Hazardous Waste Management

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INTRODUCTION

Hazardous waste management is a broad and evolving field. Applicable state and federal regulations comprising over 60,000 pages are continually being updated. Many of these regulations overlap and are subject to differences in interpretation that often lead to court rulings. Regulations, economic pressures and public perception are forcing companies to rapidly change the way they manufacture products in order to minimize hazardous waste generation.

Over 200 million tons of solid hazardous waste are generated annually in the United States. Huge quantities of hazardous waste deposited in landfills, ponds, fields, and other locations require removal or in situ treatment. Common hazardous wastes include: solvents, acids, bases, heavy metals, pesticides, plating and heat treating wastes. Six major effects of improper hazardous waste management are: groundwater contamination, contamination of surface runoff, air pollution, fire and explosion, adverse health effects via direct contact, and via the food chain.

This chapter provides a general overview of federal regulations governing hazardous waste management, as well as a brief review of the types of hazardous waste, waste minimization, and treatment and disposal technologies. Four types of hazardous waste will be discussed here: chemical waste, radioactive waste, infectious waste, and mixed waste.

1.0 REGULATORY OVERVIEW

Federal, state, and local governments regulate hazardous waste management. Federal regulatory agencies sometimes delegate authority to the state agencies provided that the state programs are at least as strict. Only federal regulations are discussed here. With a few exceptions, the Environmental Protection Agency (EPA) governs most federal hazardous waste management activities. The Department of Transportation (DOT) governs the transportation of all hazardous wastes except for High Level Nuclear Waste.

The Nuclear Regulatory Commission (NRC) governs nuclear wastes from the private sector and co-regulates mixed wastes with the Department of Energy (DOE). Other agencies, such as the Occupational Safety and Health Administration (OSHA) and the Bureau of Land Reclamation, have responsibilities within the hazardous waste management process. Important legislation is summarized below.

1.1 RCRA

Congress passed the Resource Conservation and Recovery Act (RCRA) in 1976 as an amendment to the Solid Waste Act of 1965. RCRA is composed of 10 parts covering all aspects of hazardous waste management with the exception of nuclear waste. It governs generation, storage, transportation, treatment, recycling, and disposal. The generator of hazardous waste is responsible for the waste through each of these steps and beyond. EPA was authorized by RCRA to establish and implement regulations governing hazardous waste management. This involved: (1) defining hazardous waste, (2) tracking the transportation of the waste, (3) establishing construction and operation standards for treatment, storage and disposal facilities (TSDF's) and (4) establishing guidelines for state hazardous waste management programs. The Medical Waste Tracking Act of 1988 (MWTA) expanded RCRA to include regulating the disposal and treatment of medical waste.

1.2 CERCLA

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) was passed in 1980 to address the cleanup of toxic waste sites. CERCLA provides for liability, compensation, cleanup and emergency response to existing and closed hazardous waste sites. The heart of CERCLA is the Superfund that started in 1980 as a $1.6 billion fund. The Superfund Amendments and Reauthorization Act of 1986 (SARA) revised and broadened CERCLA creating a $8.5 billion fund to be collected through special taxes. Congress asserted that regardless of who was responsible for causing the contamination, the sites needed remediation in order to protect human health and the environment.

EPA involvement begins with the identification of a potential hazardous waste site. The EPA has developed the Emergency and Remedial Response Information System (CERCLIS) to document all of the sites in the United States that may be candidates for remedial action. As of 1993, the list was approaching 30,000 sites. In order to be eligible for cleanup under CERCLA, a site must first be placed on the National Priorities List (NPL). The NPL identifies the hazardous waste sites of immediate concern and ranks them according to their relative risk to public health and the environment. As of August 1990, 1187 sites were on the NPL list identified as "Superfund sites." The EPA addresses the clean up of each site on a case by case basis. Part of EPA's process involves the identification of the Potentially Responsible Parties (PRP's) for (1) state or federal remedial action, (2) recovery of necessary response cost incurred, and (3) damages to natural resources. The PRP's may include past owners or operators, generators of the hazardous substances that are at the site, or the transporters who brought the waste to the site. EPA tries to get the PRP's to initiate clean up or to pay for the remediation, but if the PRP's cannot, the EPA uses money from the Superfund for the clean up and tries to recover the monies later. No amount of care can guarantee a person handling hazardous substances protection from liability. The liability cannot be transferred to another party.

Under CERCLA, the EPA can respond to incidents involving hazardous substances in three ways:

1. Immediate removal and emergency response to prevent significant harm (completed within 6 months)
2. Planned removal which is an expedited response to a situation that is not necessarily an emergency
3. Remedial response that requires additional time and money intended to achieve a site solution that is a permanent remedy

1.3 TSCA

The Toxic Substance Control Act (TSCA) was enacted in 1976 to prevent environmentally unsound chemicals such as DDT and PCBs from being released to the environment. TSCA gives the EPA ninety days to investigate the potential deleterious effects of new chemicals on the environment before allowing them to be manufactured. If a chemical poses a significant threat, the EPA may impose special restrictions from warning labels to an outright ban. The EPA can also require testing of existing chemicals if there is insufficient information to form a risk assessment.

1.4 HSWA

Congress passed the Hazardous and Solid Waste Amendments (HSWA) in 1984. These amendments significantly broadened the scope and effectiveness of RCRA. A major theme of the HSWA is the protection of groundwater through the following:

- hazardous waste landfill design requirements
- requirements for small quantity generators
- requirements for underground storage tanks
- requirements for landfilling of municipal wastes
- restrictions on future land disposal
- treatment requirements for waste deposited in landfills

Provisions of the HSWA ban the land disposal of specified types of hazardous wastes unless the wastes are first treated to levels that are protective of human health and the environment. The regulations specifically prohibit the disposal of bulk (non-containerized) liquid wastes in landfills and surface impoundments. It prohibits disposal of containerized liquids unless no alternative is available. The amendments set out a series of deadlines for ending land disposal of various groups of hazardous wastes.

There are three exceptions to the land ban:

1. the waste meets EPA and state treatment standards
2. a petitioner demonstrates to the EPA and/or state that the waste in question will not migrate from the disposal unit for as long as the wastes remain hazardous
3. the EPA has issued a variance extending the deadline

In addition, the Occupational Health and Safety Act of 1970, the Hazardous Materials Transportation Act of 1975 (HMTA), portions of the 1970 Clean Air Act and as amended in 1990, the Clean Water Act (1972) and the Safe Drinking Water Act (1974) also regulate certain aspects of hazardous waste management.

1.5 Code of Federal Regulations

Once Congress passes legislation, federal agencies prepare and codify regulations which are published annually in the Code of Federal Regulations (CFR). The CFR has 50 Titles. Title 10 contains the Atomic Energy Act and related NRC and DOE regulations, Title 29 the OSHA regulations, Title 40 the EPA regulations, and Title 49 the DOT regulations. The federal government publishes the daily amendments and potential changes to the annual CFR and court interpretations in the Federal Register (FR). Several private companies sell computerized versions of the CFR as well as state regulations including recent updates and legal interpretations. Users can access these databases via modem, from floppy disks, or CD-ROM format. The computer databases allow for smaller storage space requirements, provide quicker access to specific regulations, and provide various advanced searching methods.

2.0 *DEFINITION OF HAZARDOUS WASTE*

Hazardous waste has been defined by RCRA as a "solid waste, or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may (1) cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible or incapacitating reversible illness or, (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported or disposed of or otherwise managed..." Other regulations may define hazardous waste differently, however RCRA sets the standard. The term solid waste includes solids and certain liquids or gases.

As shown in Figure 1, the RCRA definition has a number of conditions and exceptions which are a result of overlap with other regulations and vestiges of earlier definitions of hazardous waste. Most of these exempted wastes are either regulated by other federal legislation or are regulated on the state and/or local level. The RCRA definition of solid waste does not include radioactive waste, because this waste is governed by the Atomic Energy Act. The flowchart illustrates the general philosophy behind defining and classifying hazardous waste. We advise the reader to consult the CFR prior to classifying a waste. As shown on the chart, RCRA classifies a waste as hazardous if the CFR lists it as a hazardous waste, or it has hazardous characteristics.

2.1 *Listed Wastes*

EPA has defined and listed certain wastes as hazardous. A mixture of a listed hazardous waste and a non-hazardous solid waste is a hazardous waste. The "mixture rule" implies that any concentration of listed waste in a material makes it a hazardous waste. In recent years, the EPA has allowed a more flexible interpretation which classifies certain wastes based on characteristic hazardous components and concentration. Furthermore, one may be able to de-list a listed waste by following procedures in 40 CFR 260. RCRA regulates unrinsed containers, inner linings, and any residue or soil contamination from hazardous waste as hazardous waste.

2.2 *Non-Listed Wastes*

If the waste is neither listed or specifically exempted, the generator must make a judgment based upon the hazardous characteristics of the waste. In some cases the generator can apply process knowledge of the waste or past experience to classify the waste as hazardous, otherwise the waste must be tested at an approved laboratory. If the waste has any of the four characteristics below, it is hazardous:

A. Reactivity (coded D003)
- normally unstable
- ignites on contact with water
- releases toxic gases in contact with water

B. Corrosivity (coded D002)
- aqueous pH < 2 or > 12.5
- corrodes SAE steel at greater than 0.25 in/year

C. Ignitability (coded D003)
- flash point < 60° C
- solid iginitable compressed gas oxidizer
- listed as a Class A or Class B explosive

D. Toxicity (coded D###)
- capable of killing, injuring, or otherwise impairing a living organism on contact

The Toxic Characteristics Leaching Procedure (TCLP) is a laboratory method for estimating the leaching potential of a landfilled material. The evaluation of toxicity is based on the concentration of the specific chemical in the leachate. These chemicals and their maximum allowable concentrations are specified by Table 1, 40 CFR 261.

2.3 Risk Assessment

Risk assessment is a quantitative means of evaluating the potential detrimental effects that an activity will have primarily on human health. Risk is a probability usually determined by obtaining a unit risk factor from toxicological data and using effective exposure data considering all pathways. Typically, the allowable target for a hazardous waste activity is a risk of 1x10-6 chance of a person getting cancer during a lifetime of exposure due to the activity. Risk analysis has many applications, for example:

1. determining allowable concentrations in the TCLP analysis and in concentrations of allowable listed wastes in solid wastes
2. determining clean up levels of hazardous waste sites under remediation
3. determining the best treatment strategies for remediating hazardous waste sites
4. permitting of new hazardous waste activities such as a new TSDF
5. factored into the Life Cycle analysis process in new product design

3.0 MANAGEMENT OF HAZARDOUS WASTES

Nearly every manufacturing or service operation generates hazardous waste. This waste can be managed on-site or be transported to a permitted treatment, storage, and/or disposal facility (TSDF). Using the manifest system, the EPA follows the trail of hazardous waste from its initial generation through final deposit or treatment.

3.1 Hazardous Waste Generators

Generators are required to comply with RCRA, OSHA and state and local regulations. If there is any release or potential release of toxic materials to the environment, generators will also have to comply with regulations in (1) the Clean Water Act, (2) the Clean Air Act, (3) SARA Title III, as well as a wide variety of other industry specific regulations and controls.

The EPA has defined three separate classes of Hazardous Waste Generators: (1) Conditionally exempt generators, (2) small quantity generators (SQG's) and (3) large quantity generators (LQG's). Several states have stricter definitions and tighter requirements for generators especially concerning accident preparedness and contingency plans.

Conditionally exempt generators (40 CFR 261) account for the largest number of generators and produce the least quantity of hazardous waste: less than 100 kg/month of hazardous waste and less than 1 kg/month of acutely hazardous waste, and store less than 1000 kg of waste on site. Although RCRA exempts them from most of the extensive permitting requirements, it still requires them to (1) identify their hazardous waste and (2) treat hazardous waste on-site or transport it to a permitted TSDF or recycling facility.

SQG's generate less than 1000 kg/month and less than 1 kg/month of acutely hazardous waste, and store less than 6,000 kg of waste on site. RCRA allows SQG's to store the wastes up to 180 days or 270 days if the nearest TSDF is more than 200 miles away. SQG's must obtain a 12 digit EPA ID number, follow proper waste transportation and storage requirements, and perform proper record keeping and reporting including tracking of manifests.

Large Quantity Generators (LQG's) are those that generate more than 1000 kg/month, or 1 kg/month of acutely toxic waste or store more than 6,000 kg of waste on site. RCRA requires these generators to comply with all requirements in 40 CFR 262-265 and related regulations outside RCRA. A LQG does not require a Transfer Storage and Disposal Facility (TSDF) permit if they: (1) store only their wastes on-site (do not accept wastes from outside the facility), (2) store all wastes in a designated area, (3) store the wastes in proper containers properly marked as hazardous waste, and (4) comply with the requirements for owners or operators in Subparts C (preparedness and prevention) and D (Contingency Plan and Emergency Procedures) in 40 CFR Part 265.

3.2 Storage of Hazardous Waste

Proper storage of hazardous waste provides for appropriate separation of wastes, separation of non-compatibles, easy access to the waste, reasonable protection from vandalism, and appropriate secondary containment. These practices result in the reduction of the incidence and severity of accidents, simplified compliance, reduced/eliminated fines, and a more economical use of space and management time. Hazardous wastes are stored in many different types of approved containers including drums, overpack containers, tanks, and impoundments.

3.2.1 Underground Storage Tanks

There are approximately 1.5-2 million underground storage tanks (UST) in the United States. UST's are regulated by the EPA through a mixture of statutory and regulatory provisions, or by the states to which the authority has been delegated. In many instances, inconsistent federal, state, and local laws have resulted in conflicts regarding the designation of "responsible parties." RCRA Subtitle I regulates tanks that contain a regulated Superfund substance or a liquid petroleum product with at least 10 percent of its volume underground (including piping connected to the tank). The statute requires tank owners to notify the state that they possess such tanks and directs the EPA to establish detection, prevention, release-detection requirements, and performance standards. Subtitle I does not cover approximately two-thirds of tanks because either other regulations cover them, or they do not pose a threat to human health and the environment. These tanks include:

- tanks holding 110 gallons or less
- farm and residential tanks holding 1,100 gallons or less of motor fuel used for noncommercial purposes
- tanks storing heating oil burned on the premises where it is stored
- tanks on or above the floor of underground areas such as basements or tunnels
- septic tanks and systems for collecting stormwater and wastewater
- flow through process tanks
- emergency spill and overflow tanks
- surface impoundments and pits
- tanks storing hazardous waste (RCRA Subtitle C)

Approximately 200,000 USTs are leaking or have leaked at one time. The four major causes of releases are corrosion, faulty installation, piping failure, and overfilling. The majority of older tanks are bare steel and therefore galvanic corrosion is the most common fault. Federal regulations issued September 13, 1988, require that new UST systems be properly installed according to industry codes, equipped with spill and overfill prevention devices, protected from corrosion and equipped with leak detection devices. Tanks no longer in use must be decommissioned either by removal or by filling with an inert material.

3.3 Transportation of Hazardous Waste

The DOT regulates all aspects of the transportation, packaging, labeling, marking and placarding of hazardous waste under the Hazardous Materials Tracing Act of 1975 (HMTA), 49 CFR Parts 172-179. The HMTA was reauthorized in 1993, and governs all hazardous material shipments.

The DOT has five different divisions that govern the transportation of hazardous waste/materials:

1. Coast Guard
2. Federal Aviation Administration
3. Federal Highway Administration
4. Federal Railroad Administration
5. Research and Special Programs Administration

Under RCRA, the EPA is directed to establish certain standards for transporters of hazardous materials and to coordinate transportation regulatory activities with the DOT. The transportation of hazardous waste may also be regulated on the local level. State and local governments may require shippers and carriers to provide information about the types of materials they handle, origins and destinations of shipments, routes followed, miles covered in a given year, proof of insurance coverage, vehicle inspection dates, and drivers employed. Some states require hazardous waste registration, special training and certification, pre-notifications of shipments and periodic summaries of activities. Local authorities may also restrict the routes that hazardous waste transporters take.

3.3.1 Generator Requirements

The generator is required to ship wastes in the proper containers and accurately mark and label them (40 CFR 262). In addition, the generator is responsible for providing the transporter with the proper placards per 49 CFR 172 Subpart F. The placards alert the first responders to a spill of hazardous materials. The placards are DOT approved and includes the hazard symbol, ID number, and UN hazard class number. The placards are placed on the ends and sides of motor vehicles, rail cars, and freight containers. Each container must be labeled with a hazardous waste label, which includes the generator's name and address, the proper shipping name, DOT hazard class, EPA hazard class, and waste type. Other appropriate labels are required such as "flammable" or "corrosive." Containers should be labeled so that the contents of a package can be identified if it is separated from its shipping papers.

3.3.2 Waste Manifests

The uniform hazardous waste manifest provides the mechanism for "cradle-to-grave" tracking of hazardous wastes. All hazardous waste shipments, except those from conditionally exempt SQG's must be accompanied by this form. States with EPA authorization can print their own version and they may have additional requirements. Part 262, Subpart D sets forth generator reporting and recordkeeping requirements, and hazardous waste import and export requirements are covered in Subpart E and F, respectively. When shipping interstate, the shipper should use the receiving states manifest. A copy of the manifest is kept by the generator, the transporter, and the owner of the receiving facility, and one copy is sent to the state. A second copy is returned to the generator upon arrival at the TSDF within 45 days of shipment. The manifest must be kept for 3 years or longer. SQG's are not required to submit copies of their manifests to the state but LQG's are. The generator must keep a log of the manifest numbers used.

The manifest requires information about the generator, waste type, DOT shipping description (49 CFR 173.2), waste quantity alternate acceptance facility, spill cleanup precautions, TSDF authorization numbers, billing information, listing of hazardous materials and non-RCRA regulated wastes, location of generator, hazardous waste numbers, physical state of waste, hazard code(s), and intended treatment or disposal method in code. It also requires the generator and transporter to certify that the wastes are in proper condition for transportation.

4.0 HAZARDOUS WASTE TREATMENT

"Treatment means any method, technique, or process, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste, or so as to recover energy or material resources from the waste, or so as to render such waste non-hazardous, or less hazardous; safer to transport, store, or dispose of; or amenable for recovery, amenable for storage, or reduced in volume." (40 CFR 260)

A facility that performs the above is required to obtain a RCRA Part B permit or operate under Interim Status until a permit is obtained. There are certain exceptions to these requirements as specified in 40 CFR 265.

4.1 Treatment Options

Table 1 summarizes many of the hazardous waste treatment technologies that are available today. Many of these technologies have been adapted from other manufacturing fields such as chemical, mining, plating, water and waste water treatment, and concrete manufacture.

The four basic classifications of treatment technologies used here are physical, biological, chemical, and thermal. Physical treatments such as air stripping, sedimentation, and adsorption separate the hazardous constituent from the waste, resulting in a reduced volume of hazardous waste. Other physical treatments such as compaction and shredding reduce the size of the waste but not the total mass. Biological treatments such as bioreactors and composting result in the biological degradation of the hazardous constituents in a waste stream. Chemical treatments such as fixation, sterilization, and chemical oxidation destroy or reduce the toxicity or mobility of the contaminant by breaking and/or making chemical bonds in the hazardous constituents of the waste. Thermal treatments such as incineration, microwave treatment, and vitrification destroy the contaminants or reduce their mobility through intense heat.

The cost information provided in the table is intended to serve as a general guideline only. The costs are from published project costs, vendor estimates, and EPA compiled reports, and have been estimated in terms of 1994 dollars. The cost of any hazardous waste treatment method is highly dependent on the specific contaminant, concentration, quantity of waste to be treated, treatment goals, regulatory fees and restrictions as well as a myriad of other performance goals.

4.2 Selecting a Suitable Waste Treatment Facility

The generator is ultimately responsible for the waste if the transporter or TSDF fails to handle the waste properly. It is therefore very important to perform due diligence in investigating a TSDF. Below are some items to check out prior to shipping wastes anywhere.

Facilities need a RCRA Part B permit or interim status permit. One should obtain copies of all permits: state, local, air and water emissions and check to see that the application or permits cover the appropriate waste types and processes. In addition, check for:

- notices of violations and court actions
- plant security, alarms, and emergency response
- safety practices and written procedures
- spill containment and groundwater monitoring
- laboratory certification
- personnel qualifications and experience
- housekeeping and waste handling practices
- financial stability: ability to pay for closure and post closure monitoring, insurance, ability to compensate injured parties and indemnity clients against loss

TSDF's are usually very specific in the type of waste that they can accept. Generators may rely on the services of a waste broker to arrange for treatment or disposal. The broker may also arrange vendor contracts, make arrangements for waste acceptance, and hire a transporter. The generator is ultimately responsible for the decisions the broker makes, and it is imperative that these selections be reviewed by a responsible member of the company.

4.3 Waste Disposal

The land disposal of hazardous waste is a highly discouraged practice in the United States. However, it is inevitable that some wastes be disposed of, because there is not enough treatment capacity nor complete treatment technologies available for all the wastes generated. Table II summarizes the various disposal technologies currently available.

4.4 Remediation

Cleaning up hazardous waste sites involves the implementation of the CERCLA regulations. The clean up process involves investigation, feasibility studies, risk assessment, record of decision, design of remediation systems, construction and implementation, and long term monitoring. This is covered in more detail in another chapter.

5.0 INFECTIOUS WASTE MANAGEMENT

Infectious wastes are biological wastes potentially contaminated with disease-producing organisms. They can pose a hazard to personnel who handle their disposal as well as to the general public. The EPA regulates medical waste management under RCRA Subtitle J promulgated in the Medical Waste Tracking Act (MWTA) of 1988. RCRA defines regulated medical waste as "...any solid waste generated in the diagnosis, treatment, or immunization of human beings or animals, in research pertaining thereto, or in production or testing of biologicals..." (40 CFR 259). The MWTA directs the EPA to establish a demonstration program for managing and tracking medical waste. Much of the regulation is controlled by state and local government and varies widely from state to state. The EPA has seven recommended infectious waste categories:

1. isolation wastes (wastes from patients with communicable diseases)
2. cultures and stocks of infectious agents and associated biologicals
3. human blood and blood products
4. pathological wastes
5. contaminated sharps
6. contaminated animal carcasses, body parts, and bedding
7. unused sharps

Storage of infectious wastes should consider the integrity of the packaging, storage temperature, the duration of storage, and the location and design of the storage area. In selecting the appropriate packaging, the waste type, and handling and treatment methods should be taken into consideration. Protection from sharps is another important factor. The biohazard symbol must be prominent.

The EPA now requires that medical waste be sterilized prior to disposal to kill all pathogens in the wastes. Not all states enforce this yet for landfills. Incineration and steam sterilization are the most frequently used treatments, however, other processes are effective. There are approximately 6,700 on site incinerators at hospitals throughout the country and approximately 60% of waste is treated on site. If no longer hazardous after treatment, the material may be disposed of at a sanitary landfill or in the sewer if locally approved.

Biological indicators, which are a resistant strain of bacteria, test the effectiveness of treatment technologies. The indicators are placed in the waste prior to treatment and their destruction indicates the success of the treatment. Table 1 includes several infectious waste treatment options.

6.0 RADIOACTIVE WASTE MANAGEMENT

6.1 Sources

Radioactive wastes come from a wide variety of sources including nuclear power plants, government reactors, private industry, defense, and medical activities. Nuclear power waste sources include mine tailings, enrichment, fuel fabrication, reactor operation, spent nuclear fuel, and decommissioning of reactors. Industrial sources include production processes, research, manufacturing of radiopharmaceutical compounds, smoke detectors, and watch dials. Defense wastes include waste from manufacture of nuclear weapons and operation of nuclear powered vessels. The volume of defense waste generated is ten times that of commercial waste. Medical sources include wastes from medical diagnosis, treatment, and research.

There are three classifications of nuclear waste: high level (HLW), transuranic, and low level (LLW). HLW are wastes that contain materials that were exposed to high level nuclear reactions or contain spent fuel from nuclear reactions. High-level wastes currently exist at federal government facilities such as the Hanford Reservation Center in Washington, the Idaho National Engineering Laboratory, the former Western New York Nuclear Service Center in West Valley, New York, and Savannah River (DOE, 1987).

Transuranic wastes, are compounds having more protons than uranium, e.g., plutonium. It is primarily produced by the reprocessing of spent fuels and in processing weapons grade material. LLW can be produced from any action involving radioactive material. The largest source is from mine tailings of uranium and thorium mines. Other sources mainly consist of contaminated clothing, equipment, structural material, cleanup materials, and a large amount of potentially contaminated material such as packing and paper and activated material.

6.2 Government Involvement

The Atomic Energy Act of 1954 (AEA) was the first legislation to include controlling radioactive waste management. As of 1986, eighteen different federal laws, governed radioactive waste management programs. These laws are enforced by the DOE, NRC, EPA, DOT, Department of the Interior, and various other smaller agencies as well as state mandated programs. Congress determined LLW to be a state issue. The Nuclear Waste Policy Act of 1982 established a framework for developing and maintaining a system for HLW management and disposal in the US. As part of this act the US Treasury established a nuclear waste fund to receive payments for disposal fees. The DOE, through the Office of Civilian Radioactive Waste Management (OCRWM), develops geological repositories in compliance with 10 CFR 60.

The NRC reviews nuclear safety, siting, construction, and operation of repositories for the commercial sector. It also inspects the activities of the OCRWM. The NRC is responsible for regulating the receipt, possession, and the use and transfer of radioactive materials to protect public health and safety and the common defense and security of the United States.

CFR Title 10 contains the NRC regulations. Part 20 provides the basic standards for protection from radiation. Other technical requirements are spelled out in 29 CFR 1926, OSHA "Safety and Health Requirements for Construction," the ASME code for pressure and piping, the American Concrete Institute "Code Requirements for Nuclear Safety Related Concrete Structures" (ACI 349-80) and relevant parts of the Uniform Building Code, the Uniform Mechanical Code and the National Electric Code.

The EPA is responsible for developing environmental standards to protect the health and safety of the public and the environment from potential hazards in the management and disposal of nuclear wastes.

6.3 Health Concerns with Radiation Exposure

Radiation exposure may cause severe acute health effects and chronic carcinogenic, teratogenic, or mutagenic effects. The principle of "as low as reasonably achievable" (ALARA) is the basis for the management of nuclear waste originally established in the Atomic Energy Act of 1954. The hazardous nature of a waste stream is measured by a number of factors:

1. activity level expressed as nanocuries/gram (nCi/g) of waste
2. the type of radioactive emission: alpha, beta, gamma
3. the half life of the waste isotopes
4. the relative physical stability of the waste
5. the mobility, leachability or in some cases volatility of the waste

Activity is measured in units of curies. One curie (ci) is equivalent to the disintegration rate of one gram of radium or 3.7×10^{-10} disintegrations/sec. A rad is the dose of ionizing radiation that produces energy absorption of 100 ergs/gram in any medium. The relative biological effectiveness (RBE) is used as a measure of the specific biological damage caused by different types of radiation. It is used to calculate the rem (roentgen-equivalent, man) dose unit which is determined by multiplying the absorbed dose in rad by the RBE.

The EPA sets standards for exposure to radioactive materials in the environment: "the combined annual dose equivalent to any member of the public in the general environment resulting from: (1) Discharges of radioactive material and direct and indirect radiation from such management and storage and (2) all operations covered by part 190 [the uranium fuel cycle] shall not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other critical organ" (40 CFR 191). Waste management facilities must meet this criteria with "reasonable expectation" for 1,000 years and provide a "reasonable expectation" that releases will be limited for 10,000 years (40 CFR 191.16).

6.4 Disposal/Storage

Nuclear wastes cannot be detoxified or the hazards reduced like other waste through traditional treatment methods. The relative hazards of nuclear waste decrease over time such that proper storage of wastes over time can render the wastes non-hazardous. In many cases the disposal of nuclear waste is a storage problem. The treatment that is performed on the wastes usually involves either concentrating the wastes to reduce volume or stabilizing the physical form of the wastes to reduce the mobility of the waste and simplify handling of the waste. Special precautions must be taken to avoid exceeding the "criticality" of the fissil material waste that could cause a runaway nuclear reaction.

Tables 1 and 2 summarize applicable treatment and disposal technologies for radioactive wastes. HLW and Transuranic waste present a health risk.

Disposal facilities for HLW and transuranic wastes must be on federally owned land and are regulated solely by the Atomic Energy Act regulations in 10 CFR part 60. The design concept for the disposal of HLW and transuranic wastes is to place the appropriate canisters in a deep geologic depository. The DOE has collected 10 billion dollars since 1998 in taxes to cover cost of building storage facilities. This is scheduled to begin in the year 2010, however the DOE has not yet cited an interim storage permit. This design concept includes a temporary storage facility known as a monitored retrievable storage or MRS. As listed in Table II, numerous other technologies have been suggested, however there is no current plan of further development of these alternative technologies.

6.5 Management of LLW

The states have responsibility to provide for the safe management of LLW generated within their borders. States may license the LLW facility themselves or the NRC will license them. In addition to radiological protection, the states must regulate other aspects of the management of the facilities. 10 CFR 61 provides certain requirements for LLW facilities.

As of June 1994, only two sites were open for LLW disposal: Barnwell County, South Carolina, and Hanford, Washington. These two sites, however, accept waste from only a limited number of locations. Other disposal sites have submitted license applications, but the federal government under environmental pressure has been slow to approve them. The lack of permanent disposal facilities for LLW has caused the thousands of generators throughout the country to store the wastes at their own sites and may cause those generators without adequate storage capacity to shut down.

States have the right to regulate radioactive wastes that are exempt from NRC enforcement. The NRC exempts waste that:

1. cause <10 millirem exposure/year/person
2. cause <1 millirem of exposure to a large group/year
3. guarantees that no person receives >100 millirems/yr from all activities at the licensed facility

6.6 Transportation

The DOT primarily governs transportation of radioactive materials as specified in 49 CFR parts 173-178. These regulations specify performance criteria for packaging, package activity limits, driver training requirements, and routing restrictions. The NRC regulates the receipt, possession, use and transfer of byproducts and sources of special nuclear materials.

The NRC also sets standards for the design and performance of packages used to transport high-level radioactive materials and conducts inspection of its licensees. Other NRC regulations require the advance notification to the states of certain shipments and provide for physical security measures.

7.0 MIXED WASTES

Mixed waste (MW) is both hazardous and radioactive. Since mixed waste is considered hazardous under RCRA and radioactive under the Atomic Energy Act, both the NRC and the EPA work to address the management of the wastes. It is generated by pharmaceutical and biomedical research laboratories, universities and research laboratories, nuclear reactors, commercial facilities, analytical laboratories, DOE/DOD facilities, new TSDF's, and old disposal sites.

DOE estimates that it generated 22,000 cubic meters of mixed wastes in 1990 and has an inventory of 107,000 cubic meters of MW from past operations. It also estimates that they will generate 600,000 cubic meters remediating their sites. In contrast, commercial mixed waste is generated at a rate of 140,000 cubic feet per year, however, 70% of commercial mixed waste is incinerated and some materials are pretreated thereby further reducing the volume.

The generation and characterization of mixed wastes will likely increase as cleanup of CERCLA sites proceeds. While land disposal restrictions require treatment of mixed wastes, there is very little treatment or disposal capacity for mixed wastes in the U.S. A new mixed waste facility is scheduled to be opened in Hanford, Washington (see Table II), however it is only designed for mixed waste from on-site remediation activities. Consequently, most mixed waste is stored either on site or at designated facilities. Storing of mixed wastes can be problematic, because RCRA may not allow storing of hazardous waste under a facilities permit. Therefore, the EPA enacted a policy to relax enforcement of storage regulations of certain mixed waste generators. Most generators are not equipped to store mixed wastes which can pose a health and safety problem for workers.

8.0 CORRECTIVE ACTION

Corrective action refers to the investigation and remediation of releases of hazardous constituents from facilities that have or are seeking hazardous waste facility permits, or are operating under interim status. RCRA Section 3004(u) requires that any permits issued after November 8, 1984 require corrective action for all releases of hazardous waste or hazardous constituents from any solid waste management unit at the facility. Corrective action beyond the facility boundary must be performed where necessary to protect human health and the environment, as part of ongoing permit conditions.

The term "release" under RCRA is broader than as defined under CERCLA. It includes releases that are exempt under CERCLA and covered by the Clean Air Act and NPDES permits. The EPA broadly defines the term "release" to include a release of any amount to soil, surface water, groundwater, or air of any hazardous waste or hazardous material listed in Appendix VIII of 40 CFR Part 261.

Once there has been a release the corrective action process begins in five steps:

1. A RCRA facility assessment is made which is a desktop review of all information available, a site inspection, and optional sampling.

2. A corrective action order is given as specified in permit conditions.
3. A RCRA facility investigation is performed to characterize the extent of contamination resulting from the spill including risk assessment and contaminant movement modeling. It includes feasibility studies of treatment technologies.
4. Interim measures that need to be taken to address releases of immediate concern.
5. A corrective measure study sets forth the proposed remediation alternatives. It is required if the contamination found exceeds an "action level."

40 CFR 254 discusses clean up levels required under Corrective Action. These levels are subject to interpretation based on health risk assessments.

9.0 WASTE MINIMIZATION

Waste minimization is modifying a process in order to reduce the volume or the toxicity of the waste generated prior to any treatment, storage, or disposal. It includes source reduction and environmentally sound recycling, equipment and process changes, product reformulation, raw material substitution, and improvements in inventory control and housekeeping, maintenance and training.

Waste generators can achieve significant savings by reducing raw material consumption, waste disposal or treatment fees, and in tax credits given for waste minimization efforts. Federal law explicitly states that waste reduction is the preferred antipollution method. The 1984 amendments to RCRA promulgated a new Federal policy that wherever feasible, the generation of hazardous waste is to be reduced or eliminated as expediently as possible. The EPA ranks management options as follows:

1. waste reduction
2. waste separation and concentration
3. waste exchange and recycling off site
4. energy/material recovery
5. incineration/treatment
6. secure land disposal

The EPA published guidance on hazardous waste minimization in the 1993 publication Hazardous Waste Minimization: Interim Final Guidance for Generators (EPA/530-F-93-009). In this document the EPA lists six basic elements generators should incorporate into their waste minimization plan:

1. top management support
2. characterization of waste generation/management costs
3. periodic waste minimization assessments
4. cost allocation
5. encourage technology transfer
6. program implementation and evaluation

9.1 Life Cycle Design

Environmental groups have criticized waste minimization in the past for being too narrowly focused and sometimes resulting in process modifications that only shift pollutants from one media to another. The solution to this problem is the concept of Life Cycle Design (LCD). LCD is a method of product and process design that incorporates the minimization of waste production throughout every step of design and every step of the life of the product. This "cradle to grave" design method considers raw material extraction, product manufacturing, use, and final residual disposal. LCD establishes a more coherent means of integrating environmental requirements with more traditional concerns in product development such as performance, cost, cultural, and legal requirements.

Life Cycle Analysis (LCA) is one of the more promising systematic approaches for identifying and evaluating opportunities to improve the environmental performance of industrial activity. It is a useful tool for evaluating the environmental consequences of a product. LCA can be used in conjunction with LCD or be employed separately. By focusing on source reduction as well as reuse, recovery, and treatment, LCA gives a more accurate portrayal of the environmental impacts and true costs of a project. The EPA has put together a Life Cycle Design Manual as a guide for conducting and interpreting life cycle inventories.

10.0 Right to Know Laws

SARA Title III and the OSHA Hazard Communication Standard of 1985 established a regulatory program that requires disclosure of information to workers and the general public about the potential dangers of hazardous chemicals. They also require development of emergency response plans for chemical emergencies. Congress enacted these laws in response to the more than 2,000 deaths caused by the release of a toxic chemical in Bhopal India in 1984. The Clean Air Act amendments of 1990 placed additional responsibilities on the EPA and OSHA to enact legislation requiring further sharing of risk information and process hazard analysis. States and municipalities have passed additional right to know laws in response to specific companies not disclosing information about their process chemicals. Title III also requires the reporting of annual releases (42 USC 9061) and required that facilities that release extremely hazardous chemicals over threshold amounts must immediately notify the community emergency coordinator and the state commission. The EPA now requires monitoring for 320 chemicals. A proposed new rule could double the requirements to 633 chemicals that have to be monitored.

The majority of state right-to-know laws address both community and employee access to information about workplace hazards. The requirements of right-to-know laws most relevant to hazardous material planning and emergency response include (1) providing public access to information on hazardous materials present, (2) conducting inventories or surveys, (3) establishing record-keeping and exposure reporting systems, and (4) complying with container labeling regulations for workplaces.

OSHA now requires chemical manufacturers and importers to prepare Material Safety Data Sheets (MSDS's) for all hazardous materials produced or used. The MSDS's must be available to a state agency, local fire chief, and the public as part of their community right-to-know programs.

The format of the MSDS form, also known as OSHA Form 20, is up to the provider. It must contain at least nine elements:

1. manufacturer's name, address, and telephone number, chemical name, synonyms and formula
2. hazardous ingredients, approximate concentration and TLV
3. physical data of product
4. fire and explosion hazard data for product

5. health hazard data
6. reactivity data
7. spill or leak procedures
8. special protective information
9. special precautions

11.0 Computer Usage In Hazardous Waste Management

The use of computers has become increasingly important in hazardous waste management. Computers provide updates to current regulations, prepare reports and manifests, perform complex modeling, perform risk assessments and LCA's, are design tools, track waste disposal, manage inventory, and provide various other convenience services. Approximately, 1500 software programs are available for pollution management activities. Several periodicals and trade magazines review the available software and provide annual summaries of the packages offered.

Regulatory agencies will often produce their own software which industry uses to do reporting. These software and databases are either on line or available by computer disk. These systems include databases, training and procedure review packages, pollution modeling programs, and emission calculation programs. One purpose for the software is to standardize calculations. Several regulatory agencies accept quarterly reports and release report information on computer disk. Computers provide direct access to environmental databases and provide on line reports to the EPA and other regulatory bodies. Databases are available either on floppy disks, CD ROM or through modem access. These databases provide chemical and toxicological data, current environmental regulations and interpretations, and abstracts of published research articles.

12.0 Recommended Reading

1. Berlin, R.E., C.C. Stanton: *Radioactive Waste Management*, John Wiley and Sons, Inc., New York, NY 1989.

2. Bureau of National Affairs, various handbooks and CD ROM databases, Washington, D.C. (800) 372-1033.

3. Environmental Protection Agency: *RCRA Orientation Manual, 1990 Edition,* EPA/530-SW-90-036, U.S. EPA, Washington, D.C., 1990.

4. Environmental Protection Agency: *Risk Assessment Guidance for Superfund, Vol I - Human Health Evaluation Manual*, U.S. EPA/540/1-89/002, Washington, D.C., 1989.

5. Keolein, G.A., D. Menerey: Sustainable Development by Design-Review of Life Cycle Design and Related Approaches, J Air and Waste Management Assoc., 44, 645(1994).

6. LaGrega, M.D., P.L. Buckingham: *Hazardous Waste Management,* McGraw Hill, Inc., New York, NY, 1994.

7. Landrum, V.J.: *Medical Waste Management and Disposal*, Noyes Data Corporation, Park Ridge, NJ 1991.

8. Lindgren, G.F.: Guide to Managing Industrial Hazardous Waste, Butterworth Publishers, Woburn, MA 1983.

9. Phifer, R.W.: *Handbook of Hazardous Waste Management for Small Generators,* Lewis Publishers, Inc., Chelsea, MI 1988.

10. Plater, Z.J.B.: *Environmental Law and Policy,* West Publishing Co., St. Paul, MN 1992.

11. Wentz, C.A.: *Hazardous Waste Management,* McGraw Hill, Inc., New York, NY 1989.

Glossary of Key Terms

HAZARDOUS WASTES are wastes that may cause or contribute to mortality or may pose a threat to human health. More detailed definitions are given in regulations such as RCRA.

RISK ASSESSMENT involves determining potential health effects due to a specific chemical and potential human exposure. This leads to an estimation of the risk of developing an effect such as cancer due to a lifelong exposure.

MIXED WASTES contain both hazardous waste and radioactive waste.

CRF or Code of Federal Regulations contains detailed information on Federal regulations including those dealing with the generation, treatment, reuse, storage, and disposal of hazardous waste.

RCRA or Resource Conservation and Recovery Act was initially passed by Congress in 1976. The original Act and its amendments cover aspects of hazardous waste management.

Further Information (a partial list)

PROFESSIONAL ORGANIZATIONS:

Air & Waste Management Association
American Academy of Environmental Engineers
American Chemical Society
American Institute of Chemical Engineering
American Society of Civil Engineers
Water Environment Federation

JOURNALS:

Journal of Air & Waste Management Association
Environmental Science and Technology
Environmental Progress
Journal of Water Environment Federation
Journal of American Industrial Hygiene Association
Journal of Environmental Engineering
Journal of Environmental Permitting
Journal of Environmental Regulation
Environmental Impact Assessment Review
Pollution Prevention
Pollution Engineering

Chemical Engineering
National Environmental Journal
The Generator's Journal
Hazardous Materials
Waste Business Magazine
Hazmat World

CONFERENCES:

Hazmat Conferences
Hazmacon

FIGURE 1. DEFINITIONS OF HAZARDOUS WASTES

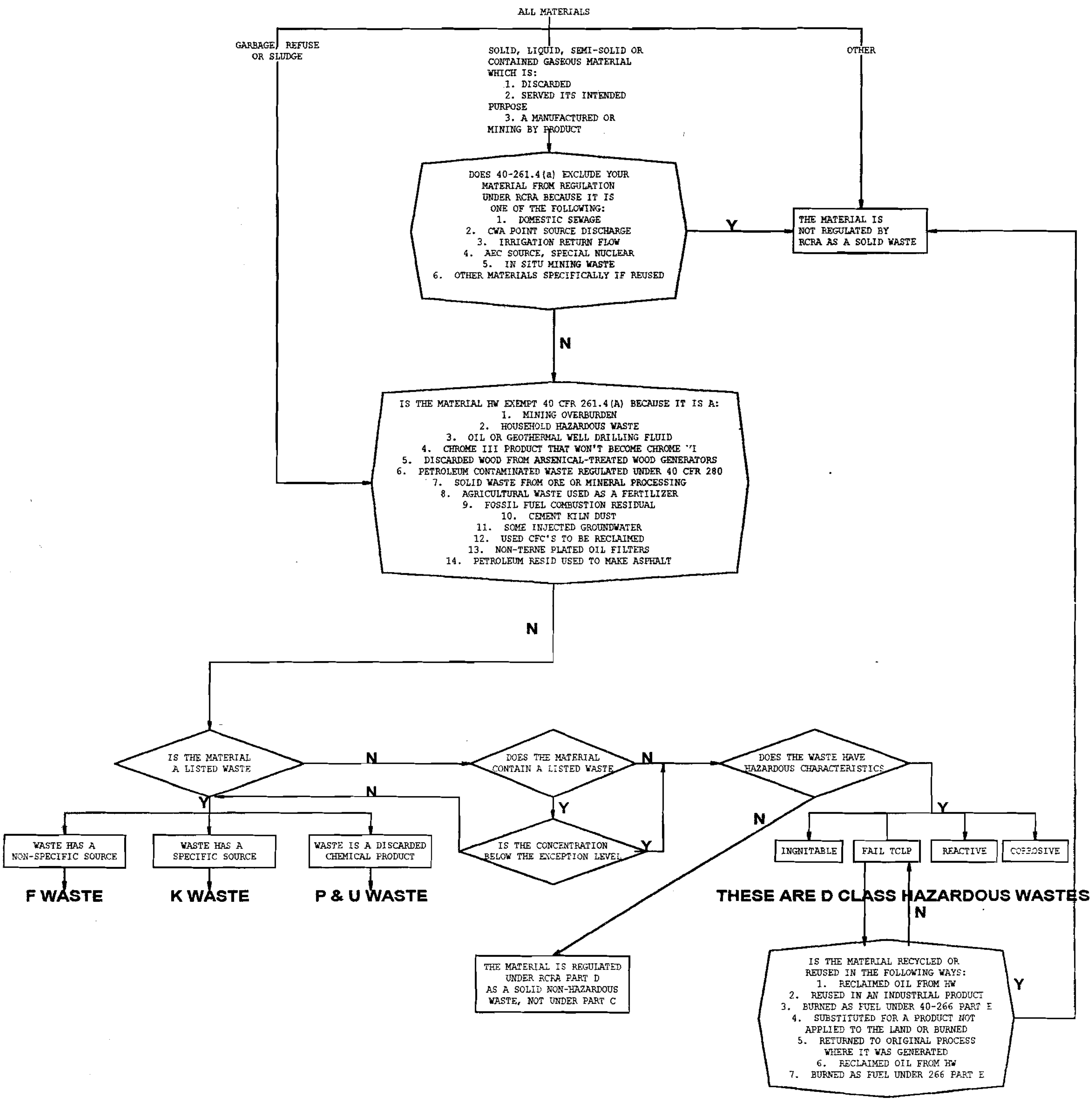

Table 1. Summary of Hazardous Waste Treatment Technologies

TECHNOLOGY	CONTAMINANT	TYPE	REQUIREMENTS	PRODUCTS	COST
ADSORPTION	ORGANIC CONTAMINANTS	G, WW, GW, OW	ADSORBENTS SUCH AS ACTIVATED CARBON ADDED TO WATER AND FILTER OUT, COST HIGHLY DEPENDENT ON CONCENTRATION	TREATED STREAMASTE CARBON, CARBON CAN ABSORB UP TO 5% ORGANICS	CARBONIS $2-3/LB.
AEROBIC BIOREACTOR	READILY DEGRADABLE TOXIC ORGANICS	GW, IW	TANK WITH AIR INJECTION AND BIOLOGICAL POPULATION	INERTS, BIOMASS AND REDUCED BOD WATERS	200/TON
AIR STRIPPING	PETROLLEUM HYDROCARBONS CHLORINATED SOLVENTS	W	VACUUM AIR STREAM	GASEOUS OR CONDENSED CONTAMINANTS AND WATER	VARIABLE
ANAEROBIC BIOREACTORS	MORE RECALCITRANT AND HIGHER CONCENTRATION ORGANICS	W WW	ANAEROBIC TANK AND BIOLOGICAL POPULATION AND POSSIBLY METHANE INJECTION	INERTS BIOMASS, ACIDS AND REDUCED BOD WATER	200/TON
BIOLOGICAL LAND TREATMENT, COMPOSTING, HEAPING	PETROLEUM AND WOOD TREATING WASTES	S, SOL, SL	OPENLAND AND MIXING EQUIPMENT	LESSER CONTAMINATED MATERIALS	50/TON
CHELATING	HEAVY METALS AND RADIONUCLIDES	S	TANK OR IN-SITU AND CHELATING AGENTS	TREATED SOIL AND LIQUID WASTES	N/A
CHEMICAL OXIDATION	WIDE RANGE OF COMPOUNDS INCLUDE: CHLORINATED HC'S, CYANIDES, MERCAPTANS, AND PHENOLS	SS, L, LW	CHEMICAL OXIDANTS INCLUDE: OZONE, CHLORING, HYDROGEN PEROXIDE, AND UV RADIATION	INERTS AND INTERMEDIATE PRODUCTS OF OXIDATION	200/TON
COMPACTION, GRINDING, SHREDDING, BALING, SECTION, ACID DIGESTION	BIOLOGICAL AND/OR RADIOIACTIVE HAZARD	SOL	APPROPRIATE EQUIPMENT	REDUCED VOLUME OF ORIGINAL WASTE BU NOT REDUCED HAZARD OR MASS	ON-SITE
ENCAPSULATIONOR MICROENCASULTION	TOXIC LEACHABLE COMPOUNDS AND RADIOISOTOPES	L, OW, S, SED	ORGANOPHILLIC POLYMERS AND BINDERS	ENCAPSULATED LANDFILLABLE OR INCINERABLE WASTE	100-200/TON
EVAPORATION/ DISTILLATION	WIDE VARIETY OF AQUEOUS OR SOLVENT BASED CONTAMINANTS INCLUDING RADIONUCLIDES	L, WW	EVAPORATION PONDS OR DISTILLATION EQUIPMENT	STILL BOTTOMS PURIFIED LIQUID	10-100/TON
GAS/VAPOR STERILIZATION	BIOLOGICAL HAZARD	SOL	FORMALDEHYDE OR ETHYLENE OXIDE IN VESSEL, GROUND SOLIDS	DISINFECTED WASTES: MAY STILL HAVE HAZARDOUS COMPONENTS	ON-SITE
INCINERATION: THERMAL OXIDIZERS OF MANY TYPES	WIDE VARIETY OF ORGANICS, INFECTIOUS WASTE AND NUCLEAR WASTES	G, S, SL, SED, SOL	CONTROLLED HIGH TEMPERATURE BUNER, FUEL, AIR AND EMISSIONS CONTROL	INERTS, ASH, TRACE AIR POLLUTANTS	500-1000/TON
ION EXCHANGE	SOME METALS, CYANIDE AND OTHER CATIONS/ANIONS INCLUDING RADIOISOTOPES	W, WW	APPROPRIATE RESINS	TREATED WATER, CONTAMINATED RESIN	20/TON
IRRADIATION	BIOLOGICAL HAZARD	SOL	ULTRAVIOLET RADIATION, DRY ENVIRONMENT	DISINFECTED WASTE; MAY STILL HAVE HAZARDOUS COMPONENTS	ON-SITE
MAGNETIC SEPARATION	METALS, RADIONUCLIDES AND NITRATES	WW, GAS	MAGNETIC CORE, SELECTIVE ABSORBERS, ORGANIC POLYMERS	TREATED WATER TO PPM LEVEL	N/A, HIGH CAPITAL
MEMBRANE PROCESSES: ELECTRODIALYSIS REVERSE OSMOSIS AND ULTRAFILTRATION	EXTREME TOXICS NOT REMOVED BY OTHER PROCESSES...WORKS ON SOLUTES	W	SPECIALIXED MEMBRANES AND HIGH PRESSURE PUMPS OR DIRECT ELECTRIC CURRENT	CONTAMINATED BRINE WATER AND CLEAN WATER	20/TON
MICROWAVE TREATMENT	BIOLOGICAL HAZARD	SOL	MICROWAVE RADIATION AND MOISTURE USED TO HEAT WASTE, SHREDDED	DISINFECTED WASTE; MAY STILL HAVE HAZARDOUS COMPONENTS	ON-SITE

TECHNOLOGY	CONTAMINANT	TYPE	REQUIREMENTS	PRODUCTS	COST
NEUTRALIZATION	CONTAMINANTS WITH pH <2 OR >12.5	L, WW, S	MIXING EQUIPMENT AND LIME, SODA ASH, OR FREE ACIDS	LARGE VOLUME OF NEUTRAL MATERIAL	100-200/TON
PHYSICAL TREATMENTS INCLUDING: SCREENING, FILTERING, CENTRIFUGATION	PRETREATMENT TO REMOVE LARGE NON-HAZARDOUS COMPOUNDS INCLUDING RADIONUCLIDES	L, WW, S	TANKS, LOADING AND UNLOADING EQUIPMENT AND OBVIOUS EQUIPMENT	CLEAN OR TREATED WATER REQUIRING FURTHER TREATMENT AND CONTAMINATED SLUDGE	50/TON
PHYSICAL TREATMENTS INCL: PRECIPITATION FLOCULATION/ COAGULATION, GAS FLOATATION AND CLARIFICATION	DISSOLVED AND SUSPENDED SOLIDS AND SOME SOLUTES USUALLY INORGANIC. MAY INCLUDE RADIONUCLIDES	GW, WW	SETTLING TANKS AND FLOCCULANTS SUCH AS ALUM. AND POLYMERS AND SLUDGE REMOVAL EQUIPMENT MAY REQUIRE AIR SUPPLY	CLEAN OR TREATED WATER REQUIRING FURTHER TREATMENT AND CONCENTRATED CONTAMINATED SLUDGE	150/TON
PYROLYSIS/MOLTEN SALT BATHS	WIDE VARIETY OF TOXIC ORGANICS	L	CONTROLLED NON-OXIDIZING BURNER	CRACKED AND THERMALLY BROKEN DOWN ORGANICS SUITABLE FOR FUEL, FURTHER TREATMENT OR DISPOSAL	N/A
SLURRY BIO-REACTORS	HEAVY AND RECALCITRANT ORGANICS	S. SL	TANKS OR LAGOONS, MIXERS AND SURFACTANTS	BIOMASS, INERTS, INTERMEDIATES AND WET TREATED SOIL	200/TON
SOIL VAPOR EXTRACTION	PETROLEUM HYDROCARBONS CHLORINATED SOLVENTS	S	VAPOR EXTRACTION EQUIPMENT	GASEOUS CONTEMINANTS AND CLEAN SOIL	50-100/TON
SOLIDIFICATION	HEAVY METALS SOME ORGANICS AND LEACHABLE LIQUIDS AND RADIOISOTOPES	S, SL, L	BINDERS, ASPHALTS, HYDRAULIC CEMENTS, UREAFORMALDEHYDE	BETTER STRUCTURAL MATERIALS, NON-LEACHING SUITABLE FOR LANDFILLING OR LEAVING IN PLACE	30-80/TON
STABILIZATION/ FIXATION	HEAVY METALS, ACID SLUDGES, SOME ORGANICS	S, SOL	POZZOLANIC REAGENTS AND LIME SILICATES	NON-LEACHING LANDFILLABLE MATERIALS OR REMEDIATED SITES	30-80
STEAM STERILIZATION/ AUTOCLAVING	SMALL SIZE SOLID BIOLOGICAL HAZARD	SOL	HIGH TEMPERATURE STEAM AND OVEN	DISINFECTED WASTEW; MAY STILL HAVE HAZARDOUS COMPONENTS	ON-SITE
STEAMSTRIPPING	VOLATILE AND SEMI-VOLATILE COMPOUNDS	W	HIGH PRESSURE STEAM AND VACUUM EXTRACTION	HIGH CONCENTRATION STREAM AND CLEAR WATER	VARIABLE
STEAMSTRIPPING, EX-SITU AND IN-SITU	VOLATILE ORGANICS	S	HIGH PRESSURE STEAM AND VACUUM EXTRACTION	HOT WATER WITH CONTAMINANTS AND STERILE CLEAN SOIL	32AZ80-200/CUBIC YARD
SUPERCRITICAL FLUID EXTRACTION	EXTRACTABLE ORGANICS	S, SL, W	HIGH PRESSURE AND TEMPERATURE FLUIDS	RECOVERED ORGANICS AND OXIDIZED ORGANICS	160/TON
THERMAL DESORPTION	PETROLEUM HYDROCARBONS, CHLORINATED SOLVENTS	S, SL	THERMAL DESORPTION OVENS, NATURAL GAS OR ELECTRIC HEATERS, AIR POLLUTION CONTROLS	GASEOUS CONTAMINANTS AND STERILIZED SOIL	50-100/TON
THERMAL INACTIVATION	BIOLOGICAL HAZARD	SOL, L	HIGH TEMPERATURE OVEN OR VESSEL	DISINFECTED WASTES; MAY STILL HAVE HAZARDOUS COMPONENTS	ON-SITE
VITRIFICATION	NON-SPECIFIC, ASBESTOS AND RADIOACTIVE WASTE	S, SED, SOL	HIGH TEMPERATURE AND/OR HIGH ELECTRIC CURRENT AIR EMISSIONS CONTROL	GLASSIFIED WASTES SUITABLE FOR DISPOSAL OR LEAVE IN PLACE	N/A

G:	Gaseous Waste
GW:	Contaminated Ground Water
HC:	Hydrocarbons
L:	Liquid Wastes
OW:	Oily Water
S:	Contaminated Soil
SED:	Sediments
SL:	Process Sludges
SOL:	Waste Solids
W:	Contaminated Water
WW:	Industrial Waste Water

Table 2. Summary of Hazardous Waste Disposal Options

DISPOSAL	DESCRIPTION	WASTE TYPE	ADVANTAGES	LIMITATIONS
ABOVE GRADE VAULTS	ENGINEERED LARGE STEEL AND CONCRETE STRUCTURE ABOVE NATURAL GRADEULTS	LLW SEGREGATED	EASY ACCESS TO WASTE	VULNERABLE TO INTRUSION AND EROSION
AUGURED HOLES	SHALLOW DRILLED HOLES ABOVE WATER TABLE	CLASS C LOW LEVEL	TESTED BY DOE, GOOD AT WORKER PROTECTION	DIFFICULT TO REMOVE WASTES, SMALL CAPACITY
BELOW GRADE VAULTS	ENGINEERED STRUCTURE BELOW GRADE DESIGNED TO BE COMPATIBLE WITH SOIL	LLW, SEGREGATED	LESS VULNERABLE TO INTRUSION AND EROSION	WASTE LESS ACCESSIBLE
CARLSBAD, NM WASTE ISOLATION PILOT PLANT	DOE PROJECT DESIGNED TO HOLD SIX MILLION CUBIC FEET IN SALT FORMATION	TRANSURANIC DEFENSE WASTES	REMOTE, ALREADY IN PILOT PLANT STAGE	CONTROVERSIAL
DEEP SPACE	CANISTERS PLACED IN INFINITE ORBIT OR INTO SUN	HLW	STUDIED BY NASA AND DOE	
DEEP WELL INJECTION	ACID WASTED PUMPED TO GREAT DEPTHS INTO FRACTURED ROCK	HLW AND TRANSURANIC BELOW CRITICAL LEVEL	WASTE FAR REMOVED FROM ENVIRONMENT	WASTE NON-RECOVERABLE
EARTH MOUNDED CONCRETE BUNKERS	COMBINED ABOVE AND BELOW GRADE DISPOSAL OF STRUCTUALLY STRONG WASTE CONTAINERS	LLW, HLW	USED IN FRANCE	VULNERABLE TO INTRUSION AND EROSION
HANFORD MIXED WASTE TRENCHED	4 27,000 CUBIC FEET TRENCHES FOR STORAGE OF MIXED WASTES FROM CLEANUP OF HANFORD SITE	MIXED WASTES	FIRST AND ONLY MIXED WASTE DISPOSAL	SCHEDULED TO OPEN NOVEMBER, 1994
ICE SHHET	CANISTERS DROPPED THROUGH ICE MELT DOWN	SELF HEATING HLW	REMOTE LOCATIONS, HEAT REMOVAL	CONCEPTUAL ONLY POTENTIAL ICE MOVEMENT
IMPROVED SHALLOW LAND DISPOSAL	WASTE PLACED IN DEEPER TRENCHES WITH IMERMEABLE CAP	LLW	REQUIRED SINCE 1982, NOT ALLOWED IN SOME STATES	MORE COSTLY AND COMPLEX THAN OLDER TECHNOLOGY
INJECTION WELLS CLASSES I, IV, V	INJECTION INTO POROUS ROCK FORMATIONS NOT COMMUNICATING WITH CLASS I GROUNDWATER	HW, PETROLEUM WASTES, SEWAGE, LLW	WIDELY PRACTICED, SECURE	POTENTIAL DRINKING WATER CONTAMINATION, SUBJECT TO LAND BAN
LANDFILL	WASTED PLACED IN SUBSURFACE CELLS WITH LINERS, COVER, LEACHATE AND GROUNDWATER COLLECTION MONITORING AND VENTING	HAZARDOUS AND MEDICAL WASTES PRE-TREATED OR NOT BANNED	SIMPLY PROVEN	HEAVILY TAXED AND DISCOURAGED, ULTIMATE LIABILITY. LAND BAN

DISPOSAL	DESCRIPTION	WASTE TYPE	ADVANTAGES	LIMITATIONS
MINED CAVITIES	HALLOWED OUT REGIONS IN MINERAL DEPOSITS	LLW	NO INTRUDER ACCESSIBILITY	HARD TO ACCESS
MODULAR CONCRETE CONTAINERS	USE OF AN OVERPACK OR "MINI VAULT" TO ENCASE DRUMS	LLW	WASTE CAN BE EASILY REMOVED	
OCEAN DISPOSAL	CONCRETE ENCASED IN DRUMS AT OCEAN BOTTOM	LLW	CHEAP, ARGUABLY LOW RISK	NOW BANNED, SOME DRUMS LEAKED
OCEAN PLATE DISPOSAL	CANISTERS OF WASTE BETWEEN CONTINENTAL SHELF AND MOVING PLATES THROUGH HOLES DRILLED	HLW AND TRANSURANIC	GEOLOGIC STABILITY	CONCEPTUAL, NOT GOOD FOR SOME ISOTOPES
SALT MINES	LIQUID WASTES PLACED INTO HOLLOWED MINES	NON-SPECIFIC	CHEAPER, INACCESIBLE	NON-RECOVERABLE
SHALE GROUT INJECTION	HIGH PRESSURE WATER CRACKS SHALE AND THEN WASTE IN CEMENT SLURRY IS PUMPED INTO FORMATION	HLW, TRANS	WASTE RELATIVELY IMMOBILE, FAR AWAY FROM SURFACE	WASTE NON-RECOVERABLE
SHALLOW LAND DISPOSAL	WASTE PLACED IN UNLIMITED EARTHEN TRENCHES UP TO 30 FEET DEEP	LLW	CHEAP AND EASY	NOW BANNED
SURFACE IMPOUNDMENT	PLACEMENT OF WASTES INTO IMPOUNDMENTS OPEN TO ATMOSPHERE	LIQUID HAZARDOUS WASTE, URANIUM MINE TAILINGS	REDUCES VOLUME, LOW TECHNOLOGY	ESSENTIALLY SHORT TERM STORAGE, HISTORICALLY PROBLEMATIC
YUCCA MOUNTAIN FACILITY	UNDERGROUND RESPOSITORY FOR WASTE IN CANISTERS WILL OPEN APPROXIMATELY 2010	NUCLEAR SPENT FUEL, DEFENSE WASTES	RETRIEVABLE WASTE, VERY REMOTE, HIGHLY REGULATED	VERY EXPENSIVE, CAPACITY LIMITED TO 70,000 TONS

HLW: HIGH LEVEL RADIOACTIVE WASTE
LLW: LOW LEVEL RADIOACTIVE WASTE
HW: HAZARDOUS WASTE

CLASS A WASTE: LLW NOT REQUIRING STABILIZATION, SHORT HALF LIFE
CLASS B WASTE: LLW REQUIRES STABILIZATION BUT WILL DECAY WITHIN 100 YEARS
CLASS C WASTE: LLW REQUIRES STABILIZATION AND SHIELDING DURING HANDLING. LONGER HALF LIFE