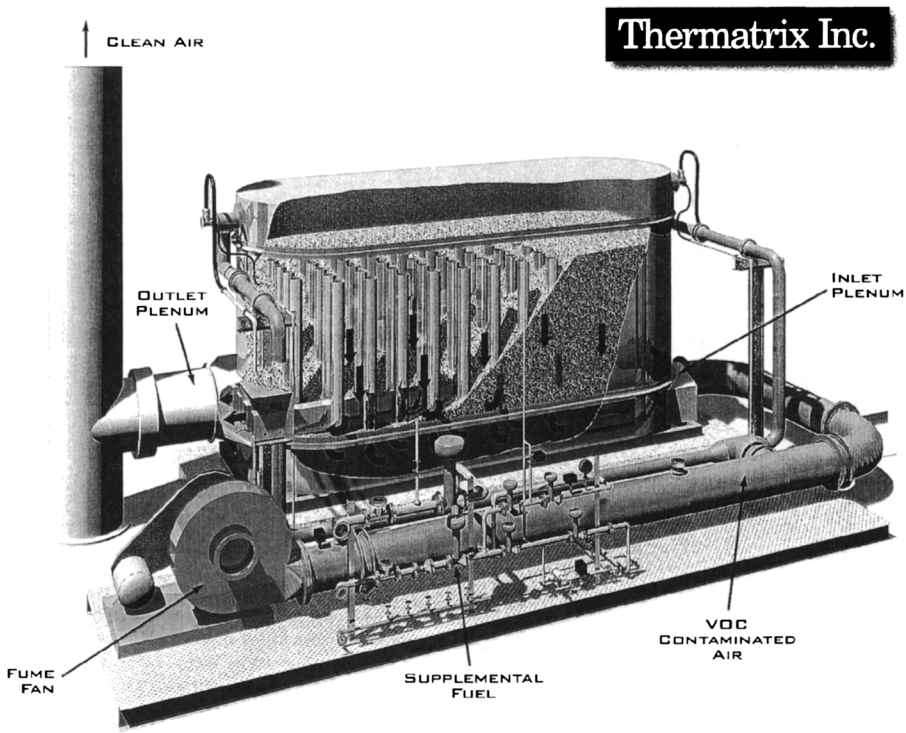


FIGURE 11.10. Typical system. Used with permission from John Wiley and Sons.

small to be settled alone. The chemicals most widely used are alum ($Al_2[SO_4]_3$) and ferric sulfate ($Fe_2(SO_4)_3$) (for theories of this treatment, see Chapter 5).

Physical treatment of hazardous materials in industrial wastes include: (1) settling; (2) filtration; (3) adsorption or absorption; and (4) flotation (refer to Chapter 5 for theories of these treatments).

The removal of dissolved organic matter by *biological* means has long proven successful in the treatment of domestic sewage and certain industrial wastes. Adapted cultures of microorganisms are placed in contact with dissolved organic matter of these wastes under the proper environmental conditions of oxygen, temperature, and pH. Organic matter is adsorbed and decomposed by the bacteria involved to yield carbon dioxide and water and some cell growth matter. The cell growth matter is later settled out and a portion returned to the process for biological enhancement, the remainder wasted and treated as sludge for ultimate disposal.

Some hazardous chemicals such as phenol from coking plants or synthetic textile mills can be degraded by certain adapted microorganisms to yield harmless end products. Efficiency of biological degradation depends on adaptation of the microorganisms,

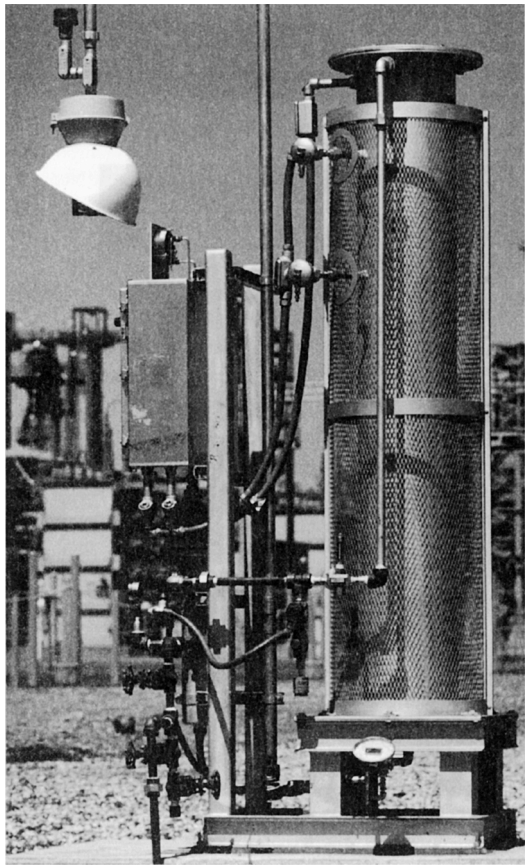


FIGURE 11.11. Typical system. Used with permission from John Wiley and Sons.

contact time, oxygen available, and the proper environmental conditions. In actual practice, two types of biological pass the waste over a fixed surface containing the microorganisms and allowing permeation of air at the surfaces as well. There are many variations of each process in existence today (refer to Chapter 8 for these variations).

Zoltek (1984) successfully used biological treatment at an existing sewage treatment plant to digest groundwater contaminated with phenolic compounds from an old pine tar plant.

Flathman and Githens (1985) cleaned up a soil and groundwater spill of isopropanol, acetone, and tetrahydrofuran by a combination of biological and physical techniques. These resulted in 90% removal of IPA and THF within 3 weeks. Acetone, an intermediate oxidation product of IPA metabolism, was removed by the end of the sixth week. The spill originated from several buried tanks that leaked contents into a 12-ft basin of sand and pea gravel.

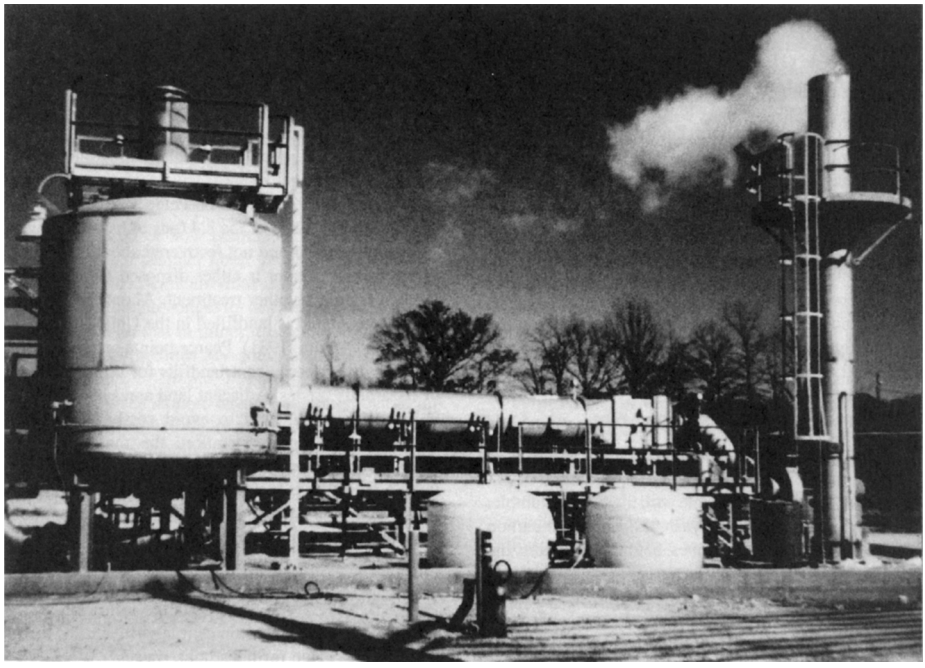


FIGURE 11.12. An installation. Used with permission from John Wiley and Sons.

Neutralization

Because excessive acid (low pH) or alkaline (high pH) in industrial wastes is considered toxic, neutralization before discharge into the environment is a must. In addition, neutralization is usually considered desirable prior to most forms of biological treatment should the wastes contain large quantities of biodegradable organic matter as well. Eight major methods of neutralization of either acid or alkaline wastes are described in Chapter 3. Your author suggests defining the titration curve of the potentially toxic industrial waste. This will allow the polluter to determine the exact quantity of neutralizing agent required to obtain any amount of neutralization obtained. Then the polluter is in a position to decide whether what amount of neutralization is cost effective. In order to do this, one must also determine the damage costs involved in non-neutralization of the wastes.

Underground Injection

In locations where the subterranean environment is suitable, it is possible to inject potentially hazardous wastes underground. Deep-well injection has been used to dispose of organic solutions from refinery petrochemical, chemical, paper, and

pharmaceutical plants. The ultimate fate of the hazardous waste should be ascertained prior to selecting this method of disposal. The acceptable waste should be free from suspended or clogging solids and material that will react adversely with the substrata into which it is being injected. The suitable underground environment should be permeable to a point of final residence and isolated there from any potential water resource. Chapter 7 describes these details.

To determine the suitability of the underground, a well is drilled and various depth core samples are analyzed for specific characteristics relating to its permeability and reactivity with the waste. Tests will also confirm the injection pressure required at various waste flow rates. Underground soils may be treated to improve permeability to reduce the injection pressure required.

The discharger must be aware of the dangers of (1) contaminating potable water supplies by lateral migration of the hazardous waste or even by vertical migration though open subsurfaces or mechanically failed soil structures, and (2) causing movement of geological faults leading to potential earthquakes in the area. In this case, the waste acts as a lubricant between two adjacent underground slabs of faulted rock causing them to move apart more easily.

Land Farming

The filling in of farming land with stabilized hazardous waste sludge is sometimes used as a disposal/utilization technique. Only in cases where the harvestable cover crop is not harmed by the sludge or is not used as a food material is this method acceptable. These constraints limit the use of this method for most hazardous wastes. However, in situations where flammable or ignitable wastes are involved, this method may be feasible. In this case the oils and other associated organic matter may be decomposed by soil bacteria using the matter for food and enhancing the surface cover crop growth. Bacterial/viral-contaminated waste sludge may also be landfarmed in certain instances where the cover crop will not be harvested in the near future. This may give ample time for the bacteria/virus to become inactivated. Stabilized and/or solidified hazardous waste may also be landfarmed in certain instances where the waste serves primarily as a soil stabilizer and a preventer of leaching into groundwater.

One type of industrial waste being landfilled is that from the construction industry. It is common practice to bury construction demolition and other debris such as damaged tree limbs, damaged plywood, wood forms, old concrete blocks and bricks, and so on. These materials may slowly be broken down under the ground without interfering with growing surface crops. A land cultivation report (EPA 1978) states that 3% of all industrial waste can be disposed of by land cultivation. They found that the amount of industrial solid waste disposed of by this process was limited by soil texture, drainage, permeability, and the waste pH, bulk density, soluble salt and metal concentration, and nitrogen and phosphorous contents. Costs for this process vary widely from \$2–\$18/m^3 of industrial waste. Transportation costs must be added to this amount.

Bahorsky (1983) concludes that land application of textile wastes can be less expensive in capital extended aeration systems, less expensive to operate, requires less

training, produce no sludge problems, be significantly less energy intensive, and give consistently high-quality effluents. However, he makes no recommendation that the land be reused subsequently for farming. It does seem possible to farm on this land after a certain period of waste treatment.

Disposal in Natural Storage Areas

A commonly recommended solution to the disposal of hazardous wastes is to return them to their natural origin or to areas of the land compatible with them. For example, coal overburden and fly ash and unburned carbon could be returned to coal mines before renovating the natural land.

Sundaresan et al. (United Nations Environmental Protection 1983) recommend returning neutralized, precipitate, and de-watered lime sludge from titanium dioxide wastes to abandoned ilemenite mines.

Permanent Landfills

In some cases, hazardous wastes are disposed of either with or without some form of pretreatment storage. Naturally many precautions must be taken in using this technique. Most important of these include the security of the waste in the landfill; it must not be reached from the surface of the land and it must not escape into surface or underground water supplies.

One such use is described by Sundaresan et al. (United Nations Environmental Protection 1983) for disposing of carbamate pesticide wastes. After neutralization as a pretreatment, the wastewater is solar evaporated in polyethylene-lined ponds. The resulting lime sludge from neutralization is disposed of as landfill. The authors state that because the sludge may contain carbamates, "adequate safeguards have to be taken." Presumably this means sealing the sludge in a permanent landfill.

LeRoy (1983) acknowledges that because all hazardous wastes cannot be incinerated or detoxicated, some with low toxic content can be disposed of in landfill provided certain conditions are observed. Wastes are permitted in landfills based on their quantity, solubility, toxicity, and concentration. In particular, sites for industrial waste where disposal is allowed in France must be impermeable, so the waste and substances leached from it are adequately confined. LeRoy (1983) reports 14 such landfills in France at special disposal charges ranging from 80 to 500 francs/ton.

In the United Kingdom, Peter Pearce (United Nations Environmental Protection 1983) reports that of the 3.4 tons of hazardous wastes generated per year and not recovered about 80% is landfilled. The remainder is disposed of either in oceans or by incineration or other treatment. About the same percentage generated is landfilled in the United States as of 1987 (Pizzuto 1981). Pearce points out some advantages for using permanent landfills for ultimate disposal of hazardous wastes. Adjacent land areas sometimes can be used by an industry to avoid costly transportation problems. Further, incineration, the major alternative treatment of hazardous wastes, costs about two to three times that of landfilling. Incineration has the disadvantage of not being suitable for many types of wastes and of generating toxic gaseous products and unburned

particles. Efficient removal of heavy metals from the exhaust and damage to the incinerator structure also poses problems. Pearce (United Nations Environmental Protection 1983) lists the following six constraints in selecting a permanent landfill site for the ultimate resting place for hazardous wastes.

1. Institutional constraints: usually legal and ownership of land
2. Geographic considerations: existing land and water use, topography, climate, hydrology, location of waste sources, population distribution, and transportation routes
3. Geological considerations: proximity to known fault zones or sink holes, potential for ground shifting causing landslides, and so on
4. Waste characteristics: property and volume of wastes determine the design and storage capacity of a landfill area
5. Management priorities: financing during the beginning phases, operating and maintaining the landfill after closing the fill
6. Environmental and social considerations: ecology, water resources, archaeological resources, sociopolitical and socioeconomic factors

Hazardous wastes can usually be landfilled unless they are known to be radioactive, highly flammable, explosive, excessively toxic, odorous, or corrosive (Department of the Environment 1978). Noncompatible or highly leachable wastes must be given special consideration in designing safe fills. Sax (1979) warns that we should watch out for the compatibility of each hazardous waste with others, which may cause spontaneous reaction in the fill, especially with water and acids. In such cases, pretreatment or segregation of different wastes may be required.

The question of how permanent are landfills is of importance. For example, consider the liners preventing leaching of potentially toxic chemicals from the fill. It is too early to predict the ultimate longevity of various liner materials for landfills. With that in mind, it is preferable and safer to design these facilities for some leachate to protect water resources.

In New Jersey, storage tanks containing volatile liquids have been painted white and covered with floating covers. Lower temperatures thus yield lower evaporation rates and ensure no loss of toxic organics to the atmosphere.

Piasicki (1983) pictorially depicts what can go wrong with permanently storing hazardous wastes in a landfill. They include (1) burrowing gophers attacking the landfill cover, (2) freezing temperatures shrinking and tearing the landfill liner, (3) mineral acid and solvents mixing and triggering a chemical fire, (4) chemicals corroding waste collection pipes or weight of waste may crush these same pipes, (5) debris may clog perforated collection outlet pipes, and (6) the landfill's protective cover can be breached by erosion, by new construction on the site, or by settling after bulk solids compact and barrels disintegrate further down in the fill. If the cover splits at the surface, rainwater can reach the waste and overload the leachate collection system or cause the entire landfill to overflow.

Sachdev et al. (1983) investigated the use of fly-ash with or without additives as a liner material for landfill disposal sites. They found the following parameters

significant for use of fly-ash as liner material. They aimed for a hydraulic conductivity of 10^{-5} cm/sec or less and a leachate with a minimal impact on groundwater.

Boiler type: The type of boiler and boiler temperature affect the physical and chemical characteristics of the fly-ash. Fly-ash from a pulverized boiler is generally finer than that from a cyclone or stoker fired boiler. The finer fly-ash has more surface area and is, therefore, more reactive.

Coal source: The coal source may affect fly-ash characteristics. There are differences between western coal fly-ashes and eastern coal fly-ashes. Western coal fly-ashes have higher lime content and higher pH than fly-ashes. The higher lime content (>10%) fly-ashes usually exhibit self-hardening properties.

Fly ash handling mode: Wet and dry fly-ash handling have different effects on fly-ash reactivity ("Great Lakes Study" 1985). Wet handling reduces the reactivity of fly-ash.

Loss-on-ignition (LOI): LOI indicates the amount of unburned carbon in the fly-ash. High LOI (and, therefore, high carbon content) in fly-ash inhibits pozzolanic activity. The concrete industry specifies a maximum LOI value of 6% in fly-ash for use in concrete manufacturing (American Chemical Society).

Particle size: The particle size of fly-ash is important. finer fly-ash offers more surface area for reaction and generally provides lower permeability than coarser material. A well-graded fly-ash is preferred over a uniform particle–size fly-ash because it would generally exhibit smaller void spaces and, therefore, lower permeability. Fly-ash used as a mineral admixture in Portland cement concrete must have a minimum of 66% by weight passing through a No. 325 sieve (American Chemical Society).

pH: A higher pH (≥10) is required to promote the precipitation of calcium silicate, which is the source of bonding in the pozzolanic process.

Lime content: Lime is the source of calcium, which reacts in the pozzolanic reaction. It is the "free" lime in the fly-ash that is available for reaction. Lime can be added if fly-ash has low lime content. A fly-ash with lime content greater than 10% normally exhibits self-hardening characteristics.

Amorphous silica content: Amorphous silica is the noncrystalline portion that reacts with calcium in the pozzolanic reaction. A fly-ash with low amorphous silica would, therefore, have low reactivity. The amorphous silica content would generally increase with increasing boiler temperature.

However, in 1985 the U.S. government officials report that one-third of toxic waste landfills might be forced to close because of results obtained by underground monitoring and by new insurance requirements ("U.S. waste deadline" 1985). Industry appears to be moving away from dumping toxic material into landfills and toward the incineration and treatment of hazardous wastes. In fact, 1,100 toxic landfills—almost two-thirds of the nation's total—were in fact closed because they could not comply with federal environmental rules ("Toxic sites close" 1985).

Ocean Dumping

The dumping of hazardous industrial wastes into ocean areas may be practiced sometimes safely because of the following attributes of oceans: (1) they tend to dissolve and disperse the wastes three-dimensionally, as contrasted to the surface use only of land resources; (2) oceans are mostly out of contact with people except for shipping and transportation—two rather "lowly" uses of water resources; (3) some pollutants may settle thousands of feet to ocean bottoms where presumably they will cause people no harm; (4) the ocean is already considered a mixture of a multitude of chemical elements and compounds; and (5) the ocean food chains are much longer than those we experience with on-land food chains, so humans are placed farther away from hazardous chemicals.

Oceans should be used only for wastes that, when diluted fully, will offer no threat to marine life, especially the kind that serves as food for humans. The oceans should provide enough time before reuse by humans for degradation of the hazardous industrial waste. Nemerow (1985) gives a detailed description of the effects of some common ocean pollutants on the viability of ocean resources. It is important to keep in mind that the aquatic ecosystem of oceans has a finite assimilative capacity for a particular contaminant without significant deleterious effects. The assimilative capacity of any particular ocean area is determined by physical processes such as mixing currents, geomorphology, types of sediments, and types of water chemistry and biology.

The National Research Council (1984) recommended in 1984 that although oceans are suitable for discharge of industrial and municipal wastes, "certain xenobiotics (human-made organics) are so persistent that they cannot be removed in treatment plants or diffused to safe limits in the ocean."

Secure Burial, Reuse, and Chemical Fixation

Prouty et al. (1983) used a containment method of incorporating toxic sludges into bricks during their manufacturing. They claim savings in energy since bricks are lighter and more porous, as well as enhanced insulation quality. Bricks are produced by mixing finely ground clay with water, forming it into the desired shape, drying, and finally burning it. They tested metal-laden sludges and found a portion of the metals volatized during brick burning, but the remaining metals were bound in the brick and will not leach from it.

Wright and Caretsky (1981) give seven techniques for chemical fixation of toxic wastes. *Cement-based fixation* is a process that mixes toxic wastes in a slurry of water and cement. When the concrete hardens, it can be used for various building purposes—sometimes in surface coatings of asphalt, vinyl, or emulsion mixtures to increase the strength and decrease the permeabilities of the concrete. Radioactive wastes and heavy metal sludges have been "fixed" in this manner. *Lime-based fixation* involves mixing the waste with lime and fine-grained silicious waste material such as fly-ash, blast furnace slag, or cement kiln dust. The *encapsulation fixation* process encloses previously bonded waste in a covering of non-reactive inert material. Usually the toxic waste is mixed with a thermosetting plastic, placed in a mold, and heated to fuse into a hard block. Many hazardous industrial wastes originated from the extraction, use, and

alteration of toxic elements in native underground sites in a form similar to that in which they were found. The concept appears reasonable. However, several obstacles must be overcome. First, the volume, weight, or mass of hazardous materials must be reduced to a point at which it would be economically feasible to return them underground. Second, the exact location to where they are returned must be suitable. That is to say, it must be available, owned by the disposer, and not likely to cause environmental problems to potential underground resources such as water, air, or land. Third, methods must be found to solidify and contain the hazardous wastes so that they will not migrate away from the burial site once they are placed underground. These are not insurmountable obstacles; however, they must be faced and settled before solidification becomes a viable solution for the safe disposal of hazardous wastes. *Self-cementing fixation* is used with waste sludge containing large amounts of $CaSO_4$ or $CaSO_3$. Small portions are de-watered and calcined under controlled conditions and remixed with the entire waste sludge and additives as necessary. The product is a hard, plaster-like relatively impermeable mass. This process is especially useful for sludges from power-plant stack gas scrubbers. The *classification process* mixes the toxic waste with sand before fusing into glass. This is used mainly for radioactive wastes. *Thermoplastic fixation* dries, heats, and mixes the toxic waste with a heated plastic material such as paraffin, bitumen, and polyethylene, cooled, and resulting solid matter stored indefinitely. Although this process is mainly used for radioactive wastes, it may be used for certain organic solvents, oxidizing salts such as nitrates, chlorates or perchlorates, and dehydratable salts.

Organic polymer fixation produces a spongy, rather than a solid, mass by blending the waste with a prepolymer and catalyst. This is done at room temperature and usually in batch basis rather than a continuous process. It is also used for industrial radioactive wastes. Francis (1984) found it much more economical and practical to treat a toxic metal land-filled sludge in place than to remove it for treatment and subsequent alternative disposal. Essentially he found that after detailed analysis of the land-filled sludge, nickel as the hydroxide was the major toxic contaminant. His plan was based on the fact that nickel hydroxide solubility in water can be effectively controlled by keeping the pH at 10.2, its point of minimum solubility. The landfill sludge site was covered with a layer of finely ground calcium carbonate to neutralize acid rain before it reached the waste. Then the site was covered with mounded, compacted, and graded earth to divert rainwater and runoff from the waste. Finally, a 12-in. layer of gravel followed by a 6-in. topsoil layer was added on the earthen cover. The topsoil is needed to provide vegetation necessary to prevent erosion. His system of containment, though costly, was estimated at about 10% of that necessary to remove sludge and to treat it other ways.

ENRECO, Inc. (1985) successfully completed the solidification phase of more than 50 sites during 1984. The company makes a careful analysis of solidification agents and then uses a unique injector to add and mix the solidification agents with the waste. Some agents that have been used include fly-ash for oil-field drilling, kiln dust for oil-field skim pits, and carbon for PCB-impounded waste sludge. In the last case, the solidified sludge was removed and transported to an acceptable landfill. In other cases, the solidified mass was buried on site. Photographs of successful operations of

(1) mixing, (2) solidifying, (3) removing, and (4) burying with land renewal were shown.

Jones et al. (1985) point out that many hazardous wastes, especially metal-plating wastes, may contain constituents that could interfere with the blinding process of solidification with type I Portland cement and fly-ash, including oil and grease, light-weight oil, phenol, sulfates, strong base, pesticides, degreaser, lead, copper, and zinc.

Exportation

Since the beginning of time, humans have developed the attitude that if we can give our problem to someone else, we are relieved of any further responsibility, or "out of sight, out of mind." Therefore, it comes as no surprise to observe industry expounding the philosophy of contracting for services to carry away hazardous wastes to a site distant from the plant where it originated. The assumption is made in these cases that it is far less expensive to pay some agent to assume the responsibility for providing the service than to assume the liability and costs yourself. It is also presumed that the disposal of the hazardous waste is safe and effective at the distant site.

Industry should shoulder the responsibility (before exporting hazardous waste) of determining not only whether this method is more economical, but also whether it is effective and safe ultimately.

In June 1983, a novel plan to export toxic PCB wastes from Florida to Honduras was uncovered ("Export plan" 1983). The plan was foiled and no criminal charges were filed. However, EPA and state officials agreed that this export plan underlined growing fears that strict regulations on toxic waste disposal in the United States could lead some American firms to try to dump their toxic materials abroad.

In March 1989, a treaty among more than 100 countries was unanimously adopted restricting shipment of hazardous waste across borders (Greenhouse 1989). The pact requires waste exporters to notify and receive consent from receiving countries before shipping the waste. In addition, the treaty requires countries exporting waste and those receiving it to ensure that the waste is ultimately discarded in an environmentally sound manner. The treaty prohibits shipments of hazardous waste to nations that have banned waste imports. It also requires that all cross-border waste shipments be packaged and labeled properly and that all companies transporting or disposing of hazardous wastes be authorized to handle wastes. Among the wastes considered hazardous are clinical wastes from hospitals, wastes from pharmaceutical factories, PCBs, compounds containing mercury or lead, and wastes from the production or use of dyes, paints, and wood-preserving chemicals. The treaty is a beginning and its nature will require additions, clarification, refining, and strengthening as time goes on.

Recovery and Reuse

Recovery and reuse of hazardous waste represents the ultimate in environmental and economical efficiency. If found feasible, such a solution prevents environmental damage and provides some monetary return to the generator of hazardous waste. Not to be overlooked are the indirect benefits of recovery and reuse to society. Most of these

benefits are associated with a slower decrease in the world's natural resources, a so-called "slowing down of entropy buildup." In addition, consumer prices for products made with recovered materials should be lower in the long run.

Therefore, the goal of all industry and its environmental engineers should be that of recovering and reusing all wastes including especially hazardous ones. Chapter 15 of this book presents a novel system for doing this.

Here, we present only some examples of effective recovery and reuse of certain hazardous industrial wastes. In addition, Wilcox and Agardy (1990) present many possibilities for effective recovery and reuse of industrial wastes.

An important consideration in this chapter should be the question of whether the business of recovery and reuse of many chemical elements and compounds considered toxic to the environment represents a beneficial service to society independent of its profitability. If so, one could expect that it would be reasonable for public subsidization to some extent of such ventures. If not, then the business of recovery and reuse must stand solely on its own economic viability similar to that of other profit-making industries.

Before recovery of hazardous wastes, one should attempt to reduce the amount of these wastes to a minimum. In that connection, the Jacobs Engineering Group (1988) proposes four major incentives for what it refers to as "waste minimization."

1. Economics
   - A. Landfill disposal cost increases
   - B. Costly alternative treatment technologies
   - C. Savings in raw material and manufacturing costs
2. Regulations
   - A. Certification of a waste-management program on the hazardous waste manifest
   - B. Biennial waste-management program reporting
   - C. Land-disposal restrictions and bans
   - D. Increasing permitting requirements for waste handling and treatment
3. Liability
   - A. Potential reduction in generator liability for environmental problems at both on-site and off-site treatment, storage, and disposal facilities
   - B. Potential reduction in liability for worker safety
4. Public image and environmental concern
   - A. Improved image in the community and from employees
   - B. Concern for improving the environment

Copper Recovery from Plating and Engraving Baths

When a hazardous industrial waste is composed almost wholly of copper as a contaminant, it usually can be recovered in quite pure form as the hydroxide. Such may be the case in electronic printing-board wastes. Even when the wastewater is contaminated slightly with other metals such as iron or zinc, copper may be precipitated and then purified, if necessary, before recovery and reuse.

Copper hydroxide is insoluble at an optimum pH of between 7 and 9. For recovery and reuse, NaOH is preferable to $Ca(OH)_2$ for raising the pH, which contaminates the recovered sludge. The pH should be kept below 9 and preferably above 8 to prevent re-solubilization of the copper hydroxide precipitate. Other contaminating metals, especially zinc and chromium, will be incompletely precipitated at this pH.

Another method of recovering copper from mixed metal wastes is that of depositing copper on brass chips in the presence of chloride. This process of copper recovery is used primarily for treating brass mill wastes where chromium, copper, and zinc are common impurities found in the effluent.

Cation exchangers may also be used on copper wastes such as those from the electronic industry in making printed circuits. Copper is present in these wastes as the sole contaminant. However, only analysis of the hazardous wastewater will reveal whether either of the latter two recovery methods is preferable to copper precipitation as hydroxide.

Cartwright (1984) describes a complete metal-plating reclamation and waste-treatment system designed, installed, and operated in Bloomington, Minnesota. The latest treatment technologies are detailed including reverse osmosis, two-bed deionization, mixed-bed deionization, activated carbon adsorption, ultrafiltration, ozoonation, slant tube clarification, and sludge de-watering. More than 90% of the rinse water from the electroplating line is purified back to 18 meg ohm quality and recycled; ultrapure makeup water is supplied from city sources and toxic wastes are precipitated as an insoluble sludge. Nickel-iron, nickel, copper, and gold metals are involved in preparing 10-cm diameter wafers of these metals on a special ceramic substrate. Cartwright (1984) describes the concept of the reclamation and minimal discharge as the "wave of the future."

Spent Caustic Soda Regeneration

Certain industrial wastes such as textile kiering and pulp-mill cooking liquors contain spent sodium hydroxide in relatively high concentration and in relatively uncontaminated form. In these cases and in other special situations, caustic soda may be recovered and reused in the same industry or sold to other plants for other uses.

Dialysis or other variations of membrane separation is a major method used in recovering pure caustic soda. The caustic permeates the membrane and dissolves in water usually much easier and faster than any other contaminants contained in the waste (see Chapter 7 of this book for theories and rate reactions for typical dialysis systems). The quantity of sodium hydroxide diffusing through the membrane depends on the time, the area of the dialyzing surface, the mean concentration difference, and the temperature. Naturally, the membrane pore size and degree of clogging will control the flux rate (permeability) of the caustic soda.

Evaporation is also used to concentrate caustic soda for recovery and reuse, especially when heat energy is relatively inexpensive and when impure caustic can be reused satisfactorily.

Mercury Recovery

Toxic mercury compounds occur in several industrial wastes, mainly in the alkali-chlorine plants using mercury cells. Small amounts of mercury escape these plants, end

up in watercourses, and are picked up and biomagnified in fish from where they reenter the human food chain. Because of the extreme toxicity of mercury, it apparently reverts to especially toxic and dangerous methyl mercury form. Because mercury is found in very small amounts in the wastes from several plants using mercury cells or thermometers, it is seldom practical to design and install large complicated treatment systems. Rather, it is more realistic to separate by gravitational means (mercury is almost 14 times as dense as water) small quantities of waste mercury at the origin of its escape from the process or use and return it to reuse in the plant.

Cadmium Recovery

Cadmium accumulation in humans has been linked with hypertension, emphysema, and bronchitis. Much cadmium waste has been attributed to automobile battery manufacturers. The major treatment techniques for removing trace amounts of cadmium include chemical precipitation, cementation, reverse osmosis, ion exchange, chelating resins, and foam separation.

The nickel-cadmium cell is an excellent storage life battery. It is a secondary cell type, that is, it depends on chemical reactions that are reversible by electric energy and, therefore, does not need chemical replacements. The cell uses nickel hydroxide as the positive electrode and cadmium-cadmium hydroxide as the negative electrode as the electrochemically active materials. Potassium hydroxide is the electrolyte in an aqueous solution. When these used batteries are delivered to chemical recovery plants, they are stored, washed, and valuable nickel and cadmium recovered.

Drainings, washings, and unusable metal parts of the batteries must be kept from polluting the soil and associated groundwater during the recovery process.

Silver Recovery from Plating and Photographic Wastes

Silver is both too toxic and too valuable to allow even the smallest amount to be discharged to waste. Two major industries use and waste sufficient silver to make it imperative for them to recover it: silver plating and photographic developing.

Silver can be precipitated as chloride, sulfide, hydroxide, or insoluble silver. These are affected by the addition of sodium disulfide, sodium hydroxide, and sodium borohydride ($NaBH_4$), a powerful reducing agent. In some instances, ferric chloride is added to enhance silver solids separation. Any other heavy metal contaminants will also be precipitated and must be removed from the solids before recovering the silver.

With a lithographic film waste, Cook et al. (1979) report the borohydride system gave the best overall results based on residual metal levels, cost, and suitability of the precipitated silver for further recovery. His chemical cost was $0.50 per troy ounce of silver removed. Nemerow (1963) reports that recovering silver from a silverware-plating plant waste by precipitating it as the chloride yielded silver concentrations in the effluent of less than 3.5 ppm from an original value of up to 250 ppm.

In addition to precipitation, silver can also be recovered by metallic replacement and electrolysis. In the case of photographic wastes containing silver, spent hyposolutions are brought into contact with a metal surface such as steel stampings, zinc, or copper.

After more than two-thirds of the silver is recovered, the metal is removed from the tanks, dried, and sold to the refiner.

In the electrolysis method, both an anode and a cathode are placed in the waste silver and an electric current passed through. Silver will plate out on the cathode. A total of 32 ft^2 of cathodic area is required for treating 50 gallons of waste containing 19 ounces of silver. After 24 hours of air agitation, 98% of the silver is removed. About 600 troy ounces of silver can be recovered before the cathode has to be desilvered or replaced.

Waste Oil Recovery

Waste oils are found in industrial discharges from many types of plants and originate from uses such as lubricating, fuel, hydraulic circuits, and refining. As might be expected from such widespread uses, the qualities of the oily residues are vastly different.

Residual oils from transformers, turbines, and some hydraulic systems are sometimes referred to as "bright oils." These oils can be recovered and directly reused for purposes that do not require the highest quality (purity) oils. An example of such secondary reuse is in stripping molds in foundries.

Waste oils from motor cooling, mill hardening and rolling and drawing of steel, and other metal lubricants and cooling are called "black oil." These oils can be recovered and regenerated for reuse by re-refining by specialized companies. It may be dangerous practice to incinerate these black oils rather than regenerate them because of the impurities such as lead given off during burning. In addition, wasteful uneconomical burning is eliminated by regeneration and reuse.

Fitzpatrick (1985) discusses companies that turn bore or mill metal. A product of these operations is always some form of oil-contaminated scrap metal. The scrap has little or no value, and is a nuisance in its present contaminated form. Fitzpatrick claims that a properly designed and sized system will reclaim valuable oil, upgrade the value of metal scrap, and reduce handling and hauling costs. He also claims that these systems return investment capital at a rate comparable to other capital equipment. Scrap chips must first be collected by some units placed beneath the various machines, raised to crushers to reduce the scrap size, discharging the scrap into containers for storage for resale, and the reclaimed oil to cleaning by settling and filtration for reuse as friction-reducing and cooling agents.

Another location in the steel mill where oil may be recovered and reused is the quench water. As steel is quenched, the metal oxide and oil combine to form a grimy scale. The scale accumulates into an oily dirty sludge. One company reports using the Barrett Sludge Extractor ("Sludge extractor" 1985) to recover most of the quench oil from the sludge and saving about $30,000/yr in oil purchases. The extractor operates like a centrifuge to spin the wet sludge at high speed and compact the sludge while driving the oil towards the center of the unit. From there the oil is collected, filtered, and recovered for reuse while the dry sludge remaining is disposed of as required by local regulations.

There are two major types of fuel oil wastes: diesel train refueling oil and auto and truck waste crank-case oils. When recovering these oils for reuse, they are generally

heated, coagulant is added, and the resulting oily slurry centrifuged to remove the impurities. The centrifugate is then resold to oil refiners and/or distributors for reuse.

Solvents Recovery

Solvents are universally used by many industries both in the gaseous and in the liquid phase. Examples of such industries are dry-cleaning, printing, paints and varnish, rubber, and metal degreasing. Besides objectionable odors, some solvents are photochemically reactive. Fluorocarbon solvents affect the upper layer (ozone) of the atmosphere. The recovery and reuse of waste solvents can be compared in philosophical and economical terms to that of waste oils. Solvents must be regenerated to separate them from their impurities. Regeneration is carried out by either steam stripping or rectification. Because regeneration equipment is expensive mainly from a capital investment standpoint, regional or collective facilities for several industries are recommended.

The Miami Herald (Oct. 27, 1983) reports of the Gold Coast Oil Company, which distilled and recycled chemical wastes, subsequently closed due to pressure from Dade County, Florida, but responsible legally for any residual toxic wastes. The company left behind about 2,500 fifty-five gallon drums of unidentified waste and unrecyclable residues and solvents. It was gooey, sticky, and discolored. The drums leaked and the material tested for "alarmingly high concentrations" of heavy metals. The lesson here is that even recycling plants may run into environmental problems resulting from additional residual wastes. Changing the solvent to one less hazardous is a well-established procedure, but it, too, can have drawbacks. For example, the refrigerant chlorofluorocarbon (CFC), widely used for the past 40 years or more, is now being replaced by a class of compounds known as hydrofluorocarbons (HFCs). However, these HFCs, which are replacing CFCs (which reacted with and destroyed the ozone layer, thereby increasing ultraviolet rays to the earth's surface) are now found to influence (and enhance) the production of acid rain, another pollutant.

Vara International of Vero Beach, Florida, is one of a number of companies that specialize in solvent recovery. It has used a special palletized activated carbon to adsorb solvents for more than 40 years. The choice of carbon is very important; special concern should be uniform particle size, low ash content, high retentivity, and strength.

Water Recovery and Reuse from Industrial Laundries

Industrial laundry wastewater, though not generally considered hazardous, may contain priority pollutants such as heavy metals. At the least, it is a complex and variable mixture of high concentrations of organic materials and suspended solids. Van Gils et al. (1984) give a consolidation of analyses of typical industrial laundry wastes (Table 11.12). They reported that lime coagulation, settling, high-rate ultrafiltration, and fixed-bed carbon adsorption proved effective in providing a reusable water at an operating cost of $3.80 per 1,000 gallons of wastewater processed. No mention is made of the disposition of the contaminants removed. Presumably, they would be landfilled or burned during regeneration of the carbon.

TABLE 11.12
Typical Industrial Laundry Wastewater Constituent Concentration

Constituent	*Concentration, mg/litre*
BOD	1,300
COD	5,000
Susp.solids	1,000
Oil and grease	1,100
Lead	4.5
Zinc	3.0
Copper	1.7
Chromium	0.88
Nickel	0.29
Chloroform	3.3
Benzene	2.5
Perchlorethylene	9.1
Toluene	5.2

Source: Adapted from Van Gils et al. (1984).

Space is often a limiting factor in smaller laundries for normal physical–chemical treatment required. However, with the increasing size of industrial laundries and more automated adsorption-filtration systems now encountered, these treatments and the reuse value of the water are more feasible.

High-gradient magnetic separators consisting of a filter bed packed with a fibrous ferromagnetic material such as stainless steel or wool screens and magnetized by a strong external magnetic field that surrounds the bed have been described and recommended as useful for treating laundry wastewater (Oberteuffer 1973; DeLatour 1973). This treatment is said to be extremely fast, with filtration rates as much as two orders of magnitude higher than conventional sedimentation-filtration processes. Once again, contaminants removed must be disposed of ultimately by burning or land-filling. Other treatments for laundry wastes can be found in Nemerow (1998).

Dye Recovery and Reuse from Textile Wastes

Textile dye wastes were reported as far back as 1952 (Nemerow 1952) as being pollutional in nature and varying in treatability depending on their chemical nature. In 1957, Nemerow described and classed commercial dyes according to their structure. At this time it was proposed to alter the color of a major class of textile dyes, the azo group, to remove the color contaminant characteristic. The azo chemical structure was altered by reduction with stannous chloride and salting with NaCl.

From that time to the present, Nemerow has been advocating recovering and reusing textile dyes. Support for this thesis was based on the difficulty and high cost of color removal from these wastes, as well as the economic value of the recoverable dyes.

In 1982 Nemerow suggested to textile industries the removal of dyes on fine filter material such as clay or fine weave fabric. The dyes can be concentrated in up to 80% solids before evaporating with waste heat the remaining 10–15% water. In considering the economics of dye recovery by this or any other method, one must consider the avoidance of damage costs or other destructive treatment costs as negative costs of dye recovery.

Bergenthal et al. (1984) demonstrated the technical feasibility of batch dye bath reconstitution and reuse at a carpet mill. They overcame several technical problems that are common to a wide variety of textile mills such as the following:

1. Selecting product styles and shades that include dye bath reuse
2. Reforming dye recipes to use a single dye group to dye many shades
3. Demonstrating the feasibility of dye bath reuse on a portion of the product while the remainder continued with normal production
4. Producing high-quality product with recycled dye baths
5. Adapting dye bath reuse to conform to the mill's standard dyeing procedures

They observed a 25–50% reduction in both pollutants and water use. Economic benefits were termed attractive and especially when dye bath dilution with steam condensates and overflow cooling waters was eliminated. This latter finding lends even more credence to recommendations that dry dyes should be recovered, stored, and reused by adjustments with fresh dyes at appropriate times in the production schedule.

Nemerow (1988) found that textile dye wastes can be treated economically and effectively by ultrafiltration. Membrane filtration studies are in progress.

Detoxification

Hazardous wastes can be detoxified in place or before disposal in another site by a variety of processes depending on the type of waste and special situation. Any of these processes portends a residual waste for ultimate disposal. However, the residual waste would no longer possess toxic properties. Detoxification at the site of hazardous waste origin is highly recommended. Not only are the toxic waste generators better able to detoxify their own waste as it originates, but they also are protecting the final disposers from accidental spills or malfunctioning systems. Also, the generators are legally and morally responsible for making their own waste safe for further transportation and/or treatment and disposal.

Sunohio (1981) developed and promoted a detoxification process consisting of a mobile chemical plant on a tractor-trailer truck. It has been used to detoxify PCBs. A chemical agent strips chlorine atoms from insulating liquids and thereby removes its toxicity. The promoters claim that the detoxified insulating fluids can then be reused for the same purpose without decreasing its effectiveness.

Piasecki (1983) reports of EPA studies of soaking toxic solvents and acids in hot baths of molten salt that destroy the toxic chemicals. The wastes are injected into a pool containing sodium carbonate heated to about 1,650°F. The hazardous hydrocarbons are burned off and converted to CO_2 when oxygen is supplied or available, whereas sulfur and chlorine react with the salt and end up in the ash residue of only less than 1% of the original volume. One advantage of this process is that it allegedly takes place at temperatures lower than those of conventional incinerators. This minimizes

the production and evolution of nitrous oxides, precursors of acid rain. Rockwell International offers a unit that can detoxify 1 ton of waste per hour.

Piasecki describes the process as pumping the contaminated oil (PCB) into a chemical soup that contains metallic sodium. The sodium strips the chlorine from the PCBs and combines with it, creating a form of sodium chloride. The biphenyls are removed as a harmless sticky residue, and the oil can be returned to the transformer, used as fuel oil, or dumped without special handling. The process can reduce PCB contamination from a level of 10,000 ppm to less than 2 ppm. Acufex Corporation was developing a truck-treatment process to re-purify contaminated soils of this PCB and return the soil to its original site.

LeRoy (1983) describes a collective detoxification establishment to consist mainly of the following:

1. A workshop for removing cyanide by oxidation
2. A workshop for removing chromate
3. An acid–base neutralizing workshop

He adds that machining fluids are also processed by physicochemical methods such as ultrafiltration and evaporation.

Hanson (1984) describes an air stripper that removes more than 99% of total chloroform extractables from a well-water supply. The air-stripping system is costing the town of Hartland, Wisconsin, about 4 cents/1,000 gal of water treated and strips about 500 parts per billion of TCE at 1,000 gal/min. Once again, however, such a treatment transfers the toxic material from the water to the air environment.

Wright and Caretsky (1981) include soil flushing, chemical detoxification, and microbial inoculations in treatment of waste dumps to detoxify them. Soil is flushed by applying water at the surface and collecting leachate with the use of shallow well points. Analysis of the leachates will indicate whether they must be treated further or may be discharged safely to water courses. This is especially useful when soils and wastes are acidic and likely to leach out heavy metals. Chemical detoxification is done the same way except some chemical agent is added to degrade or alter the toxic material to render it harmless. Seeding the soil with a microbial growth, which can degrade the contaminant(s), is also done when a suitable amount of time is available and the toxic material can be biodegraded.

The technique of "plasma arc" detoxification provides the most complete destruction with the highest energy level possible short of atomic reactors. It is claimed to have been invented by a Canadian engineer, Tom Barton. A high energy arc is transmitted between two electrodes, which heats a short chamber of air to temperatures of about 45,000°F, transforming any impurity in the chamber into a plasma. "Plasma" can be defined in this case as "ionized gas composed of electrons and positive ions in such relative numbers that the gaseous medium is essentially electrically neutral." Sometimes plasma is referred to as a "fourth state of matter."

Familiar forms of plasma-like matter are lightning bolts, fluorescent lights, and welding arcs. Barton feeds a toxic waste into the middle of the chamber where it is attacked by the plasma disintegrating the molecular bonds, and only carbon,

hydrogen, oxygen, and chlorine atoms remain. He pumps the gases to a scrubber when the potential for formation and release of residual toxic gases exists. Barton's development of the plasma arc represents an improvement over the NASA implementation of the 1960s space reentry of vehicles. His electrodes are said to withstand heat and use for longer periods than the older NASA ones. Several companies in addition to the U.S. Army are researching the plasma arc method for destruction of not only toxic wastes generated directly by industry, but also for renovation and purification of contaminated soils.

Two more conventional methods of detoxifying waters containing small quantities of volatile organic chemicals such as trichloroethylenes from dry-cleaning wastes are (1) air stripping and (2) adsorption.

Air Stripping

Air stripping is accomplished by pumping water down through a packed column through which air is being blown up and discharged above the column to the atmosphere. The air strips the volatile organics from the water that is collected beneath the column. Air-to-water ratios and their temperatures are important factors in determining removal efficiencies.

An illustration of air stripping was reported by Wench and Josephson (1984). They drew polluted leachate from under a toxic landfill to a point at which it could be pumped 1,400 ft, then sprayed in an adjustable arc at a rate of about 200 gal/min. The jet mixed air with water at a ratio of 8,000 to 1. The treatment process not only eliminated toxic organics from downstream well water but also volatilized the same during spraying in the air.

Granular Activated Carbon Adsorption

In granular activated carbon adsorption, contaminated water is fed through enclosed tanks containing a packed bed of specific size and density of activated coal material. The latter holds the volatile organic contaminants while the purified water is usually discharged at the tank bottom devoid of contaminants. The bed area and contact time are two of the more important parameters affecting the degree and rate of removal of these volatile organics.

Nyer (1985) reports that Rockaway Borough used granular activated carbon to remove trichloroethane from its underground drinking water at an average increase in the monthly bill for each household of $3.00. The system handles 1.5 mgd at an influent TCE concentration of 335 ppb.

Nyer (1985) also reports that the city of Acton, Massachusetts, air strips the volatile organics from its groundwater with removal of 96–99% at a total cost of $0.053/1,000 gallons. All organics were removed to less than 1 ppb. This naturally eliminates the possibility of toxic trihalomethanes from the drinking water following disinfection.

Oil Recovery Systems, Inc. (1985) uses an air-stripping system to remove volatile organics from water. It reports excellent results in removing chlorinated solvents such as trichloroethane, trichloroethylene, and methylene chloride, as well as petroleum hydrocarbons such as gasoline and fuel oils. However, it is significant

to note that the system of air stripping is often used in conjunction with activated carbon adsorption.

Weston engineers ("Clean-up of the Gilson" 1984) claim to have eradicated the first Superfund site cleanup by a combination of containment and treatment. They installed a 3-ft wide soil-bentonite slurry wall around a 20-acre dumpsite, thereby significantly curtailing exfiltrated water from the site. Then they constructed a full-scale 300-ppm treatment plant (based on successful pilot-plant results), which was completed in April 1985. The treatment consisted of chemical precipitation of the inorganics followed by pressure filtration to remove any remaining metallic floc. The waste stream was then preheated to about 90˚C and passed through a stripping column. Air was passed counter-currently through the column and the off-gases burned in a vapor incinerator. The column effluent was divided, the larger portion discharged within the slurry wall, and the smaller portion subjected to biological treatment by extended aeration and then groundwater recharge outside the wall. NH_4Cl and H_3PO_4 were added to enhance biological treatment. Weston estimates that it will take about 1¾ years at the 300-ppm rate to provide the two full flushes of the contaminated dumpsite necessary to remove 90% of the contaminants held in the soil water. Capital costs approximated $5 million, with annual operating costs of about $1.4 million.

GDS, Inc. has developed a patented system for soil and groundwater detoxification, which it claims is cost and performance effective (Jhaven and Mazzaca 1983). The system involves pumping contaminated groundwater into activating tanks where the microorganisms are enriched with compounds of phosphorous and ammonia, and sometimes iron, magnesium, and manganese salts. The treated groundwater is then settled and pumped in trenches for recirculation by reinjection into the original underground site. The company claims decontamination of both soil and groundwater by this process. It admits that complete site cleanup may take years but overall results in a savings of both time and money. A schematic view of the system is shown in Figure 11.13.

The EPA (1985) reported the fungus *Phanerochaete chrysosporium* was used to degrade dioxins, DDT, benzopyrene, and two kinds of polychlorinated biphenyls, or PCBs. The EPA predicts that contaminated soil could be inoculated or mixed with the fungus grown on sawdust or wood chips. It admits, however, that it may take a long time, perhaps years, to degrade large amounts of the chemicals but claims it is a better alternative.

ATW/Calweld, Inc. (1985) has introduced a "detoxifier" system that incorporates a mobile *in situ* treatment system with advanced chemical and biochemical technologies. The system is capable of chemically detoxifying or biochemically degrading aqueous toxic substances or contaminated soils, in place, to ensure a much more economical and safe cleanup solution than traditional remedial procedures. Mounted on a heavy-duty crane (Figure 11.14), these systems include an intrusion device that is powered down into the impounded waste or soil. Computer control and feedback determine the rate of descent and speed of the device, which mixes, turbulizes, pulverizes, and homogenizes the impounded contents while selecting, feeding, and integrating chemical reagents or biocatalysts and their nutrients with the conditioned contents. Oils and greases are biodegraded or transformed into nonsoluble metallic soaps. The solidified mass will not

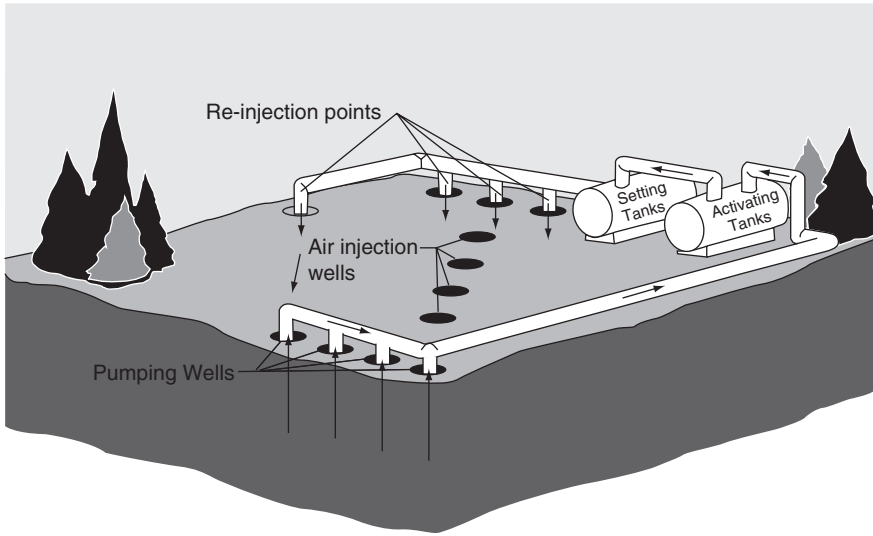


FIGURE 11.13. Soil and groundwater detoxification system.

reslurry according to the company. The company also states that any gases or vapors liberated during the process are collected and scrubbed.

NASA has shown that certain plants such as spider plants are effective in eliminating toxic gas concentrations of NO_2 and CO. Although this is perceived more as a treatment for indoor air, it could also be used under proper conditions for outdoor environments (Duke 1985).

Irvine and Busch (1979) reported the use of sequencing batch reactors (SBRs) as an excellent alternative to conventional activated-sludge biological treatment for wastewater. Irvine et al. (1984) showed that the SBR can provide substantial saving in energy and costs by removing organic compounds found in hazardous wastes biologically, rather than with activated carbon. The SBR is a periodically operated fill-and-draw reactor with five discrete periods in each cycle: fill, react, settle, draw, and idle. Herzbrun (1985) found that total organic carbon (TOC) degradation averaged 76% and phenol degradation averaged 99% during the first month of bench-scale operation. This type of treatment is intended to replace activated carbon adsorption treatment of leachates containing hazardous chemical compounds. Instead, activated carbon would be used only as a "polishing" device after SBR treatment.

Conversion of a hazardous-classified waste to a delisted one can sometimes diminish the risk to the generator of environmental suits. This may amount to considerable expenditures of both time and money to demonstrate to the EPA that treatment residuals do not have the characteristics for which they were originally listed as hazardous. In addition, building and paying for the amortization and operation expenses

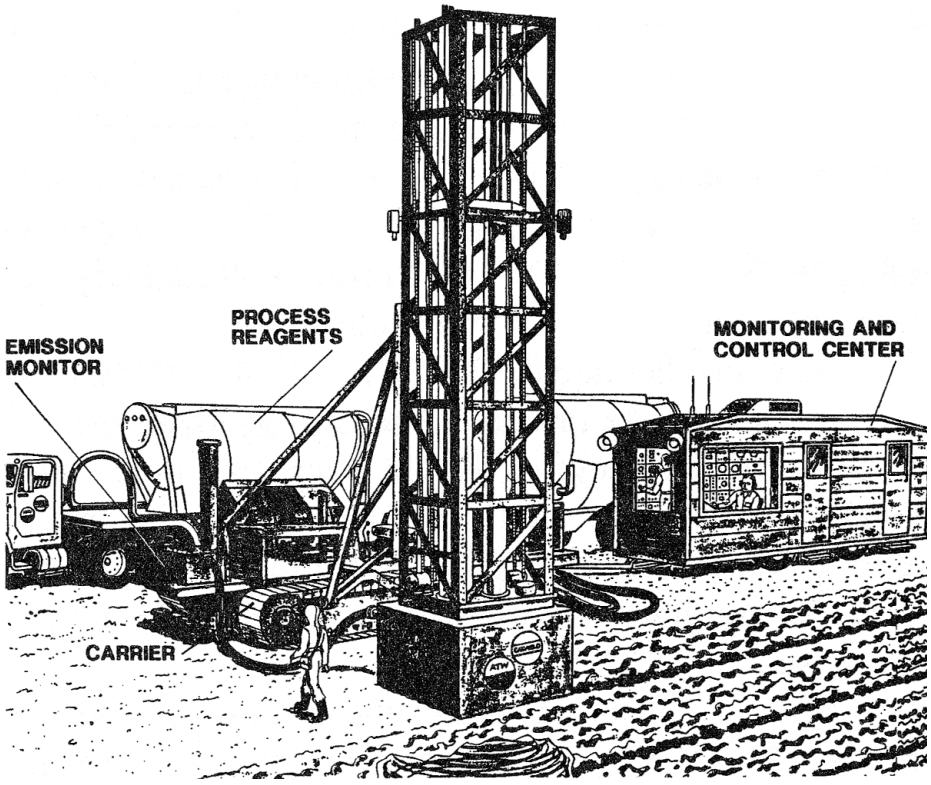


FIGURE 11.14. Detoxifier system. Used with permission from John Wiley and Sons.

of a treatment system can be costly. Also, sometime in the future, the generator's treated and delisted waste might—once again—be listed as hazardous by the EPA. In the long run, it may pay the industrial generator of a toxic waste to contract with an off-site disposal company for handling the waste. At least the industry will have a partner to share the liability of its environmental effects. Perhaps the off-site disposer can obtain delisting after treatment easier than the original industrial generator.

Regional Exchanges of Hazardous Wastes

The concept of regional exchanges or markets for transferring hazardous materials from one supplier to another user is a novel and intriguing potential solution to the dilemma facing society. A regional center enhances the exchanger rather than allowing the alternative disposal into the environment to occur. This process requires a great deal of communication, confidence, and consideration of all parties concerned. Advertisement of products, materials, and chemicals available for exchange must be extensive and

discrete. Sometimes buyers and sellers must remain anonymous. Management of the exchange must be competent and trustworthy, somewhat like a stock market exchange, but without excessive product exposure to the general public. Certainly the objective of reuse without discharge is an admirable one. The procedure needs only refinement, practice, and more experience. There is a similarity in the objectives of these exchanges with those of zero-pollution attainment described in Chapter 15 of this book. The latter goal, however, is attained by all manufacturing of related products taking place in the same industrial complex.

LeRoy (1983) reports that these exchanges have been set up in France by local initiative. Their main purpose is to create and develop new outlets for using waste and saving raw materials.

The National Conference on Waste Exchange (1983) defines a waste exchange "as an operation that engages in transfer of either information concerning waste materials or the waste materials themselves." Waste exchanges were first organized in Europe where depletion of readily available natural resources and limited land-disposal areas forced manufacturers to find alternative sources of raw materials. All of the foreign exchanges are information clearinghouses and most of them are operated by trade organizations, primarily in the chemical industry. Material exchanges are the major innovation in the waste-exchange concept developed in the United States from the mid-1970s.

Surplus materials, equipment, scrap metals, and discontinued products, as well as traditional wastes, may enter the waste-exchange cycle. Industries are using the term "investment recovery" to describe the entire process of recycling and reuse within some plants. Some firms have already investigated or instituted process modifications designed to allow for or enhance the reuse potential of byproducts generated during normal manufacturing processes. Some modifications that have proven successful include (1) substitution of reclaimed acid for typical new electroplating acids, (2) source separation and segregation of various materials, (3) concentration and volume reduction, (4) altering raw materials specifications to allow substitution of lower quality inputs, (5) using intermediate reactions designed to modify waste stream components, (6) tightening process control to take advantage of byproduct (not waste) streams, and (7) educating plant management and workers on the benefits of resource reuse.

One deterrent to successful waste-exchange programs is that of exposing private information to persons outside a particular industrial plant. The program must maintain an agreement of "confidentiality" to protect the proprietary interests of generators and to limit the direct identification of specific firms that are generating a particular material. Industry identifies "potential liability" as the primary reason for nonparticipation in waste-transfer agreements.

Four requirements have been identified (National Conference on Waste Exchange 1983) for industrial resource reuse and waste transfer:

1. Participation in waste exchange must be uncomplicated and cost effective. The exchange itself must be reputable and reliable.
2. Alternatives to conventional treatment and disposal methods that are presented by a waste exchange must be ethical and cost effective.

3. The exchange should have as wide an audience of potential users as possible and should have extensive contacts in the waste management field to be aware of all waste management options.
4. The generator must know where and in what form the waste is being reused or disposed.

Many areas of cooperation between exchanges are possible including the following: (1) common database shared on regional or national level, (2) trading of listings between exchanges for catalogue distribution, (3) network of regional contacts for information referral, and (4) licensing of exchanges to ensure maintenance of quality of service. However, industrial managers hesitate to participate in cooperative exchanges because of the potential liability for mismanagement of waste. Unfavorable economics, especially when affected by high transportation costs for hazardous wastes, may be another deterrent to cooperative exchanges.

An Argonne National Laboratory (National Conference on Waste Exchange 1983) reports that the amount of energy saved by one waste exchange over 2½ years was 10×10^9 Btu. It calculated that a savings of 10^{12} Btu/yr (the equivalent of 100,000 barrels of oil at 10^7 Btu/barrel) would result if 50 exchanges as large or as effective as the one studied existed.

As with other liquid, gaseous, and solid wastes, there are generally no tax incentives, credits, or advantages for industries that recycle hazardous wastes. On the other hand, there are taxes levied for producing them. Exceptions are the states of New Jersey and California where tax advantages are given (or are being considered) for recycling waste.

One example of regional exchange of waste information is shown in Figures 11.15 and 11.16, which serves the southern region of the United States ("Southern Waste Information 1982). It publishes and distributes to interested firms listings of materials available, materials wanted, and services available and wanted. Examples of listing forms are included in Figures 11.15 and 11.16. Materials include acid and alkalis, inorganic chemicals, metals, organic chemicals, solvents, oils and paints, paper, wood plastic, rubber, glass, and miscellaneous. Services include recycling, equipment and supplies, consulting engineering, legal and health-related consulting, tank cleaning and lining, collection and transportation, storage, treatment and disposal, and miscellaneous.

Solar Evaporation

Some hazardous wastes, if sufficiently concentrated and of low volume, can be evaporated by natural sunlight to a very small volume for ultimate disposal or for permanent fixture at the same site. This method of treatment precludes ample sunlight, minimal rainfall and humidity, and adequate land for exposure to the sun's rays.

Sundaresan et al. (United Nations Environmental Protection 1983) report solar evaporation used to dispose of quinophos, a highly toxic pesticide. The semisolid sludge and the residue after solar evaporation are usually incinerated.

They also use solar evaporation ponds for concentrating urea plant spillages. The sludge after evaporation containing about 12% arsenic is stored in drums, sealed, and kept within the factory premises for final disposal (at an unknown destination).

Waste Management Services
Listing Form

A separate from is required for each each service listed.
Limit of two listings.

1. Company Name: _____
2. Mailing Address: _____
_____
_____
3. Company Contact: _____ 4. Title: _____
5. Signature: _____ 6. Date: _____
7. Phone Number: (____)_____ 8. SIC Code: _____
9. Fax Number: (_____) _____

LISTING INFORMATION:

(1) CLASSIFICATION:
(Review all first, then select the one that best describes your firm's service)

- ☐ Recycling
- ☐ Equipment and Supplies
- ☐ Environmental Consulting
- ☐ Legal and Health - Related Services
- ☐ Tank Management
- ☐ Collection and Transportation
- ☐ Storage, Treatment, Disposal
- ☐ Emergency Response/Clean-Up
- ☐ Laboratory Analysis
- ☐ Waste Minimization
- ☐ Miscellaneous

(2) DESCRIPTION OF SERVICE:
(In 25 words or less, please describe your firm's service or product, keeping in mind what the reader of your listing may want to know. You may use the space provided below or type the listing on a separate piece of paper and attach it to this form.)

(3) LOCATION SERVED:
(Give general area where service is available, e.g., Central Georgia, Southeastern U.S., etc)

Send completed form to:
SWIX Clearinghouse
Post Office Box 960
Tallahassee, FL 32302

FIGURE 11.15. Waste Management Services listing form.

Landfilling with Leachate Treatment

The collection and subsequent treatment of leachates from hazardous waste landfills have become an acceptable alternative for disposing of these wastes. Collection systems must be designed to recover all the leachate, and treatment systems must be designed and operated to remove all the hazardous constituents from the leachates. Leachate collection systems require the use of subterranean impermeable barriers and drainage channels to central sump or reservoir sites. Treatments are concentrated mainly on removal of dissolved metals, minerals, and organic matter, as described in earlier sections of this chapter.

Material Available/Wanted Listing Form

A separate form is required for each item listed.
Limit of two listiage.

1. Company Name: _____ SIC Code #: _____
2. Mailing Address: _____
   _____
3. Company Contact: _____ 4. Title: _____
5. Signature: _____ 6. Date: _____ 7. Phone: ( ) _____
8. Fax Number: ( ) _____
9. Check One Only: ☐ MATERIAL AVAILABLE ☐ MATERIAL WANTED

   Classifications (review all first; then select one that best describes your material):

   ☐ ACIDS
   ☐ ALKALIS
   ☐ OTHER INORGANIC CHEMICALS
   ☐ SOLVENTS
   ☐ OTHER ORGANIC CHEMICALS
   ☐ OILS AND WAXES
   ☐ PLASTICS AND RUBBER
   ☐ TEXTILES AND LEATHER
   ☐ WOOD AND PAPER
   ☐ METALS AND METAL SLUDGES
   ☐ MISCELLANEOUS

10. Material to be listed (Main usable constituent, generic name): _____
11. The industrial process that generates this waste: _____
12. Main constituent and percentage: _____
13. Other constituents (including contaminants): _____
14. Percent by (check one): ☐ Volume ☐ Wet Weight ☐ Dry Weight
15. Physical State: ☐ Solution ☐ Slurry ☐ Sludge ☐ Cake ☐ Aggregate ☐ Solid ☐ Dust ☐ Gas
16. Miscellaneous information (e.g. pH, toxicity, reactivity, color, particle size, flash point, total solids, purchase date, manufacturer):
    _____
    _____
17. Potential or intended use: _____
18. Packagine: ☐ Bulk ☐ Drums ☐ Pallets ☐ Bales ☐ Other: _____
19. Present Amount: _____ 20. Frequency: ☐ Continuous ☐ Variable ☐ One Time
21. Quantity thereafter: _____ ☐ Pounds ☐ Tons ☐ Cubic Yards ☐ Gallons ☐ Kilograms ☐ Cubic Meters ☐ Liters ☐ Other _____

    per: ☐ Day ☐ Week ☐ Month ☐ Quarter ☐ Year
22. Restrictions on amounts: ☐ None ☐ Minimum ☐ Maximum _____
23. Available to Interested parties: ☐ Sample ☐ Lab Analysis ☐ Independent Analysis
24. For material wanted, acceptable geographic area (i.e. states, regions, countries):
    _____
25. If necessary to speed communications, please check if your company's name, address and telephone number may be released. ☐ YES ☐ NO

Send completed form to: SWIX Clearinghouse
Post Office Box 960, Tallahassee, FL 32302

FIGURE 11.16. Material Available/wanted listing form.

Goldstein (1984) found that metal-plating leachates from landfills can sometimes be pumped to publicly operated treatment works (POTPs).

DuPont reports the use of powdered activated carbon for the treatment of leachates from toxic waste dumps to remove these contaminants (DuPont 1984).

Disposal into Publicly Owned Wastewater Treatment Plants

Hazardous wastes may be discharged to municipal sewer systems if and when they are properly pretreated to remove and/or detoxify the hazardous components. Because of the cost savings of sending large volumes of wastewater to sewage systems, this method of treatment is especially interesting to industries. However, the hazardous component must first be removed or sufficiently diluted to be acceptable to the receiving municipality.

In keeping with this, Coughlin et al. (United Nations Environmental Protection 1983; Toxic and Hazardous Wastes 1983) used a treatment technology for metallic wastes consisting of physicochemical processes that effectively change the hazardous soluble elements into recoverable nonsoluble solids. The solids are further concentrated by a low-pressure belt filter press that recovers 95% of the solids. The remaining solids are concentrated in an electroflotation system that results in a final treated effluent of 20 ppm of total suspended solids. The solid cakelike material is landfilled with no apparent hazard because of its relatively high pH. The water phase is then discharged to a publicly owned treatment plant. This system represents a typical one for pretreatment of hazardous wastes before admission to POTPs.

Membrane Technology

The use of semipermeable membranes as barriers for the removal of hazardous compounds or elements from reaching the external environment is gaining in popularity and acceptance. Membrane openings or pores are so minute that considerable pressure must be applied to the waste to drive the fluid through them. In normal filtration, microfiltration, the pore sizes are relatively large and the waste solution to be filtered approaches the polymeric membrane perpendicularly (Figure 11.17).

In another more common technique, known as "reverse osmosis" or sometimes "hyperfiltration," the pore sizes are many times smaller and require more liquid pressure to force the smaller molecules through the pores of the membrane. The solution is passed over the surface of a specific semipermeable membrane at a pressure in excess of the effective osmotic pressure of the feed solution.

In selecting the proper membrane to separate hazardous contaminants from wastewater, several environmental parameters must be considered:

1. *Pressure to which the membrane will be subjected:* This varies from as low as 3–50 psig with microfiltration to as high as 200–1,000 psig with reverse osmosis. At the higher pressures, certain membranes may deteriorate or deform because of the mechanical strain put on them.

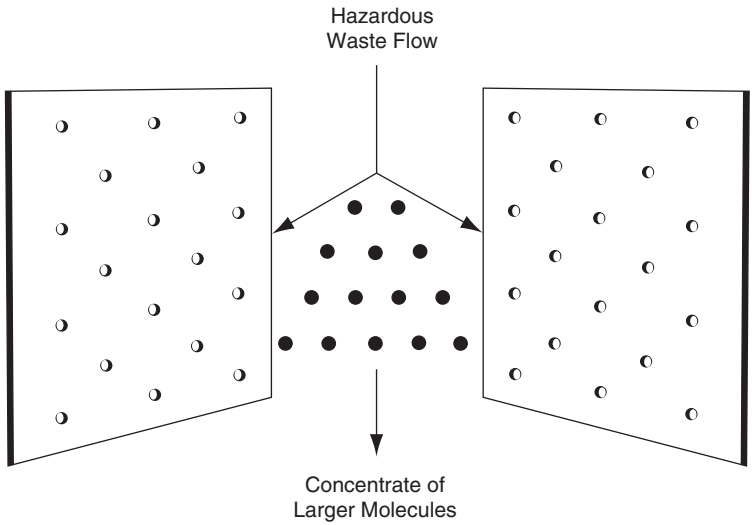


FIGURE 11.17. Separation of hazardous wastes using membrane filtration.

2. *Temperature to which the polymeric membrane will be subjected:* Most membranes will operate with varying efficiencies and lengths of life at temperatures between 0 and 85˚C.
3. *pH range of operation of the membrane will affect its life:* The value will be influenced by the hazardous waste solution pH.
4. Chemical compatibility of each membrane to the specific chemical makeup of the waste solution is important in determining not only the membrane choice, but also its durability under continued operation.

Membrane separation has proven useful for treating and recovering metal salts from plating bath wastes, recycling lubricating oils and rinse waters from can-forming and other metal-working applications, concentrating wastes and conserving process waters in certain chemical processing plants, and in the future recovering pollutants from the large water users such as pulp and paper and textile industries. These applications will be enhanced by scarcity and increased prices of freshwater.

Electrochemical Treatment

One of the objections of chemical coagulation as a hazardous waste treatment device has been the difficulty in adjusting the exact dosages of coagulant required and pH needed to remove the metals. This results in higher operational costs for both chemicals and labor.

Electrochemical treatment eliminates or tends to overcome the objections of chemical coagulation. A direct current is conducted through a cell containing carbon

steel electrodes. The current creates ferrous ions in the waste solution. The ferrous ion acts as a reducing agent and, in the case of the heavy metal chromium, results in the precipitation as the hydroxide. Other heavy metals such as Cu, Ni, Zn, Pb, and Sn are coprecipitated with the ferric hydroxide. It is claimed that no sulfates are formed, as in normal chemical coagulation, and that the effluent is acceptable for reuse in plating operations (Duffy 1983). When using this bipolar cell (carbon steel), one side is the anode and the other is the cathode. The ferrous ion produced at the anode and the hydroxide formed at the cathode react in the wastewater to form insoluble $Fe(OH)_3$. Although no chemicals are added, the carbon steel electrodes are consumed, usually 1–2 lb of iron per pound of heavy metal in the wastewater that is precipitated. Although the manufacturers admit that slightly more sludge is formed with conventional chemical coagulation, in the actual practice somewhat less sludge results. Presumably this is because the exact stoichiometric amount of iron required actually goes into solution in electrochemical treatment. The exact dosage in coagulation, on the other hand, is difficult to control.

A typical cell operating at about 25 amps of direct current (DC) requires about 5 kW of electricity per pound of heavy metal removed. Duffy (1983) reports the operational costs (which presumably include both iron metal and electricity) would be about $1.00/lb of heavy metal removed. He also claims that chelating compounds found in many plating wastewaters do not interfere with the treatment but are broken up by the iron. Although the effluent from electrochemical treatment may be nonhazardous and can be discharged safely to a receiving stream or sewage system, the sludge still remains to be disposed of (usually in landfills) and contains the toxic metals removed as hydroxides. A reduction of the pH of this sludge into the acid range will tend to liberate the metals into solution once again.

New Treatments

Since this field is so new and dynamic, many new treatment processes, in addition to those I have described, are being tested or researched. Randle (1989) summarizes many of these (Table 11.13).

Legal Aspects of Industrial Hazardous Wastes

The U.S. EPA (1998) has presented a tabular history of the U.S. laws regulating pollutant, hazardous, and toxic substance use and control of wastes. Of major concern are the Safe Drinking Water Act (1974, 1977), the Resource Conservation and Recovery Act (1976), the Toxic Substances Control Act (1976), and the Superfund Act and Reauthorization (1980, 1986).

Drinking-water standards were presented by this author in more specific terms and, in addition, Chapter 2 contains the 1996 standards. The list of hazardous and toxic substances continues to expand, while analytical capability, coupled with more refined risk analyses, has pressured the EPA to keep lowering the allowable levels of contaminant discharge. I believe that this trend will continue and, therefore, stress maximum utilization of waste products as the most economical approach to “zero pollution.”

TABLE 11.13
Some New Treatments for Hazardous Waste, Many Still on the Drawing Board

Company	*On Market Use/Method*	*Costs*
BioTrol, Inc., Chaska, MN A. Dale Pflug (612) 448 2515	Organics Bacteria attack contaminant molecules introduced in water, working on soil cleanup	Processing and capital; groundwater (100 ppm contamination), $5–$2 cents/gal; soil, $50–$75 to $100–$125/ton
Groundwater Technology, Inc., Norwood, MA John Higley (800) 635 0053	Organics Small-diameter filter scavenger, part of Filter Scavenger series, removes floating hydrocarbons	Processing: electricity. Equipment: $10,000–$12,000/unit
Micro-Bac International, Inc., Austin, TX	Organics assimilate heavy metals Bacteria metabolize toxic materials	Cost NA
Bob Billingsley (512) 837 1145 Odgen Environmental Services, San Diego	Organics Mobile circulating-bed combustion incinerator	Processing and service by Ogden: $100–$200/ton of soil
Harold Diot (800) 876 4336 Permutit Co., Paramus, NJ Luis Rodguez (201) 967 6000	Heavy metals Sulfide precipitation process removes heavy metals from waste stream	Processing: for existing system removing metals as hydroxides, at 100 gpm, $10 to $30/day Equipment: small batch unit, $50,000; large, over $50 million
Resource Conservation Co., Bellevue, WA Douglas Austin (206) 828 2400	Organics, heavy metals Solvent extraction of contaminants from soil and sediment	Processing and capital: $50–$150/yd
Ultrox International, Santa Ana, CA Jerome Berich (714) 545 5557	Organics Waste or groundwater exposed to ultraviolet light plus ozone or hydrogen peroxide	Processing groundwater, low 15–20 cents/1,000 gal, high 5 cents/gal. Equipment: $60,000–$200,000 for 10 ppm TCE at 210 gpm

TABLE 11.13 *(continued)*

Company	*On Market Use/Method*	*Costs*
Westinghouse Environmental Services, Madison, PA C. Keith Paulson (412) 722 5447	Organics, heavy metals Plasma, fired cupola remelts and recovers metals	Service: $200–$300/ton
	Organics Pyroplasma destroys heat toxics in liquids	Service: <$1/lb
	Organics Infrared conveyor belt drives heat from soil	Service: $200–$300/ton
Zimpro/Passavant Rothschild, WI Bob Nicholson (715) 359 7211	Organics, some metals absorbed by carbon Biophysical system has powdered activated carbonic assist bacteria	Processing: $1/1,000 gal Equipment: smallest unit $85,000; largest, $1 milion
	Wet air oxidation burns high-strength wastes	Processing: 6 cents/gal Equipment: 10 gpm skid mounted unit, $2 million
CF Systems Corp., Waltham, MA Tom Cody (617) 890 1200	Organics Liquified gas extraction uses gases as solvents to recover organic from refinery wastes including water, clay and oil	Processing, operating and equipment: sludge, $75/yd; water at 20 gpm, 20 cents/gal
Freeze Technologies, Raleigh, NC Ken Hunt (919) 850 0600	Liquid–liquid separation process based on freezing	Processing: NA Equipment: $1–2 million
EPA, Raritan Depot Edison, NJ Francine Everson (201) 548 8554	Organics Mobile carbon regenerator for water treatment systems	Costs NA
	Organics, heavy metals Mobile soils washer separates fine soils and contaminants from sands and gravels	Costs NA
	Organics, heavy metals	Costs NA

TABLE 11.13 *(continued)*

Company	*On Market Use/Method*	*Costs*
	Mobile *in situ* contaminant/treatment unit injects grout to contain spills; contaminants treated in place or removed for other treatment via flushing	
EPA, Cincinnati Alfred Kornel (513) 569 7421	Organics Potassium-alkaline polyethylene glycolate reagent breaks halogen bond to chemically react with pollutants	Processing: pilot unit (1.75 tons/batch), $400–$800/ton. Equipment: NA
IIT Research Institute, Chicago Gug Stresty (312) 567 4232	Organics Radiofrequency heating, *in situ*, brings contaminants and water vapor to surface, where collected for treatment	Processing: $30–$60/ton. Equipment: 50–80 ton/day unit, $500,000
Solar Energy Research Institute, Golden, CO John Thornton (303) 231 1269	Organics Contaminated water pumped from ground; solar energy system catalyst forms free radicals to attack chemical bonds of pollutants	Costs NA
Vertech Treatment Systems, Denver Nathan Chesley (303) 452 8800	Organics Aqueous-phase oxidation of contaminated solution	Processing: 10 gpm at 50,000 mg/liter chemical oxygen demand, 30 cents/gal; 50 gpm at same COD, 13 cents/gal Equipment: 10 gpm unit, $3–$5.5 million
Westinghouse Environmental Services, Madison, PA C. Keith Paulson (412) 722 5547	Organics, heavy metals verified Electric pyrolizer burns solids and sludges at extremely high temperatures	Service: $200–$300/ton

Source: From Randle (1969).

Superfund

In 1980, the U.S. Congress enacted legislation creating the Superfund to provide for cleanup of abandoned dumpsites and dangerous spills of toxic materials and to facilitate compensation of victims. The law imposes a tax on chemical manufacturing firms, the revenues from which are placed in a fund ($1.6 billion) to be used solely for these cleanups. Congress intended to force producers and disposers of these hazardous wastes to accept responsibility for their own wastes and for the fund to pay for any residual costs involved.

According to Grossman (United Nations Environmental Protection 1983, 138), the Superfund legislation required the EPA to develop by June 1981 a National contingency plan to guide the search for and cleanup of dangerous sites and to prepare to respond to emergencies such as spills and explosions. A plan was finally proposed in March 1982. "The proposal is so vague as to provide no guarantee that Superfund resources and authority will be used to clean up any site. The plan implies that EPA cares more about saving money than cleaning up sites to protect human health."

Grossman reports that in its first use of Superfund authority, after a toxic dumpsite in Santa Fe Springs, x[1974,1977,] caught fire in July 1981, "top EPA officials quickly negotiated a private settlement with one of the responsible parties . . . The settlement limited the company's cleanup responsibility instead of requiring the cleanup to continue until the hazard was removed. It also committed EPA to testify on behalf of the company in any subsequent lawsuit against it arising from the dump and the fire."

It is alleged by EPA officials that the federal government will pay for 90% of the cleanup costs, while the individual states will pick up the remaining 10%. However, when the property is government owned, the federal share will be limited to 50%.

According to Skinner (United Nations Environmental Protection 1983, 69), the EPA published the list of national priorities sites, identifying 418 sites on December 20, 1982. Provisions were made to clean up these sites by any of the following options:

1. Remove drums from the site
2. Install a clay "cap" over the site
3. Construct ditches and dikes to control surface water
4. Construct drains, liners, and grout curtains to control groundwater
5. Provide an alternate water supply
6. Relocate residents on a temporary or permanent basis

An important part of the Superfund program (according to Skinner) is to encourage voluntary cleanup by private industries and individuals when they are responsible for their releases. Skinner (1983) reported that more than $121 million had been received from industry for cleanup. The EPA also encourages state government involvement in the Superfund program. States and the EPA may enter into a Cooperative Agreement in which a state takes a leading role in a remedial action. Federal money is transferred to

the state and the state develops a work plan, schedule, and budget for the cleanup action. The state then contracts for any services it needs, and the EPA is responsible for monitoring the state's progress throughout the project.

In addition to the 10% state portion of the cleanup, the state must agree to maintain the site after remedial measures have been taken. Since CERCLA was passed in 1980 and up to September 1982, Superfund had agreed to allocations of $221 million (Skinner 1983).

Krog (1985), however, pleads for a revision of the Superfund Law as being lacking in both the original law, and the Superfund II being considered in September of 1985. She maintains that "toxic waste dumping doesn't generate money for anybody except attorneys." She points out that when an industry goes to court over a toxic waste dumpsite, the EPA must do likewise, which takes public funds out of the Superfund budget and transfers them to bank accounts for attorneys. And, according to her, this is not what the Superfund was intended for, but rather to clean up toxic dumpsites.

Former Congressman Robert Torricelli (1985), a member of the House Science and Technology Committee, points out the current problems and fallacies of the Superfund program. He laments that our "20,000 toxic waste sites are not being cleaned up. Hazardous dumps," he continues, "have merely been moved from one location to another, often creating new toxic sites in the process." He maintains that "the Superfund program promotes the storage of contaminated materials, not their permanent destruction." Although Torricelli does not say it, presumably this occurs because storage is still easier, less expensive, and less complicated than destruction of hazardous wastes. He contends that "despite the great intentions and accomplishments of the program, the result has been a lethal shell game that threatens to indefinitely prolong America's toxic legacy."

Some states have not been pleased by the progress made under Superfund. The New Jersey Department of Environmental Protection attempts to block the sale of portions of property containing hazardous wastes until an entire site is cleaned up.

Former Governor Bob Graham of Florida signed into state law, July 1, 1983 (*Miami Herald,* July 2, 1983), a comprehensive environmental bill. The bill included a "provision to impose a 2 cents/barrel tax on pollutants once a state hazardous waste cleanup fund drops to $3 million." Also included in the bill was "a provision to allow homeowners and businesses with small amounts of hazardous wastes to bring it to a state collection site for free disposal." The main part of the new law included a one-time transfer of $11 million plus interest from an existing trust fund to help clean up hazardous waste sites in Florida (estimated to number about 200).

As an example of government's intention to use new laws to prevent disasters from hazardous wastes, the premier of the Province of Ontario, Canada (statement by the Honorable David R. Peterson, July 2, 1985), said that "this government will ensure that environmental hazards do not eat away at the legacy we wish to leave our children. No longer will there be any question of who is responsible for preventing spills or cleaning them up. No longer will innocent victims be left without a route to compensation."

The U.S. Congress enacted the RCRA in 1976, which charged the EPA with implementation. Among its statutes was that of operating a hazardous waste treatment,

storage, or disposal facility. An operator must complete Part A and Part B of this permit. The former is merely an application giving a bare minimum of vital information. Part B permit involves extensive study, survey, completion of forms, meetings, and approvals before a 10-year permit can be issued.

Thorsen and Petura (1983) give a schematic presentation of the steps needed to obtain a Part B permit (Figure 11.18). The entire review of the Part B permit application is expected to take up to 6 months and, when approved, contains very specific terms and conditions that the operator must follow.

In general, two types of applicant operator—each requiring a different approach and consideration for permit—are involved: (1) industrial and (2) regional. The former is an individual plant primarily in business to make a profit and produces a hazardous waste in the process. The latter is a collector, storer, and/or treater of hazardous wastes from a number of individual commercial plants. It, too, expects to make a profit, but as a direct result of the safe handling of the toxic waste. Thorsen and Petura (1983) visualize the decision of either type of applicant as a commitment of substantial time and money. They specify a master plan (not necessarily part of the application), which should describe the following:

1. Types and approximate quantities of wastes to be handled at the site
2. Activities and functions of the facility
3. The business-related aspects (for internal use)
4. Site-development sequence
5. Strategy and resources required for implementation, including schedule, budget, and permit application sequence required to secure all necessary regulatory approvals and permits

Because of the collective extensive hazardous waste management regulations, Thorsen and Petura (1983) recommend that "someone associated with the facility, with a substantial degree of regulatory familiarity, be actively involved with the team throughout the development of the permit application." They also point out that "the concerns and regulations of both federal and state agencies must be addressed."

In 1984, there were 10 regional offices of the EPA to handle these permit applications. Here, they are shown geographically for easy reference (Figure 11.19).

Whitescaver and Clarke (United Nations Environmental Protection 1983) present toxic concentration limits for eight toxic organics and illustrate the wide range of concentrations for the same toxic pollutant. This also shows that effluent guidelines were seldom used but that 14 other techniques were employed, including negotiation and "best practical judgment" (BPJ). Another process permit flowsheet is found in Figure 11.20.

On June 17, 1985, the Canadian Environmental Minister the new Regulation 309 under the Environmental Protection Act. This new regulation is aimed at controlling the process of handling industrial wastes from the generator to the receiver. It will clearly establish the responsibilities of the industries that create wastes, the haulers who carry them, and the site operators who treat and dispose of them.

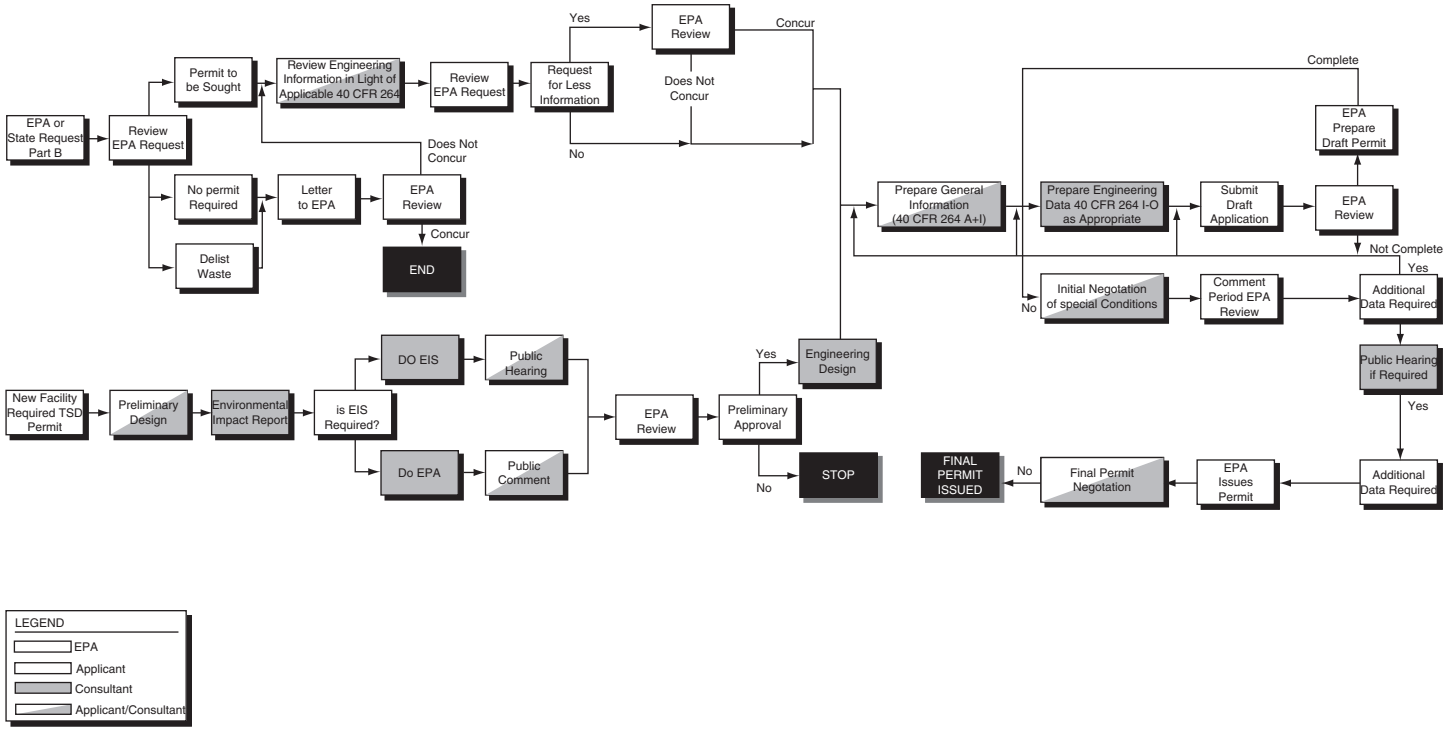


FIGURE 11.18. RCRA TSD Part B permit application.

Toxic limits for air and water are given in Tables 11.14 and 11.15. The reader can use these values to become familiar with the hazardous chemicals and to develop an idea of the concentrations likely to result in serious illnesses and death.

Even the Occupational Safety and Health Administration (OSHA) has become concerned and has pressured state labor departments to enact and enforce laws protecting plant workers from exposures to hazardous chemicals. In Florida, for example, as of October 1, 1985, employers who handle any one of 1,400 chemicals listed by the state must do the following:

1. Post notices informing employees of their rights to know about hazardous chemicals (and give a toll-free telephone number to call for information)
2. Keep for 30 years material safety sheets for each toxic chemical on the list, giving their health hazards and pertinent facts about them
3. Provide these information sheets to employees within 5 days of a request
4. Train employees in the handling, hazards, and emergency treatment for listed chemicals
5. Notify the local fire department of chemicals used and stored

A Water Pollution Control Federation workshop concerned with biomonitoring of toxic chemicals was summarized by Cairns (1985). He states that multispecies (rather than single test organism) are attractive in biomonitoring for toxics for the following reasons: they can give simultaneous data on toxicity and chemical fate; they are likely to use indigenous organisms; they can be cost effective; and they can be more representative of an ecosystem than single species tests. Only organisms can integrate all the factors involved in the toxicity of an effluent, and as Cairns reminds us, "one of the primary reasons for desiring clean water is to protect the aquatic ecosystems." Often we are more concerned with the quality of the water for external or "out-of-stream" uses.

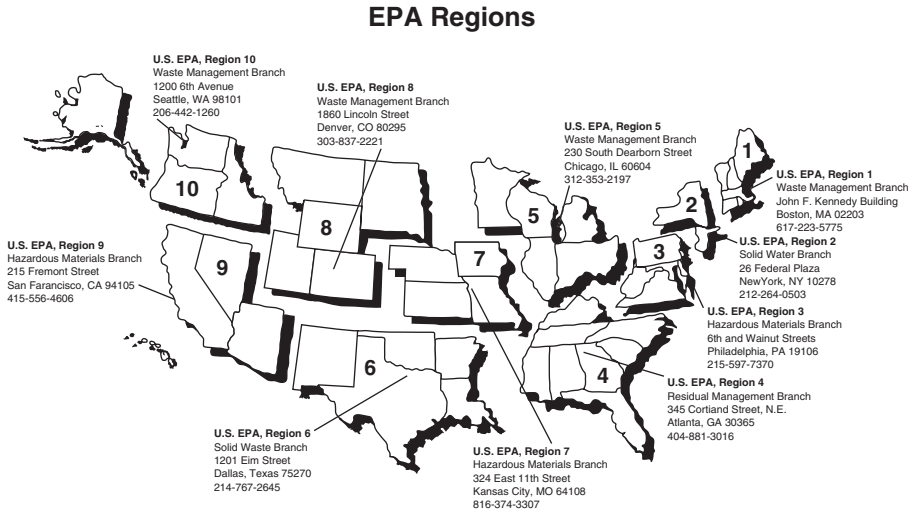


FIGURE 11.19. U.S. EPA office locations.

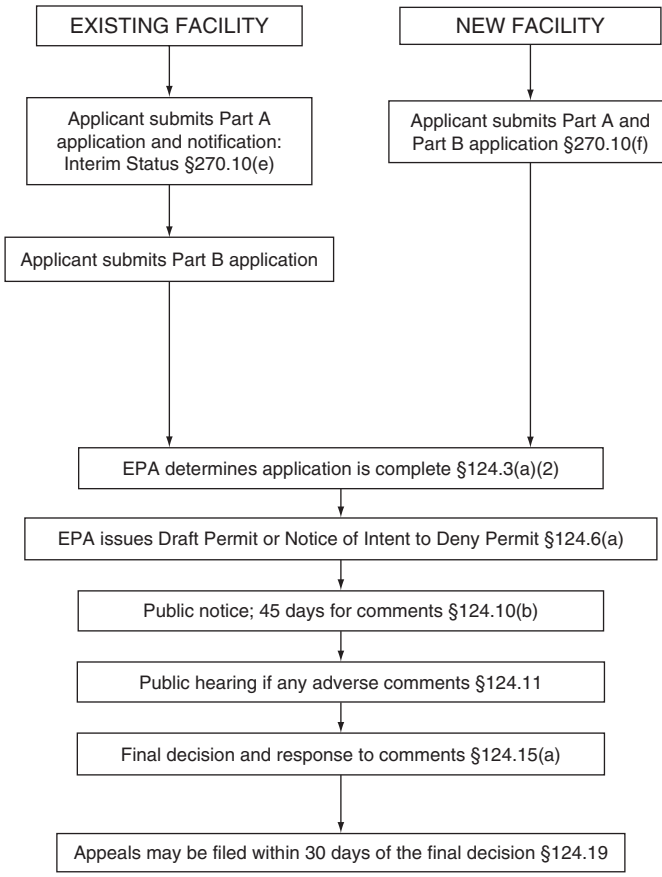


FIGURE 11.20. EPA process permit flowsheet.

On November 8, 1984, the Solid and Hazardous Waste Amendments were added to the RCRA as a reauthorization act (Weston Way 1985). This reauthorization mandates the EPA to selectively and aggressively prohibit the land disposal of specific hazardous wastes. It requires the EPA to require double liners and leachate collection systems for all landfill surface impoundments. In order to receive an RCRA permit, an owner of a landfill or impoundment will now be required to clean up or correct leaks of hazardous waste from the facility regardless of when the waste was managed. In 1986 the small-generator exclusion was lowered from 1 ton/mo to 220 lb/mo. More generators will be required to use RCRA disposal at costs of 15–30 times those of typical municipal landfill. When blending wastes with fuel oil and burning the mixture, the reauthorization requires the EPA to tighten up its rules and dates for complying, to abate abuses of the practice. Because of the need to use relatively large industrial boilers

for blending and burning, some industries may decide to transport their wastes to central facilities with larger boilers. Governing and controlling by the EPA of underground storage tanks will now include feedstock products and fuels. The EPA is now required to develop new standards for existing and new underground storage tanks in 1987. The amendments state that one intention is to minimize the generation of hazardous wastes and the land disposal of hazardous waste by encouraging process substitution, materials recover, and properly conducted surveys.

Site Assessment

The Superfund law, CERCLA, establishes three classes of persons responsible for cleanup costs: (1) all owners and operators of facilities where hazardous wastes are located, (2) anyone who contracted for the disposal of hazardous waste (i.e., the generator), and (3) anyone who transported the hazardous waste. Note that waste may be present because of planned disposal, an accidental spill or release, or dumping by an unknown party (midnight dumping).

Superfund and its numerous state parallel statutes have created a wide net of liability that affects both businesses and individuals, even those who may never have had any involvement with the hazardous materials. These responsible parties may be the owner at the time of original disposal, the current property owner, intermediate property owners, successor corporations, or financial institutions that have foreclosed. Owners may be individual, corporations, or agencies of all levels of government. In the last case, many municipalities and counties today find themselves with major cleanup burdens caused by operation of public landfills. When the web of liability involves several responsible parties, there is always a scramble to decide who pays, and the losers are usually the parties with the greatest financial assets (i.e., the "deep pockets").

Superfund provides one escape clause from this open-ended liability: would-be property owners must attempt, before receiving title to the property, to identify the likelihood that hazardous waste may be present. This is the innocent landowner defense, to conduct "all appropriate inquiry into the previous ownership and uses of the property consistent with good commercial or customary practice." An environmental site assessment (ESA) is an investigation conducted for this purpose.

There are many sources of information that can be used for this purpose. The scope and level of detail can vary. Should a gas station receive the same level of scrutiny as a chemical plant? To bring standards to the preparation of ESAs, the American Society for Testing and Materials (ASTM), working with financial institutions, the real estate industry, and environmental consultants developed and, in 1993, issued "Standard Practice for Environmental Site Assessments: Phase 1 Environmental Site Assessment Process." The ASTM standard has been accepted as the minimum investigation to qualify for the innocent landowner defense.

The ASTM standard consists of four parts: records, review, site reconnaissance, interviews, and a report. Each part has detailed internal standards. The records review covers the widest range of information. It is necessary to review the records of environmental regulators regarding the presence of hazardous waste in soil or ground-

TABLE 11.14
Water Quality Limits for Toxic Pollutants in Three Uses

	Concentration of Toxic Material Considered Limit (ug/liter)				
	Freshwater Aquatic Life		*Saltwater Aquatic Life*		
Toxic Chemical	*Acute*	*Chronic*	*Acute*	*Chronic*	*Human Health*
1. Acenaphthene	1,700	—	970	710	20 (est.)
2. Acrolein	68	21	55	—	320
3. Acrylonitrile	7,550	—	Not available		0.58–0.006 lifetime
4. Aldrin-dieldrin	0.0019 (24-hr avg)	—	0.0019 (24-hr avg)		0.0071 ng/L–0.71 ng/L
	2.5 maximum conc	—	0.71 (max conc)	—	
4A. Aldrin	3.0	—	1.3	—	0.0074 ng/L– 0.74 ng/L
5. Antimony	9,000	1,600	Not available	—	146
6. Arsenic	440	40	508	—	0.22 ng/L–22 ng/L
7. Asbestos	Not available	—	Not available	—	3,000–300,000 fibers/L
8. Benzene	5,300	—	5,100	700	0.066–6.6
9. Benzidine	2,500	—	Not available	—	0.01 ng/L–1.2 ng/L
10. Beryllium	130	5.3	Not available	—	0.37 ng/L–37 ng/L
11. Cadmium	3.0 (100 ppm hardness)	max	59 (maximum)	—	10
	0.025 (100 ppm hardness)	avg	4.5 (avg)	—	
12. Carbon tetrachloride	35,200	—	500,000	—	0.04–4.0
13. Chlorodane	2.4 max	—	0.09 max	—	0.046–4.6
	0.0043 (24-hr avg)	—	0.0040 (24-hr avg)		
14. Chlorinated benzenes	250	50 (fish 7.5 days)	160	129	Hexachlorobenzene 0.072 ng/L–7.2 ng/L Tetrachlorobenzene 38 ug/L–48 Pentachlorobenzene 74–85 Monochlorobenzene 488

TABLE 11.14 *(continued)*

15. Chlorinated ethanes	118,000	20,000	113,000	—	0.094–9.4 (1,2 dichloro ethane)
	18,000	9,400	31,200	—	18.4 mg/L–1.03 g/L (two trichloroethane)
	9,320	2,400	9,020	261	017–1.7 ug/L (two tetra-chloroethanes)
	7,240	1,100	390		(pentachloroethane)
				—	
	980	540	940	7.5	0.19–19 ug/L (hexa-chloroethane)
16. Chlorinated naphthalenes	1,600	—		—	Not available
17. Chlorinated phenols	30–500,000	970	440–29,000	—	0.1 (3 monochlorophenol) 0.1 (4 monochlorophenol) 0.04 (2,3 dichlorophenol) 0.5 (2,5 dichlorophenol) 0.2 (2,6 dichlorophenol) 0.3 (3,4 dichlorophenol) 1.0 (2,3,4,6 tetrachloroph 2.6 mg/L (2,4,5 trichlorop 0.12–12 ug/L (2,4,5 trichlo 1,800 ug/L (2 methyl 4 cl 3,000 (3 methyl, 4 chlor 20 (3 methyl, 6 chloroph
18. Chloroalkyl ethers	238,000	—	Not available	—	0.00038 ng/L to 0.038 ng/L (bischloromethyl ether) 0.003 ug/L–0.3 ug/L (for bischloroethyl ether) 34.7 ug/L (for bis-2-chlorophenol ether)

TABLE 11.14 *(continued)*

	Concentration of Toxic Material Considered Limit (ug/liter)				
	Freshwater Aquatic Life		*Saltwater Aquatic Life*		
Toxic Chemical	*Acute*	*Chronic*	*Acute*	*Chronic*	*Human Health*
19. Chloroform	28,900	1,240	Not available	—	0.019–1.9 ug/L
20. Chlorophenol	4,380	2,000 (one fish species)	Not available	—	0.01 mg/L
21. Chromium	21 (max) 0.29 (avg 24 hr)	Hexavalent	1,260 (max) Cr^{vi}	—	170 mg/L Cr^{iii}
	4,700 ug/L (100 ppm trivalent hardness)		18 (24-hr avg)	—	50 ug/L (Cr^{vi})
	44 ug/L chronic toxicity		10,300 (Cr^{+3}) chronic toxicity)		
22. Copper	5.6 (24-hr avg) 22 ug/L (100 ppm hardness) max	—	4.0 (24-hr avg) 23 (max)	— —	1 mg/L (for taste and odor) no other available
23. Cyanide	32.5 (24-hr avg) 52 (max)	—	2–30 mg/L	—	200 ug/L
24. DDT and metabolites	1.1 max 0.001 (24-hr avg) 0.6 acute toxicity TDE 1,050 acute toxicity DDE	—	0.13 (max DDT) 0.001 (24-hr avg) 3.6 acute toxicity TDE 14 acute toxicity DDE	— —	0.0024 mg/L to 0.24 ng/L for DDT
25. Dichlorobenzenes	1,120	763	1970	—	400
26. Dichlorobenzidines	Not available	—	Not available	—	0.00103–0.103
27. Dichloro ethylenes	11,600	—	224,000	—	0.0033–0.33 0.3 ng/L (for taste and odor)
28. 2,4 Dichlorophenol	2,020	365	Not available	—	3.09 mg/L (toxicity)

TABLE 11.14 *(continued)*

29. Dichloropropanes Dichloropropenes	23,000	5,700	10,300	3,040	87 ug/L
30. 2,4 Dimethyl phenol	2,210	—	Not available	—	400 ug/L (taste and odor)
31. 2,4 Dinitrotoluene	330	220	590	370	0.001–1.1 ug/L
32. 1,2-Diphenyl-hydrazine	270	—	not available	—	4–422 ng/L
33. Endosulfan	0.056 (24-hr avg)	—	0.0087 (24-hr avg)	—	74 ug/L
	0.22 (max)	—	0.034 (max)	—	
34. Endrin	0.0023 (24-hr avg)	—	0.0023 (24-hr avg)	—	1 ug/L
	0.18 (max)	—	0.037 (max)	—	
35. Ethylbenzene	32,000	—	430	—	1.4 mg/L
36. Fluoranthene	3,980	—	40	18	42 ug/L
37. Haloethers	360	122	Not available	—	Not available
38. Halomethanes	11,000	—	12,000	6,400	0.019–1.9 ug/L
39. Haptachlor	0.0038 (24-hr avg)	—	0.0036 (24-hr avg)		0.028–2.78 ng/L
	0.52 (max)	—	0.053 (max)	—	
40. Hexachloro butadiene	90	9.3	32	—	0.45–4.47 ug/L
41. Hexachlorocyclo-hexane (lindane)	0.080 (24-hr avg)	—	0.16	—	0.92–9.2 ng/L
	2.0 (max)	—			
BHC	100	—	0.34	—	1.63–163 ng/L
42. Hexachlorocyclo-pentadiene	7.0	5.2	7.0	—	206 ug/L
					1.0 µg/L (taste and odor)
43. Isophorone	117,000	—	12,900	—	5.2 mg/L
44. Lead	3.8 ug/L (100 ppm hardness and 24-hr avg)				
45. Mercury	0.00057 ug/L (24-hr avg)		0.025 (24-hr avg)	—	144 ng/L
	0.0017 ug/L (max)		3.7 (max)	—	
46. Naphthalene	2,300	620	2,350	—	Not available

TABLE 11.14 *(continued)*

	Concentration of Toxic Material Considered Limit (ug/liter)				
	Freshwater Aquatic Life		*Saltwater Aquatic Life*		
Toxic Chemical	*Acute*	*Chronic*	*Acute*	*Chronic*	*Human Health*
47. Nickel	96 (100 ppm hardness and 24-hr avg) 1,800 (max)	— —	7.1 (24-hr avg) 140 (max)	— —	13.4
48. Nitrobenzene	27,000	—	6,680	—	19.8 mg/l 30 mg/l (taste and odor)
49. Nitrophenols	230	150	4,850	—	13.4 (for 2,4 dinitrocresol) 70 (for dinitrophenol)
50. Nitrosamines	5,850	—	3,300,000	—	0.14–14 ng/l (for n-nitrosodimethylamine) 0.08–8.0 ng/l (for n-nitrosodiethylamine) 0.064–64 ng/l (for n-nitrosbutylamine) 490–49,000 ng/l (for n-nitrosodiphenylamine) 1.60–160 ng/l (for n-nitrosopyrolidine)
51. Pentachloro-phenol	55	3.2	53	34	1.01 ng/l 30 ug/l (for taste and odor)
52. Phenol	10,200	2,560	5,800	—	3.5 mg/l 0.3 mg/l (for taste and odor)

TABLE 11.14 *(continued)*

53. Phthalate esters	940	3	2,944	3.4	313 mg/L (dimethyl phthalate) 350 mg/L (diethyl phthalate) 34 mg/L (dibutyl phthalate) 15 mg/L (di-2-ethyl-hexylphthalate)
54. Polychlorinated biphenyls	0.014 (24-hr avg) 2.0 (max)	— —	0.30 (24-hr avg) 10 (max)	— —	0.0079–.79 ng/L
55. Polynuclear aromatic hydrocarbons (PAHs)	Not available	—	300	—	0.28–28 ng/L
56. Selenium	35 (24-hr avg) 260 (max) 760 (inorganic scienate)	—	54 (24-hr avg) 410 (max)	—	10 ug/L
57. Silver	4.1 (max 100 ppm hardness)	0.12 (average chronic)	2.3	—	50 ug/L
58. Tetrachloroethylene	5,280	840	10,200	450	0.08–8 ug/L
59. Thallium	1,400	40	2,130	—	13 ug/L
60. Toluene	17,500	—	6,300	5,000	14.3 mg/L
61. Toxaphene	0.013 (24-hr avg) 1.6 (max)	—	0.070 (max)	—	0.07–7.1 ng/L
62. Trichloroethylene	45,000	21,900	2,000	—	0.27–27 ug/L
63. Vinyl chloride	Not available	—	Not available	—	0.20–20 ug/L
64. Zinc	47 ug/L (24-hr avg)	—	58 (24-hr avg)	—	5 mg/L

TABLE 11.15
Allowable Concentrations for Air Contaminants Resulting from Hazardous Waste Treatment, Storage, and Disposal Emissions (EPA)

Substance	*ppm*[a]	*mg/m*[3b]
Acetaldehyde	20	40
Acetic acid	1	3
Acetic anhydride	0.5	2
Acetone	100	200
Acetonitrile	4	7
Acetylene dichloride (see *1,2-dichloroethylene*)		
Acetylene tetrabromide	0.1	1
Acrolein	0.001	0.003
Acrylamide—skin		0.03
Acrylonitrile—skin	2	5
Aldrin—skin		0.03
Allyl alcohol—skin	0.2	0.5
Allyl chloride	0.1	0.3
C allylglycidyl ether (AGE)	1	5
Allyl propyl disulfide	0.2	1
2-Aminoethanol (see *ethanolarine*)		
2-Aminopyridine	0.005	0.2
Ammonia	5	4
Ammonium sulfamate (ammate)		2
n-Amyl acetate	10	55
seo-Amyl acetate	13	65
Aniline—skin	0.5	2
Anisidine (o. *p*-isomers)-skin		0.005
Antimony and compounds (as SB)		0.005
ANTU (alpha naphthyl thiourea)		0.03
Arsenic and compounds (as AS)		0.05
Arsine	0.005	0.02
Azinphos-methyl—skin		0.02
Barium (soluble compounds)		0.05
Benzene	1	
p-Benzoquinone (see *quinone*)		
Benzoyl peroxide		0.5
Benzyl chloride	0.1	0.5
Biphenyl (see *diphenyl*)		
Bisphenol A (see *diglycidyl ether*)		
Boron oxide		2
C boron trifluoride	0.1	0.3
Bromine	0.01	0.07
Bromoform—skin	0.05	0.5
Butadiene (1,3-butadiene)	100	200
Butanethiol (see *butyl mercaptan*)		
2-Butanone	20	60
2-Butoxy-ethanol (butyl cellosolve)—skin	5	20

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*^{3}[b]
Butyl acetate (*n*-butyl acetate)	15	70
seo-butyl acetate	20	95
tert-butyl acetate	20	95
Butyl alcohol	10	30
sec-butyl alcohol	15	45
tert-butyl alcohol	10	30
C butylamine—skin	0.5	2
C tert-butyl chromate (as CrO_2)—skin		0.01
*n*Butyl glycidyl ether (BGE)	5	25
Butyl mercaptan	1	4
p-tert-butyltoluene	1	6
Cadmium fume		0.01
Cadmium dust		0.02
Calcium arsenate		0.1
Calcium oxide		0.5
Campher	0.2	
Carbaryl (Sevin®)		0.5
Carbon black		0.35
Carbon disulfide	2	
Carbon tetrachloride	1	
Chlordane—skin		0.05
Chlorinated camphene—skin		0.05
Chlorinated diphenyl oxide		0.05
Chlorine	0.1	0.3
Chlorine dioxide	0.01	0.02
C Chloride trifluoride	0.01	0.04
C Chloroacetaldehyde	0.1	0.3
α-Chloroacetophenone (phenacylchloride)	0.005	0.03
Chlorobenzene (monochlorobenzene)	10	35
o-Chlorobenzyliden malononitrile (OCBM)	20	100
2-Chloro 1,3-butadiene (see *chloroprene*)		
Chlorodiphenyl (42% chlorine)—skin		0.1
Chlorodiphenyl (54% chlorine)—skin		0.05
1-Chloro, 2,3-epoxypropane (see *epichlorhydrin*)		
2-Chloroethanol (see *ethylene chlorohydrin*)		
Chloroethylene (see *vinyl chloride*)		
C Chloroform (trichloromethane)	5	25
1-Chloro-1-nitropropane	2	10
Chloropicrin	0.01	0.07
Chloroprene (2-chloro-1,3-butadiene)—skin	3	9
Chromic acid and chromates		
Chromium, So. chromic		
Chromous salts as Cr		0.05
metal and insoluble salts		0.1

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*[3b]
Coal tar pitch volatiles (benzene soluble fraction) anthracene, BaP, phenanthrene, acridine, chrysene, pyrene		0.01
Cooper fume		0.01
dusts and mists		0.1
Cotton dust (raw)		0.1
Crag herbicide		2
Cresol (all isomers)—skin	0.5	2
Crotonaldehyde	0.2	0.6
Cumene—skin	5	25
Cyanide (as CN)—skin		0.5
Cyclohexane	30	100
Cyclohexanol	5	20
Cyclohexanone	5	20
Cyclohexene	30	100
Cyclopentadiene	8	20
2,4-D		1
DDT—skin		0.1
DDVP (see *dichlorvos*)		
Decaberane—skin	0.005	0.03
Demetron—skin		0.01
Diacetone alcohol (4-hydroxy-4-mathyl-2-pentanone)	5	25
1,2-Diaminoethane (see *ethylenediamine*)		
Diazomethane	0.02	0.04
Diborane	0.01	0.01
Dibutylphthalate		0.5
C *o*-Dichlorobenzene	5	30
p-Dichlorobenzene	8	45
Dichlorodifluoromethane	100	500
1, 3-Dichloro-5,5-dimethyl hydantoin		0.02
1, 1-Dichloroethane	20	40
1, 2-Dichloroethylene	20	80
C Dichloroethyl ether—skin	2	9
Dichloromethane (see *methylene chloride*)		
Dichloromonofluoromethane	100	400
C 1, 1-Dichloro-1-nitroethane	1	6
1, 2-Dichloropropane (see *propylene dichloride*)		
Dichlorotetrafluoroethane	100	700
Dichlorvos (DDVP)—skin		0.1
Dieldrin—skin		0.02
Diethylamine	3	8
Diethylamin (see *ethyl ether*)		
Difluorodibromomethane	10	90
C Diglycidyl ether (DGE)	0.05	0.3
Dihydroxybenzene (see *hydroquinone*)		

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*^{3}[b]
Diisobutyl ketone	5	30
Diisopropylamine—skin	0.5	2
Dimethyl acetamide—skin	1	4
Dimethylamine	1	2
Dimethylaminobenzene (see *xylidene*)		
Dimethylaniline (*N*-dimethylaniline)—skin	0.5	3.0
Dimethylbenzene (see *xylene*)		
Dimethyl 1, 2-dibromo-2, 2-dichloroethyl phosphate (dibrom)		0.3
Dimethylformamide—skin	1	3
2, 6-Dimethylheptanone (see *diisobutyl ketone*)		
1, 1-Dimethylhydrazine—skin	0.05	0.1
Dimethylphthalate		0.5
Dimethylsulfate—skin	0.1	0.5
Dinitrobenzene (all isomers)—skin		0.1
Dinitro-*o*-cresol—skin		0.02
Dinitrotoluene—skin	1	0.2
Dioxane (diethylene dioxide)—skin	10	40
Diphenyl	0.02	0.1
Diphenylmethane diixocyanate (see *methylene bisphenyl isocyanate* [MBI])		
Diporopylene glycol methyl ether—skin	10	60
Di-sec, octyl Phthalate (Di-2-ethylhexylphthlate)		0.5
Endrin—skin		0.01
Epichlorohydrin—skin	0.5	2
EPN—skin		0.05
1, 2-Epoxypropane (see *propyleneoxide*)		
1, 3-Epoxy-1-propanol (see *glycidol*)		
Ethanethiol (see *ethylmercaptan*)		
Ethanolarine	0.3	0.6
2-Ethoxyethanol—skin	20	75
2-Ethoxyethylacetate (cellosolve acetate)—skin	10	53
Ethyl acetate	40	150
Ethyl acrylate—skin	3	10
Ethyl alcohol (ethanol)	100	200
Ethylamine	1	2
Ethyl seo-amyl ketone (5-heptanone)	5	25
Ethyl benzene	10	45
Ethyl bromide	20	90
Ethyl butyl ketone (3-heptanone)	5	25
Ethyl chloride	100	300
Ethyle ether	40	120
Ethyl formate	10	30
C Ethylmercaptan	1	3

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*[3b]
Ethyl silicate	10	85
Ethylene chlorohydrin—skin	0.5	2
Ethylenediamine	1	3
Ethylene dibromide	2	
Ethylene dichloride	5	
C Ethylene glycol dinitrate and/or nitroglycerin—skin	0.02	0.1
Ethylene glycol monomethyl ether acetate (see *methyl cellosolve acetate*)		
Ethylene Imine—skin	0.05	0.1
Ethylene oxide	5	9
Ethylidine chloride (see 1,1-*dichloroethane*)		
N-Ethylmorpholine—skin	2	10
Ferbam		2
Ferrovanadium dust		0.1
Fluoride as dust		0.3
Fluoride (as F)		0.3
Fluorine	0.01	0.02
Fluorotrichloromethane	100	500
Formaldehyde	0.3	
Formic acid	0.5	0.9
Furfural—skin	0.5	2
Furfuryl alcohol	5	20
Glycidol (2,3-epoxy-1-propanol)	5	15
Glycol monoethyl ether (see 2-*ethoxyethanol*)		
Halnium		0.05
Heptachlor—skin		0.05
Heptane (*n*-heptane)	50	200
Hexachloroethane—skin	0.1	1
Hexachlorocaphthalene—skin		
Hexane (*n*-hexane)	50	180
2-Hexanone	10	40
Hexone (methyl isobutyl ketone)	10	40
	5	30
Hydrazine—skin	0.1	0.1
Hydrogen bromide	0.3	1
C Hydrogen chloride	0.5	0.7
Hydrogen cyanide—skin	1	1
Hydrogen fluoride	0.3	
Hydrogen peroxide (90%)	0.1	0.1
Hydrogen selenide	0.005	0.02
Hydrogen sulfide		
Hydroquinone		0.2
C Iodine	0.01	0.1
Iron oxide fume		1
Isoamyl acetate	10	55

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*[3b]
Isoamyl alcohol	10	35
Isoamyl acetate	15	70
Isoamyl alcohol	10	30
Isophorone	3	14
Isopropyl acetate	25	95
Isopropyl alcohol	40	100
Isopropylamine	0.5	1
Isopropylether	50	210
Isopropyl glycidyl ether (IGE)	5	25
Ketene	0.05	0.09
Lead and its inorganic compounds		0.02
Lead arsenate		0.015
Lindane—skin		0.05
Lithium hydride		0.002
LPG (liquefied petroleum gas)	100	180
Magnesium oxide fume		2
Malathion—skin		2
Maleic anhydride	0.03	0.1
C Manganese		0.5
Mercury		
Mesityl oxide	3	10
Methanethiol (see *methyl mercaptan*)		
Methoxychlor		2
2-Methoxyethanol (see methyl cellosolve)		
Methyl acetate	20	60
Methyl acetylene (propyne)	100	165
Methyl acetylene-propadiene mixture (MAPP)	100	180
Methyl acrylate—skin	1	4
Methyl-a (dimethoxymethane)	100	300
Methyl alcohol (methanol)	20	25
Methylamine	1	1
Methyl amyl alcohol (see *methyl isobutyl carbinol*)		
Methyl (*n*-amyl) ketone (see *2-heptanone*)	10	50
C Methyl bromide—skin	2	8
Methyl butyl ketone (see *2-heptanone*)		
Methyl cellosolve—skin	3	8
Methyl cellosolve acetate—skin	3	12
Methyl chloride	10	
Methyl chloroform	35	190
Methylcyclohexane	50	200
Methylcyclohexanol	10	50
o-methylcyclohexanone—skin	10	45
Methyl ethyl ketone (MEK) (see *2-butanone*)		
Methyl formate	1-	25

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*[3b]
Methyl iodide—skin	0.5	3
Methyl isobutyl ketone (see *hexone*)		
Methyl isocyanate—skin	0.002	0.005
C Methyl mercaptan	1	2
Methyl methacrylate	10	40
Methyl propyl ketone (see *2-pentanone*)		
C Methyl styrene	10	50
C Methylene bisphenyl isocyanate (MBI)	0.002	0.02
Methylene chloride	50	
Molybdenum		
Soluble compounds		0.5
Insoluble compounds		2
Monomethyl aniline—skin	0.2	0.9
C Monoethyl hydrazine—skin	0.02	0.04
Morpholine—skin	2	7
Naphtha (coal tar)	10	40
Naphthalene	1	5
Nickel carbonyl	0.0001	0.0007
Nickel, metal, and soluble compounds as Ni		0.1
Nicotine—skin		0.05
Nitric acid	0.2	0.5
Nitric oxide	3	3
p-Nitroaniline—skin	0.1	0.6
Nitrobenzene—skin	0.1	0.5
p-Nitrochlorobenzene—skin		0.1
Nitroethane	10	30
Nitrogen dioxide	0.5	0.9
Nitrogen trifluoride	1	3
Nitroglycerin—skin	0.02	0.2
Nitromethane	10	25
1-Nitropropane	3	9
2-Nitropropane	3	9
Nitrotoluene—skin	0.5	3
Nitrotrichloromethane (see *chloropicrin*)		
Octachloronaphthalene—skin		0.01
Octane	50	200
Oil mist, mineral		0.5
Organo (alkyl) mercury		0.001
Osmium tetroxide		0.000
Oxalic acid		0.1
Oxygen difluoride	0.005	0.01
Paraquat—skin		0.05
Parathion—skin		0.011
Pentaborane	0.0005	0.001
Pentachloronaphthalene—skin		0.05

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*[3b]
Pentane	100	300
2-Pentanone	20	70
Perchloromethyl mercaptan	0.01	0.08
Perchloryl fluoride	0.3	1
Petchloryl fluoride	0.3	1
Petroleum distillates (naphtha)	30	200
Phenol—skin	0.5	2
p-Phenylene diamine—skin		0.01
Phenyl ether (vapor)	0.1	0.7
Phenyl ether-biphenyl mixture (vapor)	0.1	0.7
Phenylethylene (see *styrene*)		
Phenylglycidyl ether (PGE)	1	6
Phenylhydrazine—skin	0.5	2
Phosdrin (mevinphos)—skin		0.01
Phosgene (carbonyl chloride)	0.01	0.04
Phosphine	0.03	0.04
Phosphoric acid		0.1
Phosphorus (yellow)		0.01
Phosphorus pentachloride		0.1
Phosphorus pentasulfide		0.1
Phosphorus trichloride	0.05	0.3
Phthalic anhydride	0.2	1
Picric acid—skin		0.01
Pival (2-pivalyl-1,3-indandione)		0.01
Platinum (soluble salts) as Pt		0.000?
Propargyl alcohol—skin	0.1	
Propane	100	180
n-Propyl acetate	20	85
Propyl alcohol	20	50
n-Propyl nitrate	3	11
Propylene dichloride	8	35
Propylene imine—skin	0.2	0.5
Propylene oxide	10	25
Propyne (see *methyl acetylene*)		
Pyrethrum		0.5
Pyridine	0.5	2
Quinone	0.01	0.04
RDX—skin		0.2
Rhodium, metal fume, and dusts, as Rh-soluble salts		0.0001
Ronnel		1
Rocenone (commercial)		0.5
Selenium compounds (as Se)		0.02
Selenium hexafluoride	0.005	0.05
Silver, metal, and soluble compounds		0.001

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*[3b]
Sodium fluoroacetate (1080)—skin		0.005
Sodium hydroxide		0.2
Stibine	0.01	0.05
Scoddard solvent	50	300
Strychnine		0.015
Styrene	10	
Sulfur hexafluoride	100	600
Sulfuric acid		0.1
Sulfur monochloride	0.1	0.6
Sulfur pentafluoride	0.003	0.03
Sulfuryl fluoride	0.5	2
Systox (see *Demetron*)		
2,4,5T		1
Tantalum		0.5
TEDP—skin		0.02
C Terphenyls	0.1	0.9
1.1.1, 2-Tetrachloro-2,2-difluoroethane	50	400
1.1.2, 2-Tetrachloroethane—skin	0.5	4
Tetrachloroethylene	10	
Tetrachloromethane (see *carbon tetrachloride*)		
Tetrachloronaphthalene—skin		0.2
Tetraethyl lead (as Pb)—skin		0.008
Tetrahydrofuran	20	60
Tetramethyl lead (as Pb)—skin		0.007
Tetramethyl succinonitrile—skin	0.05	0.3
Tetranitromethane	0.1	0.8
Tetryl (2,4,6-trinitrophenyl-methylinitramine)—skin		0.15
Thallium (soluble compounds)—skin as T1		0.01
Thiram		0.5
Tin (inorganic compounds, except oxides)		0.2
Tin (organic compounds)		0.01
Toluene	20	
C Toluene-2,4-diisocyanate	0.002	0.001
o-Toluidine—skin	0.5	2
Toxaphene, (see *chlorinated camphene*)		
Tributyl phosphate		0.5
1,1,1-Trichloroethane (see *methyl chloroform*)		
1,1,2-Trichloroethane—skin	1	5
Titaniumdioxide		2
Trichloroethylene	10	
Trichloromethane (see *chloroform*)		
Trichloronaphthalene—skin		0.5

TABLE 11.15 *(continued)*

Substance	*ppm*[a]	*mg/m*^{3}[b]
1,2,3-Trichloropropane	5	30
1,1,2-Trichloro 1,2,2-trifluoroethane	100	800
Triethylamine	3	10
Trifluoromonobromomethane	100	600
2,4,6-Trinitrophenol (see *picric acid*)		
2,4,6-Trinitrophenyl-methylnitramine (see *tetryl*)		
Trinitrotoluene—skin		0.2
Triorthocresyl phosphate		0.01
Triphenyl phosphate		0.3
Turpentine	10	60
Uranium (soluble compounds)		0.005
Uranium (insoluble compounds)		0.03
C Vanadium:		
V_2O_{25} dust		0.08
V_2O_5 fume		0.01
Vinyl benzene (see *styrene*)		
Vinylcyanide (see *acrylonitrile*)		
Vinyl toluene	10	50
Warfarin		0.01
Xylene (xylol)	10	45
Xylidine—skin	0.5	3
Yttrium		0.1
Zinc chloride fume		0.1
Zinc oxide fume		0.5
Zirconium compounds (as Zr)		0.5

[a]Parts of vapor or gas per million parts of contaminated air by volume at 25°C and 760 mmHg pressure.
[b]Approximate milligrams of particulate per cubic meter of air.

water on the property or on surrounding property. The history of use of the site is necessary. Numerous sources such as air photos, historical property-use maps, tax records, building permits, or any other type of historical information can be used.

The site reconnaissance is conducted by an environmental professional to observe the present and, to the extent possible, past use of chemicals and hazardous substances on the property and adjoining property. Areas to be observed include, for instance, storage facilities, process areas, and waste-disposal areas. Access to all parts of the facility is imperative during such a reconnaissance, but is often difficult.

The final information component is gathered from interviews with current and prior owners and occupants of the site. The site manager or superintendent is an invaluable resource. Facility records, particularly regarding environmental management

and compliance, are useful. Interviews with local officials who deal with the facility on a day-to-day basis, such as fire department or environmental compliance personnel, are valuable.

The environmental professional then prepares a report following the recommended report format. This report includes documentation of the data compiled and supporting the conclusions of the report.

Who is qualified to prepare an ESA? Virtually any person who has an understanding of environmental processes or science, and who understands the purpose behind the methods specified by the ASTM, is qualified. Specific technical training in an environmental discipline may not be required; individuals with experience in the operation of chemical manufacturing or use, or of waste disposal, may be qualified. Some states have registration procedures for environmental professionals that include educational and experience criteria.

Bankruptcy apparently is no longer an escape route for an industry to avoid cleanup costs of hazardous waste dumps. The U.S. Supreme Court ("A clean victory" 1986) decided that bankrupt companies "retain an obligation to safeguard the public's safety after they go broke." In a five-to-four decision written by Justice Lewis F. Powell, Jr., "The Federal bankruptcy code is not meant to allow property to be abandoned in violation of state health laws." Although many more cases are expected to reach the court, the public's interest appears to be a major concern in any decision involving hazardous wastes whether old, abandoned, or current.

The federal government is not exempt from problems of disposing hazardous wastes legally. Federal agencies were found by a congressional study ("3 U.S. agencies" 1986) to have deposited tons of toxic wastes into a leaking California dump during 1985. Evidently the EPA banned the use of the facility for Superfund waste. The bulk of the 8,300 tons of toxic wastes came from the Department of Defense. The General Accounting Office maintained, however, "that although EPA can mandate how it handles toxic wastes under its own jurisdiction, it lacks authority to force others to follow its policies relating to licensed dumps that are having environmental problems. The only way EPA can prevent federal agencies from using a particular disposal facility is to close it."

The 104th U.S. Congress threatened to amend the Superfund cleanup law so that the taxpayers rather than the polluters would pay for the cleanup. The proposed bill, if it had passed, would have eliminated cleanup liability for pollution caused prior to 1980, when Superfund was passed, or 1986, when insurance companies stopped underwriting industrial liability. Sites contaminated earlier would have been cleaned up at taxpayers' expense or not cleaned up at all. Under CERCLA, liable polluters can obtain 30% of their cleanup costs paid by the pollution tax fund.

Industrial Insurance

Despite adequate precautions of waste planning, treatment, recovery, and reuse, industrial plants should protect themselves against eventual failure. Damages caused by accidental spills or unavoidable errors of discharge to the environment can be covered by adequate insurance.

In an editorial in the *Wall Street Journal* (1981), any company that stores, treats, or disposes of solvents, acids, alkalis, or other hazardous materials is advised to have some insurance. The RCRA of 1976 holds industry responsible for a "cradle to the grave" accounting of hazardous materials produced by themselves. The EPA was required by this act by January 1981 to ensure industry's coverage of $3 million for each case of long-term damage up to a maximum of $6 million a year, excluding legal defense costs. For sudden spills, the required coverage is $1 million for each case and up to $2 million a year. Many insurance brokers are of the opinion that the EPA's proposed limits are not sufficient to cover a major accident. In 1981, only three U.S. insurance companies were offering coverage for these damages. Therefore, many U.S. industries provide their own insurance for accidental spills.

Insurance problems have also carried over to the trucking industry, which is largely responsible for hauling away hazardous wastes. According to Giltenan (1985), "The reluctance of the insurance industry to cover pollution liability is causing near panic among handlers of hazardous materials, and truckers are being especially hard hit." As a result of insurance costs and reluctance to insure, many truckers—especially marginal ones—are getting out of the hazardous materials business. Under Section 30 of the Motor Carriers Act of 1981, truckers are required to carry a minimum of $5 million insurance coverage for bodily, property, and environmental-restoration (pollution) liability. The spill area of liability has also become too costly for insurance carriers to continue underwriting this coverage. Some large truckers are paying the higher premiums and carrying policies in excess of $5 million. Most of the higher insurance costs are blamed on the increased tendency of courts to rule in favor of environmental pollution victims. Some of the higher costs are being passed on to chemical shippers, making the costs of hazardous waste disposal even higher.

The Chemical Process Industry (CPI) notes the change in the insurance industry towards industrial environmental coverage ("CPI Scrambles 1985). It feels that " inexpensive (pollution) insurance may never again be available, certainly not in the short term." Without adequate pollution insurance, the CPI faces troublesome times. How can it protect itself against liabilities associated with sudden and accidental mishaps, such as gas leaks, and non-sudden and gradual instances, such as seepage from waste holding sites? Large companies are considering self-insurance to cover the dangers. Smaller companies are looking to trade-association and broker-assisted programs offering primary coverage for the major firm needs (worker's compensation, product liability, comprehensive general liability, and automobile liability/physical damage insurance). Insurance premiums, if obtainable, will be much more expensive, especially if pollution liability is clearly included. As a last resort, the federal government may enact legislation to assist the chemical industry. The exact nature of the assistance is not yet known, but it is likely that it will be similar to that offered the nuclear industry and for those needing flood insurance.

Federation (WEF, formerly WPCF) Committee Chairman Dan Hinricks revealed ("Hazardous waste conferences" 1985) that because of the complex liability issues involved in hazardous waste cleanup, the insurance market has almost totally dried up. He said, "The need is there, but if companies can't get insurance, they certainly

aren't going to get into the business." He calls the insurance situation "the single, most important concern in the hazardous waste industry."

Illegal Dumping

Jaffe (1983) asserts that

> Despite tougher controls on the disposal of toxic wastes, illegal dumping has not been curbed. Instead, the law enforcement official say, waste haulers have found new ways to skirt the laws and new places to unload their poisonous cargo. States rely on a so-called "manifest system," which it forms for detailing the route and final location of all toxic wastes. In the manifest the kinds and quantity of waste chemicals are recorded. The hauler must include where the delivery is to be made and the disposer must tell the manner of final treatment. However, the illegal dumpers' answer to the manifest system has been "creative accounting and forgery."

Many illegal dumping suits have been filed and decisions have been rendered by the courts. It is not the purpose here to describe or elucidate the circumstances of each.

Storage of Hazardous Industrial Wastes

Hazardous wastes are generated by industry in small quantities generally. Whether they are exported for treatment and disposal or handled for treatment on the premises, they usually are stored temporarily. Storage is necessary in these cases to obtain sufficiently large quantities for efficient continual treatment. If these toxic wastes are collected and transported to some distant site for treatment, they often are also stored for some period at the distant site.

Once we accept storage as an integral step in the ultimate treatment of hazardous wastes, it becomes necessary to provide proper storage treatment. The following criteria should be integrated into the design and operation of hazardous waste storage:

1. Limited access: Entrance should be available only to previously certified and qualified plant personnel.
2. Proper ground location: Storage should be located at a proper distance from living and working people, with consideration for wind direction and velocity.
3. All storage ground area must be impermeable to spilled or leaked wastes. When spills or leaks occur, they cannot be allowed to permeate into the ground but must be drained off the impermeable surface to a collection sump from which they are pumped to treatment or transfer.
4. Containers or tanks must be corrosion proof and tight fitting.
5. Ample storage area: Provide several times the anticipated maximum storage area to account for breakdown in collection and treatment systems.

6. Monitoring devices: Leaks and fires into the surrounding air and on the ground out of the storage area should be monitored by continuously operated sensing equipment.
7. Storage area leak plan: An action plan for catastrophe-type leak occurrence should be available, publicized, and readily available if such a hazard takes place.

The Chemical Conservation Corporation (ChemCon) made available ("New transfer waste facility" 1985) a new hazardous waste transfer (storage) facility to generators in central Florida. The property is 1.2 acres, with undeveloped area adjacent for expansion. It is enclosed by a 6-ft chain-link fence, with a single security gate at the entrance. The truck area is graded concrete, which will contain spills and minimize chemical absorption. With a capacity of 5,500 ft^2 for hazardous waste storage, the floor is heavily sealed concrete, divided into flammable and corrosive drum storage areas by a spill-containment curb. Each area slopes to a center drain, leading into one of two emerging 120-gallon waste containers located outside the building. Fire walls separate storage from personnel areas, and the storage electrical system is explosion proof. A hazardous waste sprinkler system protects the entire building with fire detection devices as well. These detection devices automatically signal the Orange County Fire Department and a portable telephone system ensures constant communication. Detection devices on all entries to the storage building are linked to the Orange County Sheriff's Department.

Hazardous wastes stored here are transferred to ultimate disposal facilities for incineration, reclamation, neutralization, chemical fixation, or sanitary landfill. Currently, this storage (transfer) facility is handling 1.5 million gallons of hazardous waste per year for 350 industrial customers in 1,500 drum quantities.

Safety Storage ("Chemical storage containers" 1985) has designed and constructed containers to comply with both NFPA standards and OSHA regulations. Many local hazardous material storage ordinances require hazardous chemicals to be stored in secondary containment structures to prevent spills or leaks from contaminating groundwater. Their containers are made of 10- to 14-gauge ASTM-A569 steel, possess secondary spill capacity of 500 gallons, and hold 30- to 55-gallon drums. The interiors are protected from chemical attack by a resistant epoxy coating. Outside dimensions are 8 by 8 by 22 ft. Each unit is static grounded to prevent ignition of flammable wastes by electrical discharge. Fire protection is provided with a water line and three fire sprinkler heads. Roofs are specially designed to handle explosions and floors are thick plywood underlain with subfloors of 12-gauge epoxy-lined steel. Many other optional features for hazardous waste storage safety are available on an optional basis. These containers may be leased to assist industry in conserving capital.

Stone (1985) advocates the use of selected existing mined space as technically and economically feasible for permanent storage of untreatable wastes or the toxic end products of hazardous waste treatment. Advantages of this type of storage include the following:

1. In deep mined space, the waste would be below drinking-water aquifers.
2. It is isolated from the public and the surface ecology.

3. If required, waste can be isolated from hydrological environment by encapsulation or containerization.
4. Security can be readily maintained.
5. In a sealed mine, no continuing maintenance will be required.
6. If retrievability is desired, the mine could be used as a long-term underground warehouse.

Such treatment must protect all parts of the environment during construction while adding waste, and for an indefinite period into the future, storage underground uses the minimum of existing land surface. One possibility in mines is that of abandoned salt mines, which are relatively free of people and industry. Although this practice has been used for storage of certain hazardous wastes for a number of years, one must be certain that the chemicals do not react with themselves or with the salt in the mine.

Storage of hazardous chemicals before and during use is a vital phase of material production. The reader can attest to this by reviewing some of the examples of accidents that have occurred from too little attention to this subject.

Transportation and Spill Prevention of Industrial Hazardous Wastes

Transporting hazardous wastes to an external site for storage, treatment, or disposal must be considered an integral part of its ultimate solution. It is usually done by truck or rail. Both modes of transportation involve hazards of accidental spills or wrecks that may release the wastes to an unsuspecting and unprepared environment. Trucks exhibit more flexibility in delivery and pickup. In the last decade, it was estimated also that rail accidents were two or three times more prevalent than truck accidents.

Although rail accidents are down, their severity is up (Cushman 1989). It was estimated that 4 billion tons of hazardous materials were shipped by rail annually, involving 250,000 shipments daily. The problem of moving hazardous chemicals by rail is not only that they may be explosive, poisonous, or corrosive, but also that trains move them through industrial areas and residential areas of cities. States and localities, along with the federal government, regulate chemical shipments by road and rail, but confusion and complex compliance have resulted in burdens for carriers. Congress is examining possibilities of legislation allowing larger cities to approve of transportation routes and the Department of Transportation to select the safest routes.

Several states have incurred 10 or more railroad accidents involving toxic wastes (Cushman 1989). In both modes of transportation, the waste generator must accept the responsibility of complete and correct disclosure of the chemical contents of the hazardous wastes. The more information about the composition and characteristics of the wastes to be transported, the safer will be the trip (in the case of an accident) to the

disposal site. The transporter assumes the responsibility for safe delivery of the waste to the disposer. When the transporter accepts the waste, he or she should sign a verification statement with the generator that he or she is transporting a given volume of specific hazardous waste.

The same statement should be signed and given to the disposer once the wastes have arrived and been unloaded at the disposal site. Packaging of hazardous wastes should be done in conformance with Department of Transportation regulations. Usually, liquid wastes are packaged in 55-gallon drums, sealed, and surrounded by vermiculite for insulation against the shock of collisions or pumped into tank cars supplied for the purpose by truckers or railroad haulers.

The truck fleet used by ChemCon ("New transfer waste facility" 1985) travels more than 1 million miles per year and has been accident free for its 3 years of operation.

Nemerow (1987) discusses the scavenger system that hauls, treats, reclaims, and disposes of a variety of industrial wastes. These wastes are usually small in volume and difficult and/or hazardous to dispose of by the producer in normal ways. The expenses of transportation may be considerable and determine in the long run whether exportation/treatment is a better alternative to on-site treatment.

Spills

As an example of protection against spills, the Proform Company offers a system for eliminating spills in areas where rail cars are loaded, unloaded, washed, or fueled. It provides a structural fiberglass-reinforced plastic track collector pan system to collect and isolate spills for treatment and disposal. The system components include collector pans that attach to rails and cross drains that connect with preinstalled underground pipes leading to a sump for treatment (Proform, Inc. 1985).

Jim Bradley, the Minister of Environment for Ontario, Canada, announced on July 3, 1985, that "our initial priorities include regulation of the transportation of dangerous goods . . . " Bradley was new in this high position and recognized how vital it is to transport hazardous materials safely.

Example of Twentieth-Century Hazardous Waste Treatment

LaBranche and Collins (1996) conducted research experiments to determine whether hazardous wastes containing volatile organic petroleum products (VOCs) could be removed by air stripping and the optimum conditions for doing so. Full factorial experimental trials were conducted to determine the influence of inlet water flow rate and temperature on trichloroethylene (TCE), perchlorethylene (PCE), and total petroleum hydrocarbon (TPH) removal. Results indicated that economical air stripping of VOC and TPH compounds could be achieved using low liquid flow rates (20–75 L/min), high air/water ratios (225–898), and medium liquid temperatures (16–28˚C) in tray-type air strippers.

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