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Hazardous Waste TSDF - Background Information for Proposed RCRA Air Emission Standards

Volume I - Chapters 1 - 8, & Appendices A - C

Emission Standards Division

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Radiation
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ENVIRONMENTAL PROTECTION AGENCY

Background Information and Draft Environmental Impact Statement
for
Hazardous Waste Treatment, Storage, and Disposal Facilities -
Tanks, Surface Impoundments, and Containers

Prepared by:

5/20/91
(Date)

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1. Section 3004(n) of the Resource Conservation and Recovery Act as amended, requires EPA to develop standards for air emissions from hazardous waste treatment, storage, and disposal facilities (TSDF) as necessary to protect human health and the environment. The proposed standards would require organic emission control equipment be installed, operated, and maintained on all TSDF tanks, surface impoundments, and containers into which is placed hazardous waste with a volatile organic concentration equal to or greater than 500 parts per million by weight.

2. Copies of this document have been sent to the following: Federal Departments of Labor, Health and Human Services, Defense, Transportation, Agriculture, Commerce, Interior, and Energy; the National Science Foundation; the Council on Environmental Quality; State and Territorial Air Pollution Program Administrators; EPA Regional Administrators; Local Air Pollution Control Officials; Office of Management and Budget; and other interested parties.

3. The comment period for review of this document is 60 days from the date of publication of the proposed standards in the Federal Register. Ms. Gail Lacy may be contacted at (919) 541-5261 regarding the date of the comment period.

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ABBREVIATIONS AND CONVERSION FACTORS

The EPA policy is to express all measurements in Agency documents in the International System of Units (SI). Listed below are abbreviations and conversion factors for equivalents of these units.

Abbreviations	Conversion Factor
L - liters	liter X 0.26 = gallons gallons X 3.79 = liters
kg - kilograms	kilograms X 2.203 = pounds pounds X 0.454 = kilograms
Mg - megagrams	megagram X 1 = metric tons megagram X 1.1 = short tons short tons X 0.907 = megagrams
m - meters cm - centimeters	meters X 3.28 = feet centimeters X 0.396 = inches
kPa - kilopascals	kilopascals X 0.01 = bars bars X 100 = kilopascals kilopascals X 0.0099 = atmospheres atmospheres X 101 = kilopascals kilopascals X 0.145 = pound per square inch pound per square inch X 6.90 = kilopascals
ha - hectares	hectares X 2.471 = acres acres X 0.40469 = hectares
rad - radians	radians X 0.1592 = revolutions revolutions X 6.281 = radians
kW - kilowatts	kilowatts X 1.341 = horsepower horsepower X 0.7457 = kilowatts

Frequently used measurements in this document are:

0.21	m^3	~	210 L	~	55 gal	
5.7	m^3	~	5,700 L	~	1,500 gal	
30	m^3	~	30,000 L	~	8,000 gal	
76	m^3	~	76,000 L	~	20,000 gal	
800	m^3	~	800,000 L	~	210,000 gal	
1.83	kg O_2/kW/h	~	3 lb O_2/hp/h			
	kW/28.3 m^3	~	1.341 hp/10^3 ft^3			
	kPa•m^3/g•mol	~	0.0099 atm•m^3/g•mol			

1.0 INTRODUCTION

Hazardous waste treatment, storage, and disposal facilities (TSDF) managing wastes containing organics are potential sources of organic air emissions. These organic air emissions can contain toxic chemical compounds as well as ozone precursors. Cancer and other adverse noncancer human health effects can result from exposure to these organic air emissions. In addition, these emissions contribute to formation of ozone, which causes adverse impacts on human health (e.g., lung damage) and the environment (e.g., reduction in crop yields). Excessive ambient ozone concentrations are a major air quality problem in many large cities throughout the United States.

In 1984, Congress passed the Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA) of 1976. Section 3004(n) of HSWA directs the U.S. Environmental Protection Agency (EPA) to promulgate regulations for the monitoring and control of air emissions from hazardous waste TSDF as may be necessary to protect human health and the environment. Standards are being developed by EPA under the authority of §3002 and §3004 of RCRA to reduce organic air emissions from TSDF. The standards would apply to owners and operators of permitted and interim status TSDF under RCRA Subtitle C. This document presents information used in the development of the proposed RCRA air emission standards for TSDF.

1.1 CONTROL OPTIONS

To select a basis for the proposed standards, EPA identified and evaluated a variety of possible strategies for applying organic air emission controls to TSDF. Each strategy considered by EPA is referred to as a "control option." Different control options were identified by varying the types of waste management units that would need to use emission controls and the level of organic air emission reduction that would be required for the emission controls. Each control option defines a unique set of wastes (based on the volatile organic content of the waste) and organic air emission control levels that allows EPA to perform an analysis to estimate the nationwide human health and environmental impacts expected to occur if standards based on a particular control option were promulgated. The EPA compares the control option impacts relative to a common set of reference values called the "baseline." The baseline represents the estimated human health and environmental impacts that would occur in the absence of developing the standards.

The EPA selected five control options for analysis. All five of the control options would require that all TSDF tanks, surface impoundments, and containers managing hazardous waste with a volatile organics content greater than a specified concentration use emission controls. The specified volatile organic concentration at which a waste stream would be required to use emission controls is referred to as the "action level." The primary differences between the control options are the value used for the action level and whether a closed vent system and control device are used in combination with the cover for the tank and surface impoundment units requiring emission controls. A detailed description of the five control options is presented in Chapter 5.0 of this document.

1.2 HEALTH AND ENVIRONMENTAL IMPACTS

In evaluating the health and environmental impacts of the emission control options, EPA relied primarily on the use of computerized analytical models. These models are complex computer programs that process a wide variety of information and data concerning the TSDF industry in the United States. The data processed by the model include results from nationwide surveys of the TSDF industry, characterizations of TSDF processes and wastes, as well as engineering simulations of the relationships between: (1) waste management unit type, the quantity and composition of the waste managed in the unit, and the air emission mechanism; (2) air emission control technology, control efficiencies, and associated capital and operating costs; and (3) population exposure to TSDF air emissions and resulting nationwide cancer incidence.

The Source Assessment Model (SAM) provides estimates of the nationwide impacts by summing the estimated facility impacts across all facilities in the model. Further information on the emission models and emission estimates is included in Appendix C; the SAM is further discussed in Appendix D. The estimated emissions were used as input to dispersion and risk models that produce an estimate of risk and cancer incidence in the exposed population. These health effects were estimated based on a composite unit risk factor, which is an emission-weighted average of the unit risk factors for the individual organic carcinogens contained in the emissions. The Human Exposure Model was used to estimate cancer incidence, and the Industrial Source Complex Long-Term Model was used to estimate the maximum lifetime risk to the most exposed individual (MEI). The health effects analysis included cancer risk to the MEI and noncancer impacts, which may be long-term (chronic) or short-term (acute) health effects. The assessment methodology for chronic, noncancer effects involves a comparison of estimated ambient concentrations with reference air concentrations, or health "thresholds." Additional information on the health effects analyses is included in Appendixes E and J. The estimated health and environmental impacts of the selected control options are shown in Table 1-1.

1.3 COST AND ECONOMIC IMPACTS

Estimates of the nationwide costs for the control options are based on estimates of the control costs for individual waste management units within a TSDF. For each control option, EPA developed a detailed estimate of the total capital investment, annual operating costs, and total annual costs of each emission control technology applied to each waste management unit. To obtain nationwide costs from model unit costs, a weighted average model unit control cost was derived for each control applied to each waste management unit. These control costs, divided by the weighted average model unit throughput, provided cost factors used to generate control cost estimates for each TSDF. The SAM was used to generate nationwide costs by summing individual facility costs across all facilities. Additional information on the cost impacts for the control options is presented in Chapter 7.0.

The economic analysis results indicate that all five control options are projected to have small impacts--less than 1 percent--on the unit cost of hazardous waste management services at facilities that treat and dispose

TABLE 1-1. RESIDUAL HEALTH AND ENVIRONMENTAL EFFECTS OF CONTROL OPTIONS FOR TSDF ORGANIC AIR EMISSIONS[a]

Control option number	Action level, ppm	Organic emissions, 10^3 Mg/yr	Cancer incidence, cases/yr	Maximum individual risk, lifetime
BASELINE	--	1,800	140	2×10^{-2}
1	0	92	5.9	5×10^{-4}
2	500	96	6.4	5×10^{-4}
3	500	130	8.4	5×10^{-4}
4	1,500	140	14	8×10^{-4}
5	3,000	180	16	9×10^{-4}

TSDF = Treatment, storage, and disposal facility.
-- = Not applicable.

[a]Control options 1 through 5 apply to wastes containing organics at concentrations greater than the action level associated with the particular option. They entail covers and control devices for tanks (including waste fixation) and impoundments, and covers and submerged loading of containers. For covered storage and quiescent treatment tanks, venting to a control device is required if the vapor pressure of the waste in the tank exceeds 10.3 kPa (1.5 psi) for control options 1, 2, 4, and 5. No control devices are applied to covered storage and quiescent treatment tanks in control option 3. The impacts presented in this table are only for the TSDF units affected by the proposed standards.

these wastes. The unit-cost increases for storage-only facilities are substantial for several industrial sectors when viewed as a share of hazardous waste management costs. These cost increases translate into nationwide compliance costs of between $4 million and $31 million for storage-only facilities. The economic analysis is further described in Chapter 8.0.

2.0 REGULATORY AUTHORITY AND STANDARDS DEVELOPMENT

This chapter presents an overview of EPA's regulatory framework for controlling organic air emissions from hazardous waste treatment, storage, and disposal facilities (TSDF). Regulatory authority for the control of air emissions from hazardous waste TSDF under the Resource Conservation and Recovery Act (RCRA), as amended, is discussed in Section 2.1. The EPA's standards development plan for controlling waste management air emissions under RCRA and the Clean Air Act (CAA) is summarized in Section 2.

2.1 REGULATORY AUTHORITY

In November 1984, Congress passed the Hazardous and Solid Waste Amendments to the Resource Conservation and Recovery Act of 1976. As amended, RCRA §3004 authorizes EPA to establish standards that regulate the operation of hazardous waste TSDF. Air emission standards are required under §3004(n), which states:

> ... the Administrator shall promulgate such regulations for the monitoring and control of air emissions at hazardous waste treatment, storage, and disposal facilities, including but not limited to open tanks, surface impoundments, and landfills, as may be necessary to protect human health and the environment.

Section 3004(n) does not confer new authority, but rather requires the Agency to exercise its preexisting authority to control air emissions from hazardous waste management. Several rulemakings related to the control of air emissions already have been undertaken by EPA under RCRA authority. For example, EPA has promulgated standards for the control of air emissions from hazardous waste incinerators (40 CFR 264, Subpart O). Standards for air emissions from the burning of hazardous waste in boilers and industrial furnaces and amendments to Subpart O standards were proposed April 27, 1990 (55 FR 17862). The Agency also has promulgated standards under 40 CFR 264 and 265 for windblown dust from wastepiles, landfills, and land treatment operations. Additionally, final standards for miscellaneous units and for research, development, and demonstration units under 40 CFR 264, Subparts X and Y, contain provisions that require prevention of air releases that may have adverse effects on human health or the environment.

Air emissions from hazardous wastes are generated or released from numerous sources at TSDF. Air emission sources identified by EPA to date include waste treatment processes such as distillation and fixation, equipment leaks, surface impoundments, tanks, containers, landfills, wastepiles, and land treatment facilities. Organic air emissions from hazardous wastes managed in these sources include photochemically reactive and nonphotochemically reactive organics, some of which are toxic or carcinogenic, and also may include toxic or carcinogenic inorganic compounds. Depending on the source, particulates (including metals, aerosols of organics, dust, as well as toxics and carcinogens) also may be released. Reduction of the toxic or carcinogenic emissions will reduce the incidence and risk of both cancer and noncancer health effects in the exposed population; reduction of ozone precursors in the organic emissions also will assist in reducing ozone formation.

2.2 STANDARDS DEVELOPMENT FOR WASTE MANAGEMENT AIR EMISSIONS

Given the wide variety of TSDF sources and the complex analyses and data required to assess emissions from these sources and their impacts, EPA is taking several separate actions. On June 21, 1990 (55 FR 25454), EPA promulgated standards for the control of organic air emissions from (1) hazardous waste management process vents associated with distillation, separation, fractionation, air or steam stripping, and thin-film evaporation processes under Subpart AA to 40 CFR Parts 264 and 265, and (2) leaks in piping and other equipment managing hazardous waste under Subpart BB to 40 CFR Parts 264 and 265.

The EPA also is further addressing the potential health effects resulting from exposure to particulate emissions at TSDF. This is being done through development of detailed guidance to supplement existing standards under 40 CFR 264 and 265 for windblown dust from landfills, land treatment facilities, and wastepiles.

The standards developed for proposal that are supported by this background information document (BID) would control the class of organic air emissions from surface impoundments, tanks (including vents on closed, vented tanks), containers, and waste fixation process units. The EPA is also evaluating the need for standards to control emissions of individual chemical constituents from these sources. Standards for individual constituents will be developed separately in the future as necessary to address residual health risk that may remain after controls are implemented for organic emissions as a class.

The control options and their associated environmental and health risk impacts for organic air emissions from surface impoundments, tanks, containers, and waste fixation process units are discussed in Chapters 5.0 and 6.0 of this document. The evolution of the standards for these sources is described in Appendix A of this document. As discussed in Appendix A, this BID reflects revisions that have been made based on comments received since the May 18, 1988, meeting of the National Air Pollution Control Techniques Advisory Committee. In the next step of the standards development process, a draft proposal package will be assembled and reviewed by the EPA Assistant Administrators and the Administrator for concurrence before the standards are proposed in the Federal Register. Information received and generated in studies in support of the proposed standard is available to the public in Docket F-90-CESP-FFFFF on file in Washington, D.C.

As part of the Federal Register notice of proposal, the public is invited to participate in the standard-setting process. The EPA invites written comments and will hold one or more public hearings to receive comments on the proposed standards from interested parties. All public comments will be analyzed, and written responses will be prepared. A document will be prepared that summarizes the comments and provides the Agency's responses. If public comments indicate that changes to the proposed standards are warranted, the standards will be revised accordingly before publication in the Federal Register.

3.0 INDUSTRY DESCRIPTION AND AIR EMISSIONS

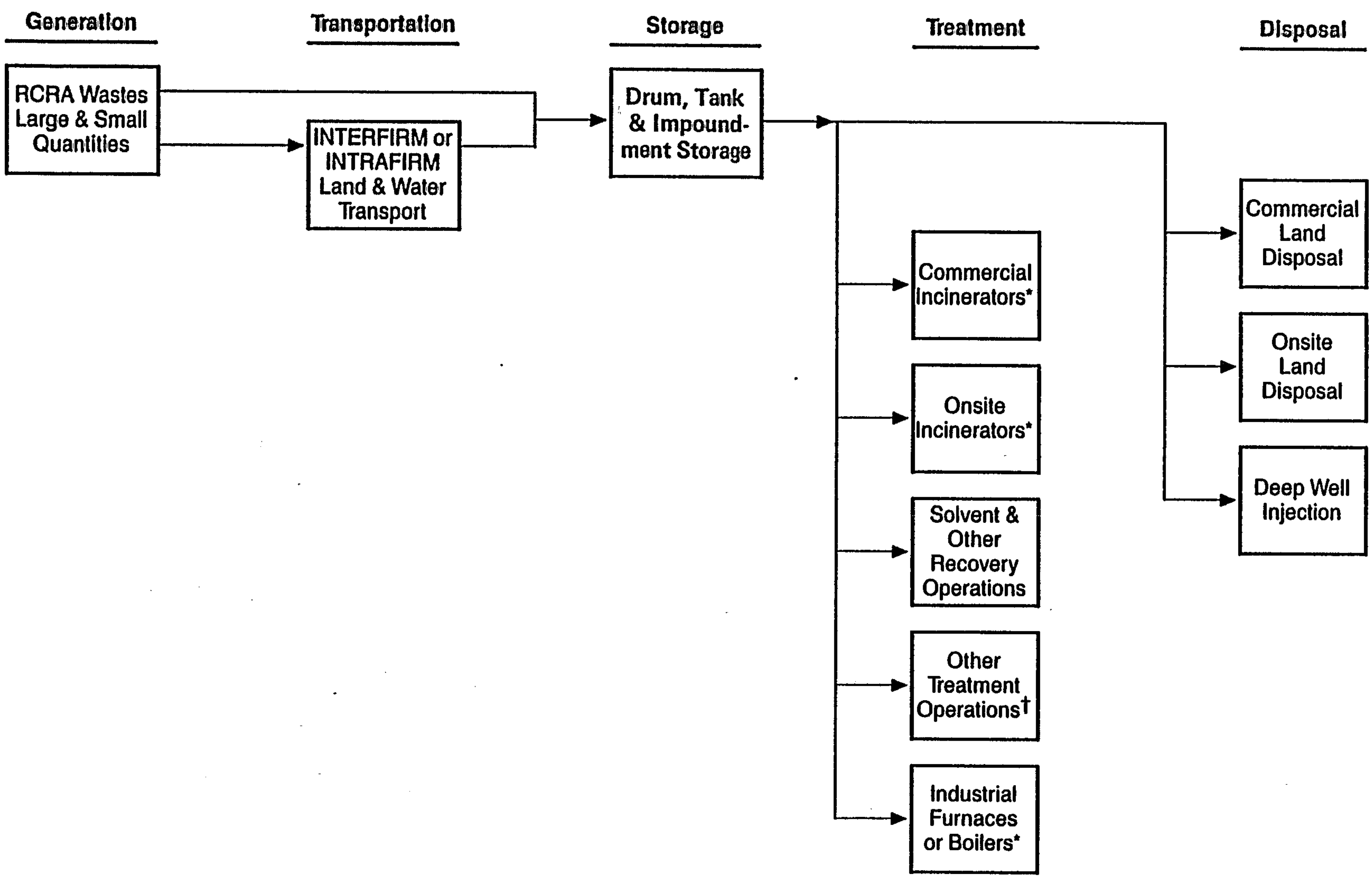
This chapter presents a brief overview of the hazardous waste industry and a summary description of the techniques used in estimating nationwide organic air emissions for hazardous waste treatment, storage, and disposal facilities (TSDF) in the United States. The hazardous waste industry and TSDF emission sources are described in Section 3.1. The estimation of TSDF nationwide emissions is presented in Section 3.2. Emission estimation techniques include the development and use of (1) TSDF emission models, which provide a mechanism for analyzing air emissions from TSDF management processes and applicable emission control technologies, and (2) a computer program developed to process the data and information on the TSDF industry and to perform emission calculations based on the available data. Discussions of air pollution controls and control strategies at TSDF follow in Chapters 4.0 and 5.0, respectively.

3.1 THE HAZARDOUS WASTE INDUSTRY

The hazardous waste industry in the United States is diverse and complex. The universe of hazardous waste generators represents a broad spectrum of industry types and sizes. Wastes generated vary considerably in both composition and form; and the waste management processes and practices used in treating, storing, and disposing of hazardous wastes are also widely varied. Figure 3-1 presents a simplified waste system flow chart for the hazardous waste industry. Key elements of the industry are: generation, transportation, treatment, storage, and disposal. The major elements of the hazardous waste industry are discussed in the following sections.

3.1.1 General Hazardous Waste Description

General waste descriptions include hazardous wastes in the following forms: contaminated wastewaters, spent solvents residuals, still bottoms,



*Regulated by the Office of Solid Waste.
†Onsite and commercial.

Figure 3-1. Simplified hazardous waste system from generation to disposal.

spent catalysts, electroplating wastes, metal-contaminated sludges, degreasing solvents, leaded tank bottoms, American Petroleum Institute (API) separator sludges, off-specification chemicals, and a variety of other waste types. In reviewing waste data, more than 4,000 chemical constituents have been identified as being contained in the various waste types examined.[1]

Title 40 of the Code of Federal Regulations (CFR), Part 261.3 (40 CFR 261.3), defines hazardous waste as four categories:

- Characteristic wastes--wastes that exhibit any hazardous characteristic identified in 40 CFR 261 Subpart C, including: ignitibility, corrosivity, reactivity, or extraction procedure (EP) toxicity
- Listed waste--wastes listed in 40 CFR 261, Subpart D
- Mixture rule wastes--wastes that are (1) a mixture of solid waste and a characteristic waste unless the mixture no longer exhibits any hazardous characteristic, or (2) a mixture of a solid waste and one or more listed hazardous wastes
- Derived from rule wastes--any solid waste generated from the treatment, storage, or disposal of a hazardous waste, including any sludge, spill residue, ash, emission control dust, or leachate (but not including precipitation runoff).

Hazardous wastes are designated by Resource Conservation and Recovery Act (RCRA) alphanumeric codes. Codes D001 through D017 are referred to as "characteristic wastes." D001 represents wastes that are ignitible in character; D002, those that are corrosive; and D003, those that are reactive. Extracts of wastes that contain toxic concentrations of specific metals, pesticides, or herbicides are assigned one of the codes D004 through D017.

"Listed wastes" encompass four groups of alphanumeric codes published in 40 CFR 261, Subpart D. Hazardous wastes generated from nonspecific industry sources such as degreasing operations and electroplating are listed as codes beginning with the letter "F," e.g., F001. Hazardous wastes from specific generating sources such as petroleum refining are assigned codes beginning with the letter "K," e.g., K048. Waste codes beginning with "P" or "U" represent waste commercial chemical products and manufacturing chemical intermediates (whether usable or off-specification).

40 CFR 261, "Identification and Listing of Hazardous Wastes," not only lists hazardous wastes but also identifies specific wastes that are excluded from regulation as hazardous. These excluded wastes can be stored, treated, or disposed of without a RCRA permit.

3.1.2 Generators

The overwhelming majority of hazardous wastes are produced by large-quantity generators, those firms that generate more than 1,000 kg of hazardous waste per month. It has been estimated that there are about 71,000 large-quantity generators of hazardous waste in the United States.[2] These generators account for 99 percent of the 275 million Mg/yr of hazardous waste produced and managed under RCRA in 1985.[3] Hazardous waste generators are most prevalent in the manufacturing industries (standard industrial classification [SIC] codes 20-39). Manufacturing as a whole accounts for more than 90 percent of the total quantity of hazardous waste generated. Among specific industries, the chemical, petroleum, metals, electrical equipment, and transportation industries are the major generators of hazardous wastes. Two industry groups that stand out as generators are the chemical and petroleum industries (SIC 28 and 29); these industries alone account for more than 70 percent of total waste generation. The chemical industry (SIC 28), with only 17 percent of the generators, generated 68 percent of all the hazardous wastes produced in 1981. Another prominent group in the manufacturing sector was metal-related industries (SIC 33-37); these industries generated about 22 percent of all hazardous wastes in 1981.[4]

The 1981 Survey of Hazardous Waste Generators and Treatment, Storage, and Disposal Facilities (Westat Survey)[5] showed that only 15 percent of the generators were nonmanufacturing or unclassified under SIC. The survey results also provide estimates of number of generators producing specific types of hazardous wastes. Just over half the generators indicated that they generate spent solvents, both halogenated and nonhalogenated (RCRA waste codes F001-F005). Generators of sludges from wastewater treatment systems associated with electroplating and coating operations and generators of quenching and plating bath solutions and sludges accounted for 16 percent of the generator population. Only 10 percent of the generators generated listed hazardous wastes from specific industrial sources (e.g., slop oil emulsion solids from the petroleum refining industry--K049). Forty-three percent of generators produce ignitible wastes (RCRA waste code D001), a third generated corrosive wastes (D002), and more than a quarter generated wastes that failed EPA's test for toxicity (D004-D017). Just under 30 percent of the generators reported hazardous wastes that were spilled, discarded, or off-specification commercial chemical products or manufacturing chemical intermediates ("P" and "U" prefix waste codes).

The physical characteristics of the 275 million Mg of RCRA hazardous waste managed in 1985 vary from dilute wastewater to metal-bearing sludges to soils contaminated with polychlorinated biphenyl (PCB). Over 90 percent (by weight) of RCRA hazardous waste is in the form of dilute aqueous waste. The remaining wastes are organic and inorganic sludges and organic and inorganic solids. Figure 3-2 categorizes hazardous waste by physical characteristics.

Although small-quantity generators (those that generate more than 100 kg and less than 1,000 kg of hazardous waste per month) represent a large proportion of the number of hazardous waste generators nationally (more than 26,000),[7] they account for only a very small fraction of the hazardous wastes generated. About 25 percent of the country's hazardous waste generators are small-quantity generators, but these generators contribute less than one-half of 1 percent of the total hazardous waste generated.[8] The majority of the small-quantity generators are automotive repair firms, construction firms, dry cleaners, photographic processors, and laboratories. The wastes produced by small-quantity generators span the full spectrum of RCRA hazardous wastes. According to EPA's National Small Quantity Hazardous Waste Generator Survey,[9] the majority of small-quantity generator waste is derived from lead acid batteries; the remainder includes such hazardous wastes as acids, solvents, photographic wastes, and dry cleaning residues.

3.1.3 Transporters

Once a RCRA hazardous waste is generated, it must be managed (i.e., stored, treated, or disposed of) in accordance with legal requirements. Although nearly all hazardous waste is managed to some degree at the site

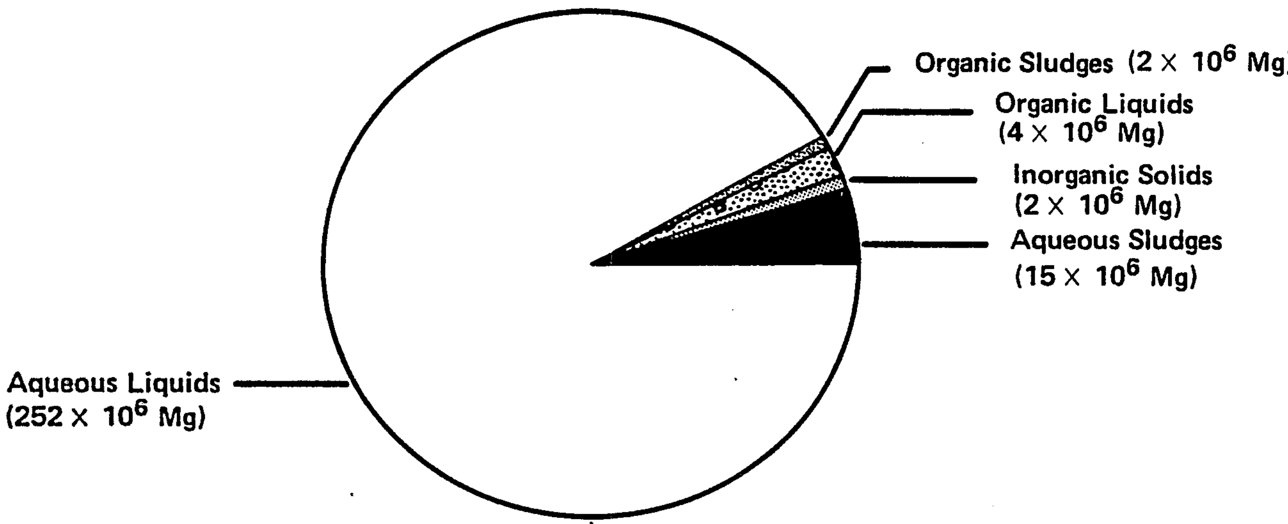


Figure 3-2. Estimate of physical characteristics of RCRA hazardous wastes.[6]

where it is generated, the Westat Survey has shown that only about one in six generators manage their hazardous waste exclusively onsite.[10] Of those generators that ship hazardous wastes to offsite management facilities for treatment, storage, and disposal, roughly a quarter still manage part of their hazardous wastes onsite. Although the survey estimated that 84 percent of the generators ship some or all of their hazardous wastes offsite, the vast majority of the quantities of hazardous waste are nonetheless managed onsite. Data supplied by generators indicate that about 96 percent of all generated hazardous wastes are managed onsite, with only 4 percent being shipped offsite for treatment, storage, or disposal.

In response to the movement of hazardous waste, a large industry has developed that transports hazardous wastes from generators to TSDF. It has been estimated that over 13,000 transporters are involved in moving hazardous wastes by land or water from generators to TSDF.[11]

3.1.4 Treatment, Storage, and Disposal Facilities

A significant segment of the hazardous waste industry is involved in hazardous waste management (i.e., treatment, storage, and disposal activities). Table 3-1 provides the RCRA definition of treatment, storage, and disposal. TSDF must apply for and receive a permit to operate under RCRA Subtitle C regulations. The RCRA Subtitle C permit program regulates 13 categories of waste management processes. There are four process categories each within storage and treatment practices and five categories within disposal practices. Table 3-2 presents the 13 major categories by RCRA process code.

Some of the 13 RCRA process categories can be further classified by characteristics of the waste management processes. For example, tank treatment may be quiescent or agitated/aerated (referring to the presence or lack of movement/mixing of the liquid contained in the tank). Such process varieties and similarities are reflected in the characterization of the industry when estimating nationwide TSDF emissions. Figures 3-3 through 3-5 provide a more detailed look at examples of the various management processes. As can be seen from the range of treatment and disposal processes, the industry is complex and not easily characterized. The hazardous waste industry is also dynamic; that is, in response to

TABLE 3-1. RESOURCE CONSERVATION AND RECOVERY ACT (RCRA) HAZARDOUS WASTE MANAGEMENT DEFINITIONS[a]

Term	Definition
Storage	"Storage" means the holding of hazardous waste for a temporary period, at the end of which the hazardous waste is treated, disposed of, or stored elsewhere.
Treatment	"Treatment" means any method, technique, or process, including neutralization, 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.
Disposal facility	"Disposal facility" means a facility or part of a facility at which hazardous waste is intentionally placed into or on any land or water, and at which waste will remain after closure.

[a]Definitions are presented as stated in RCRA regulations (40 CFR 260.10) as of July 1, 1986.[12]

TABLE 3-2. NATIONWIDE QUANTITY OF HAZARDOUS WASTE MANAGED BY SPECIFIC PROCESSES

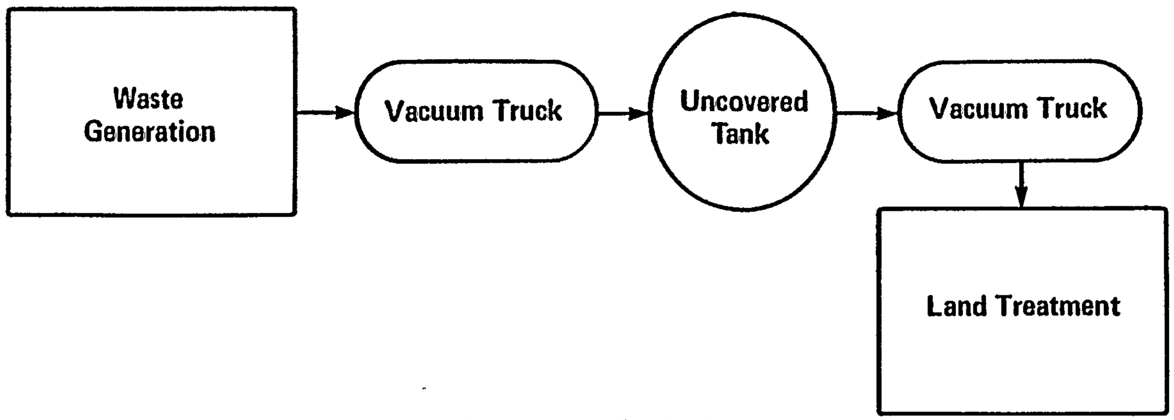
Waste management process	RCRA process code	Number of active facilities with process[a]	Waste quantity managed,[a] 10^6 Mg/yr
Storage			133
Container	S01	1,440	
Tank	S02	911	
Wastepile	S03	57	
Impoundment	S04	223	
Treatment			154
Tank	T01	291	
Impoundment	T02	127	
Incineration	T03	158	
Other[b]	T04	319	
Disposal			49
Injection well	D79	61	
Landfill	D80	90	
Land treatment	D81	54	
Ocean disposal	D82	NA	
Impoundment	D83	47	
Total[c]		>2,300	275

RCRA = Resource Conservation and Recovery Act.
NA = Not available.

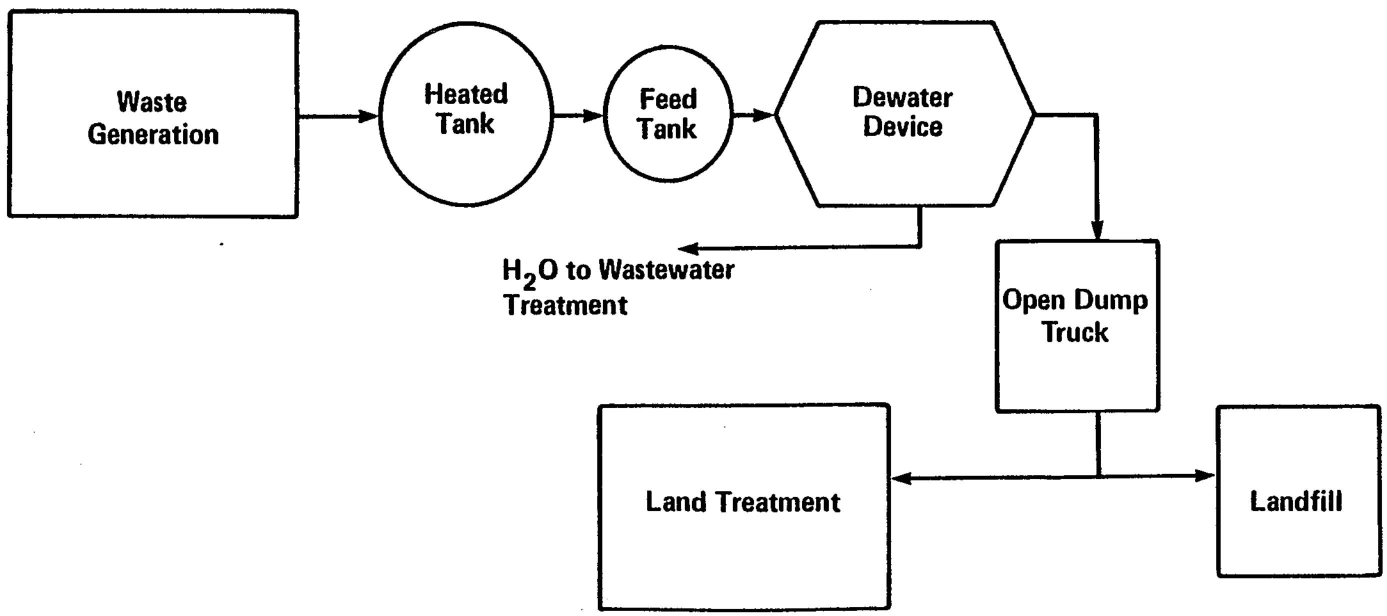
[a]Based on the 1986 Screener Survey.[13] Excludes facilities that manage less than 0.01 Mg/yr in storage, treatment, and disposal processes. Quantities were not reported in this survey by specific management process.

[b]"Other" refers to physical, chemical, thermal, or biological treatment processes not occurring in tanks, surface impoundments, or incinerators.

[c]Facilities do not add up to about 2,300 because some facilities have more than one process. Waste quantities presented do not add to the total of 275 million Mg of hazardous waste produced and managed in 1985 because some facilities may process a waste in more than one management process. For example, a waste may be stored prior to treatment or treated prior to disposal.

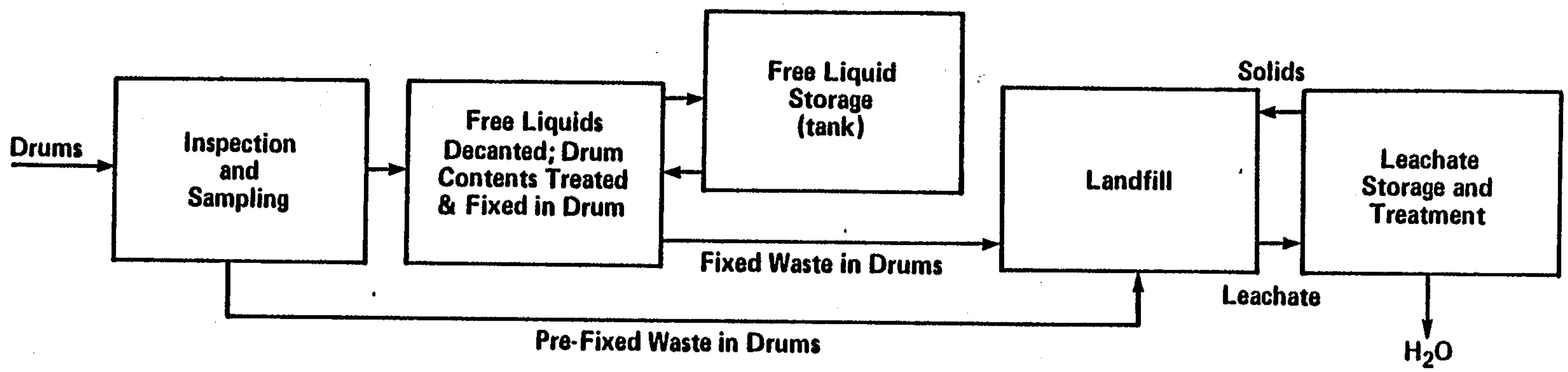


A. Land treatment of bulk sludges or liquids

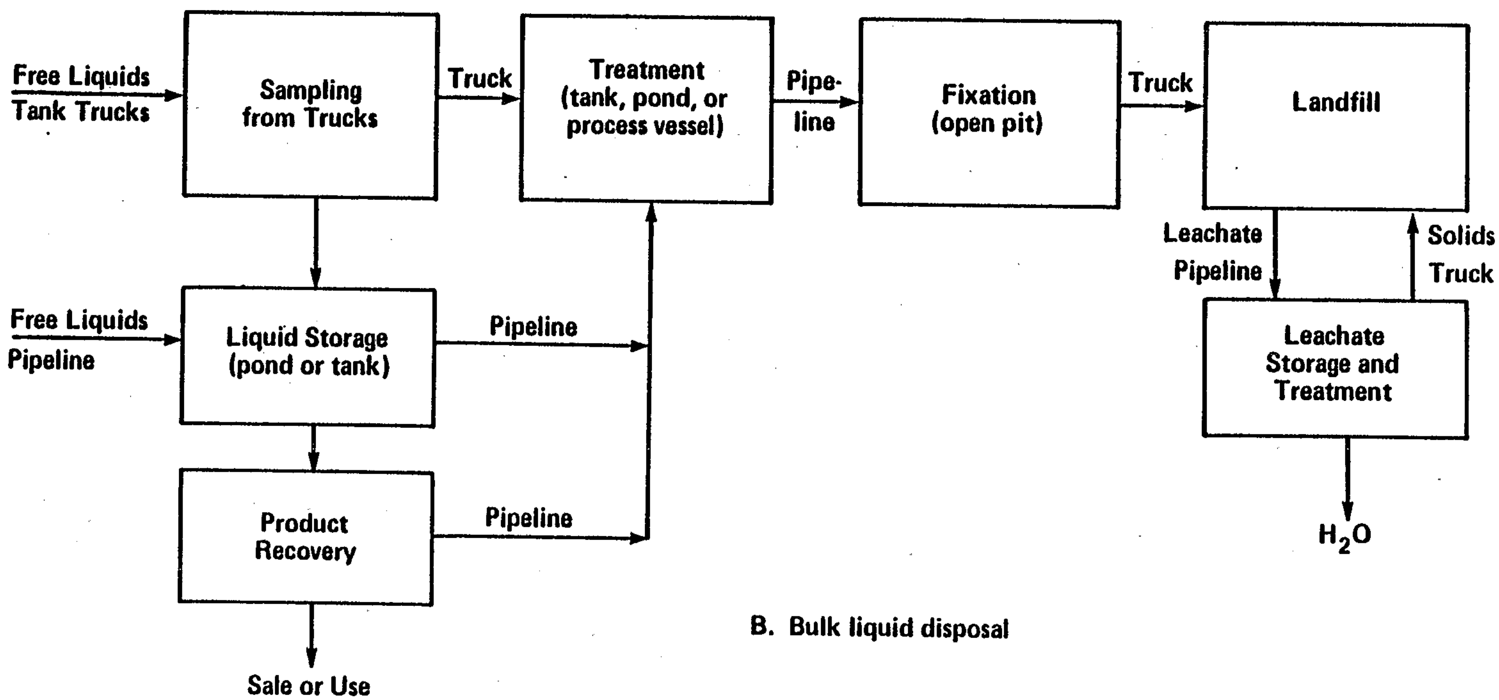


B. Land treatment of filtered solids

Figure 3-3. Two examples of onsite hazardous waste land treatment operations.



A. Drum disposal



B. Bulk liquid disposal

Figure 3-4. Two examples of active landfill operations.

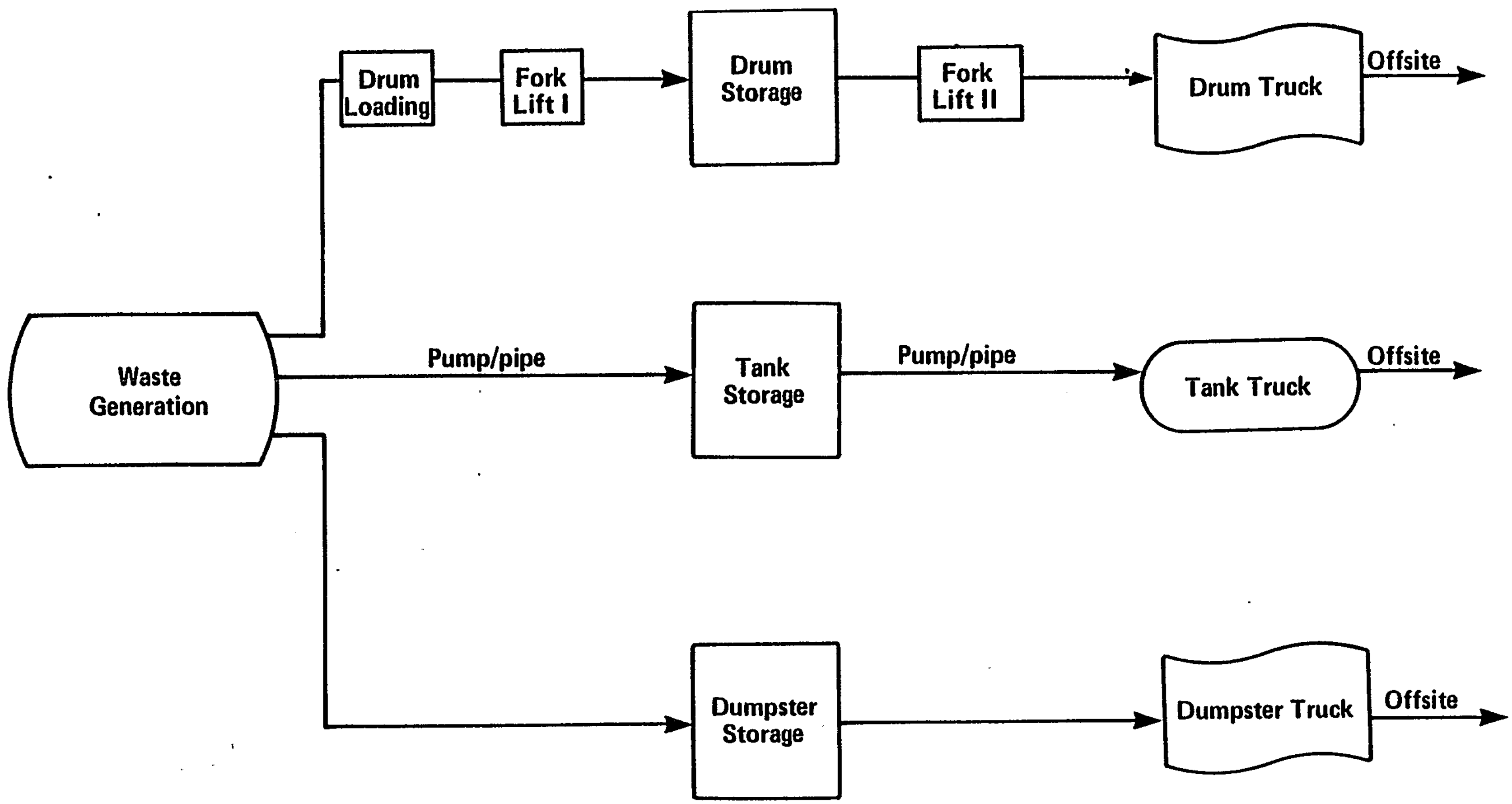


Figure 3-5. Example onsite hazardous waste storage facility.

changing demands and regulations, the facilities change the ways wastes are treated, stored, and disposed of.

The total estimated quantity of hazardous wastes managed at more than 2,300 TSDF in 1985 was 275 million Mg. The waste quantities handled by each of the three main waste management processes (i.e., treatment, storage, and disposal) are presented in Table 3-2. The waste quantities given in Table 3-2 will not sum to the total national estimate because some wastes pass through more than one process; for example, a waste may be stored prior to treatment or treated prior to disposal. Also provided in Table 3-2 is a breakdown of the number of active TSDF by specific type of treatment, storage, or disposal process. In the storage category, container storage is a management process utilized by more than half the TSDF; tank storage occurs at slightly more than a third of the TSDF. Of the treatment processes, tank treatment is widely practiced, but no single treatment process is used in a majority of facilities. In the disposal category, landfills are the dominant disposal units operated at TSDF.

The information presented above is taken from a TSDF data base of waste management practices compiled for use in examining the industry and its environmental and health impacts. Three data bases were used to generate this TSDF data base. Two major sources were the Hazardous Waste Data Management System (HWDMS)[14] and the 1981 Westat Survey, both of which are EPA Office of Solid Waste (OSW) data bases. More recent information from the OSW 1986 National Screening Survey of Hazardous Waste Treatment, Storage, Disposal, and Recycling Facilities (1986 Screener) was also used to make the TSDF data base as current as possible.[15] Each of these three data bases provided a different level of detail regarding particular aspects of the TSDF industry. For example, the HWDMS provided waste management process codes, wastes codes, and facility SIC codes. The 1986 Screener provided information on total annual waste quantities managed by the facility and operating status (active or closed) for the entire industry. The Westat Survey, on the other hand, deals with only a subset of the industry but provides a greater level of detail regarding individual facility operations; for example, the distribution of waste quantities handled by each waste management process is available for each facility in the data base.

3.1.5 TSDF Emission Sources

The organic emission sources associated with each type of storage, treatment, and disposal process are summarized in Table 3-3. The emission sources in this table are arranged into six categories based on their common emission characteristics and/or their routine association with other processes. These are (1) impoundments and tanks, (2) land treatment, (3) landfills and wastepiles, (4) transfer and handling operations, (5) injection wells, and (6) incinerators.

For open (or uncovered) surface impoundments and tanks, the major source of organic emissions is the uncovered liquid surface exposed to the air. The conditions under which liquids are stored in uncovered impoundments and uncovered tanks ranges from quiescent to highly turbulent since, in some cases, aeration and/or agitation are applied to aid in treatment of the waste. Emissions tend to increase with an increase in surface turbulence because of enhanced mass transfer between the liquid and air. For both uncovered and covered storage tanks, loading and breathing losses are a major source of emissions.

At land treatment facilities, wastes are either spread on or injected into the soil, after which they are normally tilled into the soil. Other activities that are likely to occur at land treatment facilities include transfer, storage, handling, and dewatering of the wastes to be land-treated. Examples would include loading and unloading of wastes in vacuum trucks and dewatering of wastes using one of the various types of available filtration devices. Each of the land treatment process stages illustrated in Figure 3-3 is a potential source of organic air emissions. The major emission source associated with land treatment is the land treatment area itself.

A landfill is a facility, usually an excavated, lined pit or trench, into which wastes are placed for disposal. Some existing landfills may not be lined; however, all new facilities are lined to meet RCRA permit requirements. All wastes containing liquids and destined for disposal in a landfill must be treated or "fixed" to form a nonliquid material. The landfilling of waste is a source of organic emissions from several emission

TABLE 3-3. HAZARDOUS WASTE MANAGEMENT PROCESS EMISSION SOURCES

Management process	Emission source
<u>Impoundments and Tanks</u>	
(S04, T02, D83) (S02, T01)	
Quiescent impoundments (storage & treatment)	Quiescent liquid surface
Quiescent tanks (storage & treatment)	
Uncovered	Quiescent liquid surface
Covered	Working and breathing losses
Aerated/agitated impoundments (treatment)	Turbulent liquid surface
Aerated/agitated uncovered tanks (treatment)	Turbulent liquid surface
Impoundment lining	Dredging (exposed waste surface)[a]
Impoundment inlet	Splash loading[b]
<u>Land Treatment (D81)</u>	
Land application	Application of waste to soil Applied waste before tilling Applied waste after tilling
Dewatering devices	Vacuum pump exhaust for vacuum filters[a] Exposed waste surface in belt filter presses Filter cake collection and disposal
<u>Landfills (D80) and Wastepiles (S03)</u>	
Active landfill	Transport of waste to landfill (open trucks) Unloading and spreading of wastes Landfilled waste Leachate (within the confines of the liner system)

(continued)

TABLE 3-3 (continued)

Management process	Emission source
Landfills and Wastepiles (con.)	
Closed landfill	Landfill surface gas vents and manholes Leachate (within the confines of the liner system)
Wastepiles	Wastepile surface Leachate (within the confines of the liner system)
Waste fixation	
Pit and mixer	Splash loading into fixation pits[b] Mixing of waste and fixative Mechanical mixer vents
Drum	Drum inspection[a] Drum decanting[a] In-drum fixation[a]
Transfer and Handling Operations (S01, S02)	
Vacuum trucks	Vacuum pump exhaust Spills during truck loading Truck cleaning[a]
Open dump trucks	Waste surface during loading and transport Spills Truck cleaning[a]
Equipment leaks[c]	Losses from pumps, valves, sampling connections, open-end lines, and pressure-relief devices
Containers	
Drums Tank trucks Railroad tank cars Marine tankers Barges Dumpsters	Waste loading Spillage in transit Spillage during waste loading/unloading Exposed waste surface Cleaning losses[a]

(continued)

TABLE 3-3 (continued)

Management process source category	Emission source
<u>Injection Wells (D79)</u>[d]	
<u>Incinerators (T03)</u>[e]	Exhaust gas stacks

[a]No emission estimating method exists for this source.

[b]No emission estimating method exists for this source. Unlike enclosed sources such as tanks, this is an open source and vapor saturation does not occur.

[c]Emissions from equipment leaks are associated with all management processes that involve the use of pumps, valves, sampling connections, open-ended lines, and pressure-relief devices.

[d]This management process is being regulated under a different standard. The equipment leak emissions related to the injection well disposal process are evaluated in this document.

[e]Incinerator emission sources, such as exhaust gas stacks, are regulated under 40 CFR 264, Subpart O, "Incinerators." The equipment leak emissions related to incineration are evaluated in this document.

points, as illustrated in Figure 3-3. This figure shows typical process stages for two variations in landfill processing; each of the processing steps identified is a potential emission source. The landfill surface, whether open, covered with earth daily, or closed with a cap is an emission source. A waste fixation pit is another source of organic emissions that could be associated with landfills. Activities at the landfill, such as waste transport and waste unloading and spreading, are also sources of emissions. Wastepiles are similar to landfills and the same emission sources can be found; they are, in essence, temporary landfills.

Each of the process steps illustrated in Figure 3-5 is a potential emission source associated with hazardous waste transfer, storage, and handling operations. Loading operations contribute to overall emissions, especially splash loading of waste as opposed to submerged loading. Spills also occur during waste transfer and handling and, for liquid wastes that are pumped, emissions may occur from fugitive sources such as pumps and valves or at open-ended lines, pressure-relief valves, and sampling connections. Organic emissions are associated with all three of the storage methods shown in Figure 3-5: drums, dumpsters, and tanks.

Miscellaneous sources of emissions such as drum cleaning or the crushing and landfilling of empty drums containing waste residues also contribute to organic air emissions. The improper handling of drum residue can lead to emissions along with waste residues lost to the environment by uncontained drum crushing operations. In addition, RCRA permit conditions require annual dredging of surface impoundments; the dredging operation, a waste transfer process, may also be a source of organic emissions.

3.2 ESTIMATES OF ORGANIC EMISSIONS

A modeling approach based on applicable mass transfer equations was selected as the method of estimating organic emissions from TSDF. Models initially developed by the EPA Office of Solid Waste were refined to incorporate inputs relevant to estimating air emissions. The models selected for use are formulated for individual management processes at TSDF and account for such factors as process design and operating parameters as well as the meteorological effects on emissions. These emission models were used to generate estimates of the amounts of organics in the incoming wastes that are emitted to the air or biodegraded during processing. More traditional emission estimating techniques and methodologies, such as basing emission estimates on the results of a limited number of actual TSDF source tests, are not appropriate for the diverse operations found in this industry. The TSDF industry and its waste management processes are too varied to use source test data as the sole basis to estimate industry-wide emissions.

The use of emission models makes it possible to generate emission estimates under a wide variety of source conditions and waste compositions. The accuracy of estimates made by the emission models in comparison to actual field measurements of emissions for specific sites has been examined. That comparison is discussed in Appendix C. In general, it was found that, where comparisons could be made, emission model estimates compared favorably with field data. Appendix F contains the TSDF source test data.

The following sections describe the bases for developing estimates of organic compound emissions from TSDF using the modeling approach. Section 3.2.1 discusses the elements necessary for producing nationwide emission estimates for individual waste management units. Section 3.2.2 discusses how those elements are combined in a single computer model to produce the nationwide emission estimates.

3.2.1 Emission Estimation Data Requirements

Key elements in the estimation of organic emissions from TSDF are the availability of: (1) facility-specific information, (2) management process emission characteristics, and (3) waste compositions. Facility-specific information and data include the types of waste management processes present in those facilities, the RCRA waste codes managed at the facilities, and the total quantity of waste managed for each of the facilities nationwide. Some facility-specific information is available through data bases established for other EPA projects, e.g., the HWDMS, the 1981 Westat Survey, and the 1986 Screener (refer to Appendix D, Section D.2.1.4, for a description of how these data sources are used). Where facility-specific data such as waste compositions and management process characteristics (e.g., aerated versus quiescent operations) are insufficient, estimated values based on existing data bases of industry-specific waste compositions and operating practices are used. (See Appendix D, Sections D.2.2 and D.2.4, for waste composition and operating practice discussions, respectively.) Section 3.2.2.1 describes the facility information available for the generation of nationwide estimates.

In addition to facility-specific data, emitting characteristics of the waste management units are needed to estimate nationwide emissions. Typically, emission measurements are made at the source and those measurements serve as the basis for characterization of similar emission sources. In the case of TSDF, there is a diversity of sources and factors within a source that have a significant impact on emissions, waste composition being a major one; this variation makes estimation of nationwide TSDF emissions directly from only measured data impractical. Other factors that restrict this approach include the overall lack of emission test data for the range of TSDF management processes and the absence of standardized test methods that allow meaningful comparisons of available emission data to be made. As an alternative, emission models have been adapted to facilitate generation of waste management process emission estimates. These emission models are presented in Appendix C, Section C.1. To use the emission models, it is necessary to define certain waste management unit design and operating characteristics (such as surface area and waste retention time for surface impoundments). Given that this level of detail is not available for most facilities, process parameters based on model management units were developed for use in calculating emissions (also, costs of control and emission reductions). Using survey results and information from other sources such as design manuals and site visit reports, model units were developed in terms of operating and design parameters spanning typical ranges of surface area, retention times, and other characteristics representative of the TSDF industry. A sensitivity analysis was conducted for each model to determine which input parameters, over what range, have significant effects on emission model estimates. Appendix C, Section C.2, discusses the sources of information and rationale used to develop the TSDF model units and lists the specific characteristics of each model waste management unit that are needed to compute emissions using the appropriate emission model.

The other key element in estimating emissions is the composition of the waste in the waste management unit. The specific chemicals found in each waste management unit nationwide are not known. However, facility-specific data described above do identify RCRA waste codes and their management process codes. Existing data bases of waste compositions are available by industrial category for waste codes. These waste codes allow the assignment of waste compositions to process codes in order to estimate emissions. These data bases have been combined into a single data base that contains waste compositions for over 300 SIC codes. The data base presents waste composition as a function of SIC, RCRA waste codes, and their physical/chemical forms. The file is described briefly in Section 3.2.2.2 and described in detail in Appendix D, Section D.2.2.

Table 3-4 presents the relative emissions predicted by the emission models for selected model waste management units. This table lists predicted uncontrolled organic emissions by model unit for five different model waste compositions. The specific compositions of the five model wastes are given in Appendix C, Section C.2.2, along with the rationale for their development. The results in Table 3-4 illustrate the variability in emissions that may occur from waste management units for different waste compositions. The table also shows emission variability between waste management units for the same waste type. No conclusions should be drawn from this latter comparison without considering the differences in waste throughput between the waste management units. It should be pointed out that, to the extent possible, the composition and quantities of the actual waste streams processed at the existing facilities were used in estimating nationwide emissions. The model wastes are presented here to illustrate the variability in potential air emissions in relation to waste composition and management process.

In calculating nationwide TSDF air emissions, emission models are used with the model waste management unit design and operating characteristics to produce emission factors for the model units. The model unit emission factors are estimates of the fraction of specific organic compounds entering the waste management unit that become air emissions from that unit. Derivation of these emission factors involves combining the steps discussed

TABLE 3-4. SUMMARY OF SELECTED MODEL HAZARDOUS WASTE MANAGEMENT UNIT UNCONTROLLED ORGANIC EMISSION ESTIMATES FOR MODEL WASTES (Mg/yr)[a]

Model unit[b]	Model waste type: Aqueous sludge/ slurry	Dilute aqueous	Organic liquid	Organic sludge/ slurry	Two-phase aqueous/ organic
Covered storage tank (S02D)	0.117	2.12	0.437	1.11	0.891
Covered quiescent treatment tank (T01E)	0.24	4.6	1.19	1.40	1.94
Quiescent uncovered storage tank (S02I)	24	8.1	514	586	9.7
Quiescent uncovered treatment tank (T01B)	34	19	954	1,026	31
Quiescent storage impoundment (S04C)	686	159	--	--	183
Quiescent treatment impoundment (T02D)	946	269	--	--	326
Quiescent disposal impoundment (D83A)	842	130	--	--	16,000
Uncovered aerated/ agitated treatment tank (T01G)	870	130	--	--	--
Aerated/agitated treatment impoundment (T02J)	1,920	390	--	--	380
Waste fixation (Fixation Pit B)	4,110	--	--	--	31,700
Drum storage (S01B)	0.0036	0.0000909	0.0236	0.0298	0.000181
Dumpster storage (S01C)	0.72	--	0.049	1.44	--
Wastepiles (S03E)	139.7	--	--	--	100

(continued)

TABLE 3-4 (continued)

Model unit[b]	Model waste type				
	Aqueous sludge/ slurry	Dilute aqueous	Organic liquid	Organic sludge/ slurry	Two-phase aqueous/ organic
Landfill-active (D80E)	358[c]	--	--	--	299[c]
Landfill-closed (D80H)	0.068	--	--	--	2.09
Land treatment (D81C)	269	21.6	--	--	--

-- = Indicates this model unit does not manage this model waste type, thus an uncontrolled emission estimate is not available.

[a]This table lists the estimated organic emissions for selected model waste management units when the listed model wastes are managed in those units. The model unit definitions are given in Appendix C, Section C.2.1. The model waste compositions are also described in Appendix C, Section C.2.2. These compositions and resulting emission estimates are not intended to be representative of nationwide TSDF operations but rather are presented to illustrate the variability in potential air emissions in relation to the waste composition and management process.

[b]The parenthetical listings are the model unit designations under which the model unit definitions can be found in Appendix C, Section C.2.2.

[c]This estimate does not assume that regulations restricting land disposal of bulk liquids are in effect.

previously in this section with a knowledge of the properties of the compounds for which emission factors are required. The development of emission factors is explained in detail in Appendix D, Section D.2.4.

3.2.2 Nationwide TSDF Emissions

Nationwide organic air emissions from the TSDF industry were estimated using the Source Assessment Model (SAM), a computerized simulation program designed to generate nationwide emissions estimates on a facility, waste management unit, or emission source basis. Summation of individual facility results provides the nationwide emission estimate. The SAM utilizes a variety of information and data concerning the TSDF industry to calculate emissions. The SAM processes the information and data from a number of input files that contain TSDF-specific information (facility location, waste management processes used, and types and quantities of wastes managed), waste characterization data (approximate compositions of typical wastes), and air emission model estimates (emission factors based on characteristics of both TSDF waste management units and waste types).

Because of the complexity of the TSDF industry and the current lack of detailed information for all TSDF, it is unlikely that the SAM estimates are accurate for an individual facility. However, it is believed that the SAM emission estimates are a reasonable approximation on a nationwide basis and the TSDF modeling approach provides the best basis for analysis of options for controlling TSDF air emissions.

A brief discussion of the input data files, assembled for and used by the SAM to calculate air emissions, and the output emissions files generated by the SAM are presented in the following sections of this chapter. Figure 3-6 outlines the main SAM files and functions used in estimating nationwide emissions from the TSDF industry. The SAM, its data inputs and outputs, and the overall logic used in the model's calculations are discussed in more detail in Appendix D.

3.2.2.1 SAM Input Files. There are four main data files that are inputs to the SAM nationwide uncontrolled emission estimates: the Industry Profile (a file of waste management practices for each TSDF in the Nation), the waste characterization file (also referred to as the Waste Characterization Data Base), the chemical properties file, and the emission factors

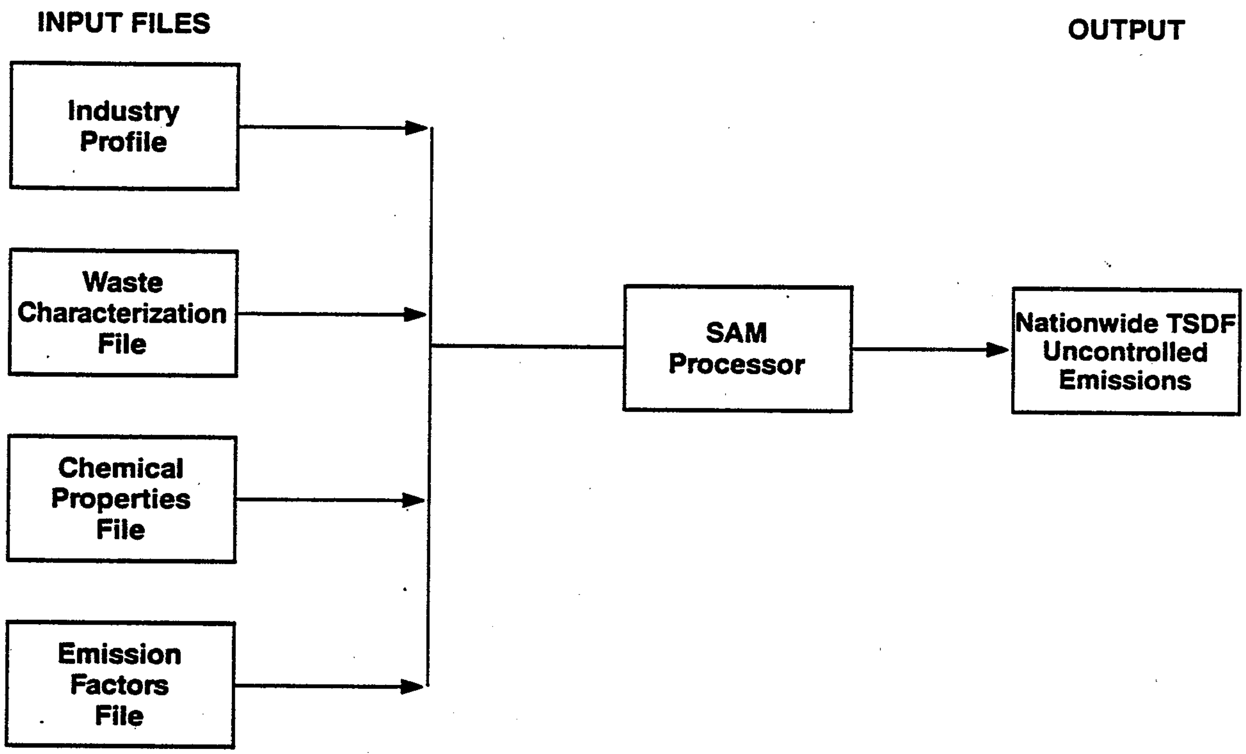


Figure 3-6. Source Assessment Model (SAM) input files used in estimating nationwide treatment, storage, and disposal facilities (TSDF) uncontrolled air emissions.

file. These inputs provide the information and data necessary to calculate nationwide TSDF uncontrolled emissions.

3.2.2.1.1 Industry Profile. The Industry Profile data base was developed to provide a list of TSDF nationwide and to describe facility-specific waste management practices in terms of the types and quantities of wastes handled and the processes utilized. Several hazardous waste industry surveys and data bases, available through EPA's Office of Solid Waste, serve as the basis of the SAM Industry Profile (see Appendix D, Section D.2.1). The information and data from each of these surveys and data bases were used in the SAM to estimate nationwide emissions and impacts of potential control options.

The information that the SAM uses from the Industry Profile to estimate nationwide emissions includes the following for each TSDF: (1) facility identification number (FCID), (2) location coordinates of the facility, (3) the primary SIC code for the facility, (4) the RCRA waste codes managed at the TSDF, (5) the waste quantity for each of the waste codes, and (6) the management process codes applicable to each waste code. It is important to note that the SIC and waste codes link the facility to the waste characterization file, which gives estimated waste compositions.

3.2.2.1.2 Waste characterization file. This waste characterization file contains waste data that have been compiled to represent chemical-specific waste compositions for each waste found within an SIC code. An RCRA waste may be generated in one of several physical/chemical forms; for example, a waste may be an aqueous liquid or an organic sludge. The waste characterization file contains the composition of waste streams in terms of chemical constituents and their respective concentrations for each physical/chemical form of a waste associated with a particular RCRA waste code in an SIC category. If specific chemical constituents were not found in the original data, chemical assignments were made based on a review of similar TSDF processes. Wherever available, specific chemicals were retained in the waste characterization file. The data provided in the waste characterization file are accessed by the SAM for each TSDF emission calculation. (See Appendix D, Section D.2.2, for a more detailed discussion.)

3.2.2.1.3 Chemical properties file. Emission estimation for each of the more than 4,000 waste chemical constituents identified in the waste characterization file would require property data for all compounds; many of which are not available. Therefore, to provide the emission models with appropriate constituent physical, chemical, and biological properties, the waste constituents were categorized and grouped into classes based on volatility (i.e., vapor pressure or Henry's law constant) and biodegradation. These categories were defined to represent the actual organic compounds that occur in hazardous waste streams and serve as surrogates for the particular waste constituents in terms of physical, chemical, and biological properties in the emission calculations carried out by the SAM. (See Appendix D, Section D.2.3, for a more detailed discussion.)

3.2.2.1.4 Emission factors file. For each waste management process (e.g., aerated surface impoundment or treatment tank), the respective emission models applicable to the process were used to determine the amount or fraction of the organic compound entering the unit that is emitted to the air and the fraction that is biodegraded. The calculations were made for each chemical surrogate category for each waste management process. In addition to emission factors for process-related emissions, emission factors developed for transfer and handling-related emissions were also incorporated into the SAM program file. The emission factors used for estimating TSDF emissions in this document were calculated using the TSDF air emission models as presented in the March 1987 draft of the Hazardous Waste Treatment, Storage, and Disposal Facilities: Air Emission Models, Draft Report.[16] Since that time, certain TSDF emission models have been revised. A new edition of the air emission models report was released in December 1987.[17] The principal changes to the emission models involved refining the biodegradation component of the models for biologically active systems handling low organic concentration waste streams. With regard to emission model outputs, the changes from the March 1987 draft to the December 1987 version affected, for the most part, only aerated surface impoundments and result in a minor increase in the fraction emitted for the chemical surrogates in the high biodegradation categories.[18] For the other air emission models, such as the land treatment model, which were also revised to incorporate new biodegradation rate data, the changes did not result in appreciable differences in the emission estimates. Since the December 1987 report version was issued, new data on biodegration rates have been obtained and comments were received.[19] Based on these data and comments, the biodegradation model for aerated wastewater treatment systems was further revised to incorporate Monod kinetics. Additional investigation and comments led to an evaluation of changes to the model units used for aerated tanks and impoundments. These changes improve the technical basis for the biodegradation model. However, the combined effect of these changes did not significantly affect the estimated nationwide emissions and other impacts presented in this document.[20] Therefore, the emission factors remain based on the March 1987 draft of the air emissions model report and the model unit definitions were not changed. (Appendix C, Section C.1.1.1.3, contains more details on the biodegradation modeling and Appendix D, Section D.2.4, contains a more extensive discussion of emission factors.)

3.2.2.2 Uncontrolled Nationwide Emissions. The SAM computes nationwide uncontrolled TSDF emissions by first identifying particular waste management process units within the facility from the Industry Profile. Once a management process is identified, the SAM then calculates emissions on a chemical-by-chemical basis. The quantity of a particular chemical in the waste stream is multiplied by the appropriate emission factor, which is determined by the chemical, physical, and biological properties of the chemical. Emissions for the unit are the sum of the emissions for each chemical constituent in the waste stream. Emissions for each management process unit can then be summed; emissions from source categories (management units with similar emission characteristics, e.g., quiescent storage impoundments and quiescent treatment impoundments) are then summed to yield a nationwide emission estimate.

The nationwide emission estimates for the current TSDF community are based on 1985 data containing general operating conditions and practices, the time covered by the most recent TSDF industry survey. These emission estimates are considered to represent the uncontrolled situation or case; review of the existing applicable State regulations has shown a wide variation in level of control required for these sources, with many States having no control requirements for TSDF.

The uncontrolled nationwide TSDF emission estimate as determined by the SAM is 1.8 million Mg of organic emissions annually. The breakdown of nationwide emissions by source category is provided in Table 3-5. (Chapter 6.0 presents additional information on these uncontrolled emissions.) Table 3-5 shows that storage tanks are estimated to be the single largest emitting source nationwide. Treatment tanks and impoundments that are aerated to promote biological activity are the second highest single source. These two source categories combined account for about 70 percent of the annual emissions estimated.

3.3 REFERENCES

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3. U.S. Environmental Protection Agency. The Hazardous Waste System. Office of Solid Waste and Emergency Response. Washington, DC. June 1987. p. 1-4.

4. Westat, Inc. National Survey of Hazardous Waste Generators and Treatment, Storage and Disposal Facilities Regulated Under RCRA in 1981. Prepared for the U.S. Environmental Protection Agency, Office of Solid Waste. April 1984. p. 141.

5. Reference 4, p. 65.

6. Reference 3, p. 2-3.

7. Reference 2, p. 4.

8. Abt Associates, Inc. National Small Quantity Hazardous Waste Generators Survey. Prepared for the U.S. Environmental Protection Agency, Office of Solid Waste. Washington, DC. February 1985. p. 2.

9. Reference 8, p. 2.

10. Reference 4, p. 69.

11. Reference 2, p. 4.

12. Code of Federal Regulations. Title 40, Part 260.10. Definitions. U.S. Government Printing Office. Washington, DC. July 1, 1986. p. 340-347.

TABLE 3-5. NATIONWIDE UNCONTROLLED TSDF ORGANIC EMISSION ESTIMATES[a]

Source category	Nationwide uncontrolled emissions, 10^3 Mg/yr
Drum storage	0.19
Dumpster storage	78
Storage tanks	756
Quiescent surface impoundments[b]	209
Quiescent treatment tanks	48
Aerated/agitated tank and surface impoundments	515
Wastepiles	0.13
Landfills	40
Waste fixation	2.1
Incineration[c]	0.88
Land treatment	73
Spills	0.43
Loading	6.8
Equipment leaks	80
Total	1,810

TSDF = Treatment, storage, and disposal facility.

[a]This table presents the nationwide estimates of uncontrolled TSDF organic emissions generated by the Source Assessment Model described in Appendix D. Emissions are presented for management processes that have similar emission characteristics, i.e., source categories.

[b]Includes quiescent surface impoundments used for both storage, treatment, or disposal.

[c]Uncontrolled incinerator emissions includes emissions from wastes that are routinely incinerated with stack exhaust gas emission controls. These sources are currently regulated under 40 CFR 264 Subpart O. The uncontrolled emission scenario does not include wastes that are or would be incinerated as a result of implementing the RCRA land disposal restrictions (LDR). The baseline and two example control strategies do, however, account for the incinerator emissions resulting from the LDR. The emission scenarios are explained in Chapter 5.0.

13. Memorandum from MacIntyre, Lisa, RTI, to Docket. November 4, 1987. Data from the 1986 National Screening Survey of the Hazardous Waste Treatment, Storage, Disposal and Recycling Facilities used to develop the Industry Profile.

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19. Chemical Manufacturers Association. Comments of the Chemical Manufacturers Association on the Environmental Protection Agency Document "Hazardous Waste TSDF - Background Information for Proposed RCRA Air Emission Standards - Volumes I and II." Washington, D.C. July 11, 1988. 105 p.

20. Reference 18.

4.0 CONTROL TECHNOLOGIES

A variety of control technologies is available that can be used to reduce organic air emissions from hazardous waste treatment, storage, and disposal facilities (TSDF). All of these control technologies are not applicable to all TSDF emission sources. The applicability of a control technology to a TSDF emission source depends on the type of waste management unit as well as the characteristics of the hazardous waste managed in the unit. The purpose of this chapter is to introduce the control technologies that are potentially applicable to TSDF emission sources. Chapters 5.0 through 7.0 present analyses to evaluate the organic air emission reductions, health risk and environmental impacts, and costs for implementing alternative combinations of the control technologies to TSDF emission sources on a nationwide basis.

4.1 APPLICATION OF CONTROL TECHNOLOGIES TO TSDF EMISSION SOURCES

4.1.1 Control Technology Categories

Control technologies applicable for TSDF organic air emission reduction can be classified into five major categories:

- Suppression controls
- Add-on controls
- Organic removal and hazardous waste incineration processes
- Process modifications
- Work practice improvements.

Suppression controls contain or capture the organics at the TSDF emission source. For example, placing a cover on the surface of the waste contains the organics in the waste medium and inhibits the release of organic vapors to the atmosphere. Installing an enclosed waste management unit in place of an open unit or erecting an enclosure over an existing waste management unit captures the organic vapors released from the waste and allows the control of the vapors using an add-on control device.

Add-on controls reduce organic air emissions by removing organics from the captured vapor stream prior to discharge of the gases to the atmosphere. This is achieved by extraction of the organics from the vapor stream or by destruction of the organics in the vapor stream.

Organic removal and hazardous waste incineration processes remove volatile organics from the hazardous waste before the waste arrives at the next TSDF waste management unit. These processes offer an alternative to using add-on controls to control organic air emissions after they have been emitted from the TSDF unit. The type of organic removal or incineration process used varies depending on the hazardous waste forms.

Process modifications achieve organic air emission reductions by changing the equipment or procedures used to manage hazardous waste.

Work practice improvements are steps that the TSDF personnel can implement during everyday waste management unit operations to minimize organic air emissions. For example, programs can be implemented to promptly detect and repair leaking equipment.

This chapter presents descriptions of the control technologies that are potentially applicable to the TSDF emission source categories identified in Chapter 3.0. The control technologies are organized using the five control technology categories described above and presented in the order listed in Table 4-1.

4.1.2 Organic Air Emission Control Efficiency

The effectiveness or efficiency of each control technology to reduce organic air emissions is a key parameter used for the TSDF control option analyses presented in Chapters 6.0 and 7.0. The preferred method for determining the potential organic air emission control efficiency for a particular control technology is by the source testing of full-sized control devices. Unfortunately, source testing is not practical for certain types of control technologies because of the large area that must be enclosed to obtain accurate results or physical conditions that prevent measurement devices from being placed at the source of the emissions.

TABLE 4-1. TSDF CONTROL TECHNOLOGY CATEGORIES

Suppression controls

- Fixed-roof tanks
- Floating roof tanks
- Pressure tanks
- Floating membrane covers
- Air-supported structures
- Flexible membrane covers
- Rigid membrane covers
- Rigid structures

Add-on controls

- Carbon adsorbers
- Thermal vapor incinerators
- Catalytic vapor incinerators
- Flares
- Boilers and process heaters
- Condensers
- Absorbers

Organic removal and hazardous waste incineration processes

- Steam stripping units
- Air stripping units
- Thin-film evaporation (TFE) units
- Batch distillation units
- Dewatering units
- Hazardous waste incinerators

Process modification

- Coking of petroleum refinery sludges
- Mechanical mixing for waste fixation
- Submerged loading of containers
- Subsurface injection

Work practice modification

- Leak detection and repair
- Drum storage area housekeeping

Consequently, the control efficiency must be estimated using information such as laboratory test data and mathematical models.

This chapter discusses the organic air emission control efficiencies that each control technology is capable of achieving when applied to TSDF emission sources. The source test data used to determine the control efficiencies for many of the control technologies are summarized in Appendix F. Appendix H presents detailed descriptions of the methodology and calculations used to determine the control efficiencies for the control technologies for which no source test data could be obtained.

4.1.3 Secondary Air and Cross-Media Impacts

The control technologies applicable to TSDF emission sources achieve organic air emission reductions by using physical, chemical, and thermal processes that may create additional environmental impacts. The impacts resulting from the emission of non-organic air pollutants are termed "secondary air impacts." The impacts from production of new liquid or solid wastes are termed "cross-media impacts."

Control technologies based on extraction processes remove the volatile organics in the form of liquid or solid by-products. Often these by-products can be recycled or burned as a fuel. However, in some situations, there is no other alternative but to dispose the by-products as wastes, thereby creating additional demands on wastewater treatment units and landfills. Control technologies based on destruction processes convert organic vapors to carbon dioxide, water, and small quantities of various other chemical compounds. Depending on the original organic composition in the waste, non-organic air pollutants may be formed that need to be controlled. Supplying electricity and process steam required to operate certain TSDF control technologies may create air emissions, wastewater discharges, and solid wastes from non-TSDF sources such as industrial boilers and utility power plants.

Because a control technology may produce secondary air and cross-media impacts, the human health and environmental benefits from the organic air emission reduction that can be achieved by applying the control technology to TSDF emission sources are evaluated relative to the secondary air and cross-media impacts produced by implementing the control technology. This chapter identifies the types of secondary air and cross-media impacts associated with each of the control technologies. Chapter 6.0, Section 6.3, presents the results of the secondary air and cross-media impacts analysis.

4.2 SUPPRESSION CONTROLS

Suppression controls consist of covers and enclosures. These controls serve to keep the volatile organics in the hazardous waste process streams instead of being released to the atmosphere. However, the potential remains that the volatile organics in the waste could ultimately be released to the atmosphere from a point downstream in the storage, treatment, or disposal of the waste unless suppression controls are used in conjunction with add-on control, organic removal, or process modification control technologies.

Covers that directly contact the waste medium suppress the volatization of the organics by creating a physical barrier at the waste surface. There is no or very little vapor space between the waste surface and the underside of the cover where volatile organic vapors can collect. The effectiveness of a cover in suppressing organic air emissions depends on the permeability of the cover, the leak rate at the cover edges and from any fittings on the cover, and the frequency that the cover is opened to add or remove material from the waste management unit.

Organic air emissions can also be suppressed by forming a closed vapor space above the waste surface. Enclosing the vapor space can be achieved by erecting a structure around the entire waste management unit or, for some types of open-top units, installing a rigid cover. The organic vapors from the waste are confined by the enclosure and prevented from being emitted to the atmosphere. However, if the enclosure vents directly to the atmosphere, the enclosure suppression effectiveness will be diminished significantly. Therefore, many types of enclosures must be used in combination with an add-on control device to provide effective TSDF organic air emission control.

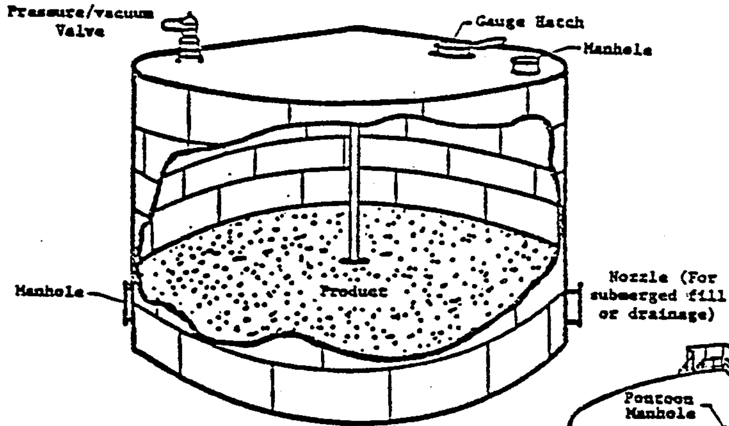
4.2.1 Fixed-Roof Tanks

A fixed-roof tank is a vertical cylindrical steel wall tank with a cone-shaped or dome-shaped roof that is permanently attached to the tank shell (see Figure 4-1).[1] Vents are installed on the roof to prevent the tank internal pressure from exceeding the tank design pressure limits and, thereby, causing physical damage or permanent deformation to the tank structure. The vents can either open directly to the atmosphere, be equipped with valves that open at specified pressure or vacuum settings, or be connected to an add-on control device (e.g., carbon adsorption system, vapor incinerator).

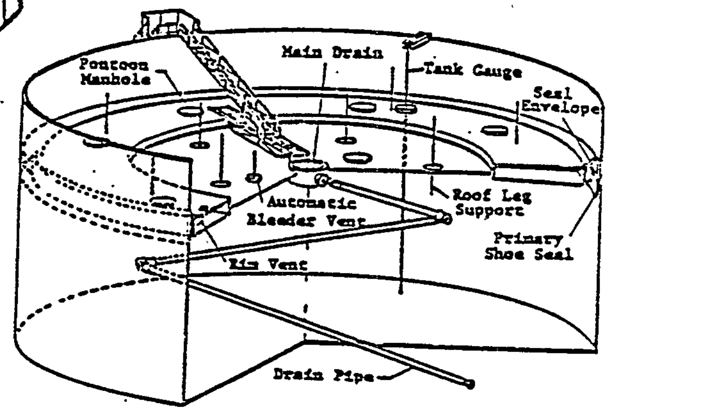
Storage or treatment of organic-containing liquid or sludge wastes in fixed-roof tanks instead of open-top tanks reduces organic air emissions. By covering the tank, the waste surface is sheltered from the wind. This decreases the mass transfer rate of organic compounds in the waste to the atmosphere. The extent to which organic air emissions are reduced varies on many factors including waste composition and concentrations, windspeed, and the ratio of the tank diameter to the depth of the liquid contained in the tank.

Theoretical and empirical models have been developed to study open-top and fixed-roof tank emissions. Several of these models were selected for the TSDF analyses and are described in Appendix C, Section C.1.1. Using the models, estimated organic air emission from a 76 m^3 (20,000 gal) open-top tank were compared to an equivalently sized fixed-roof tank storing the same type of waste material. This analysis is described in Appendix H, Section H.2.1. For a windspeed of 4.5 m/s (10 mph), the estimated organic air emissions from the fixed-roof tank are 86 to 99 percent lower than the open-top tank emissions depending on waste composition. Thus, using fixed-roof tanks in place of open-top tanks can provide significant suppression efficiencies.

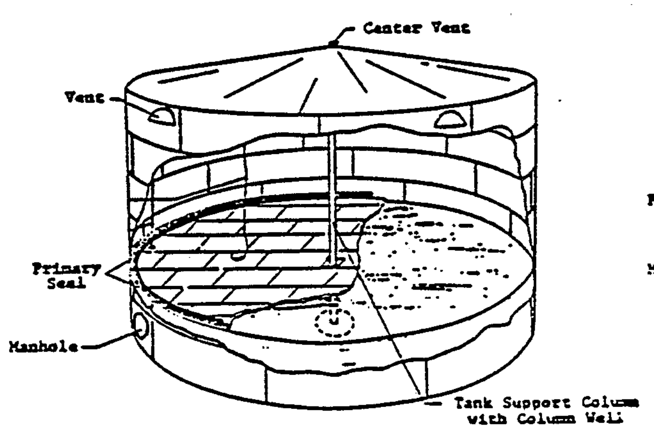
An existing open-top tank can be converted to a fixed-roof tank by retrofitting the tank with a dome roof. Aluminum, geodesic dome roofs are available from several manufacturers.[2,3] These domes have been used successfully to cover petroleum and chemical storage tanks. The domes are clear-span, self-supported structures (i.e., require no internal columns be placed in the tank) that can be installed on open-top tanks ranging in diameter from 5 to over 100 m (15 to over 330 ft).



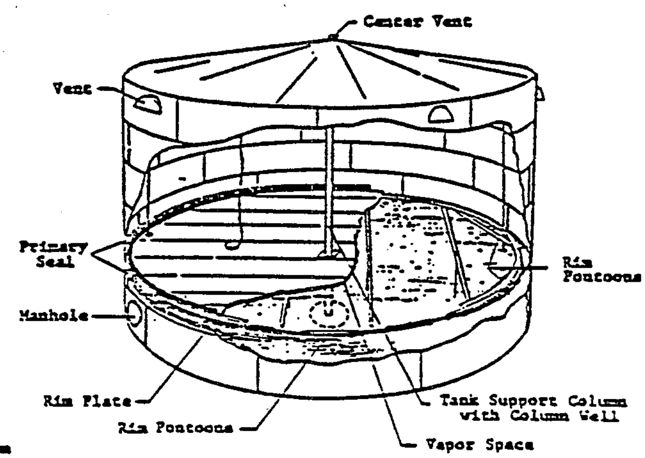
Typical fixed roof tank.



External floating roof tank.



Contact Deck Type



Noncontact Deck Type

Internal floating roof tanks.

Figure 4-1. Storage tank covers.

Although fixed-roof tanks provide large reductions in organic air emissions from open-top tanks, fixed-roof tanks still can emit significant quantities of organics. The major sources of organic air emissions from fixed-roof tanks are breathing losses and working losses.[4] Breathing losses occur from the expulsion of vapor through the roof vents because of the expansion or contraction of the tank vapor space resulting from daily changes in ambient temperature or barometric pressure. These emissions occur in the absence of any liquid level change in the tank. Working losses occur from the displacement of vapors resulting from filling and emptying of the tank.

Breathing and working losses from fixed-roof tanks can be reduced by installing an internal floating roof, connecting the tank roof vents to an add-on control device, or installing pressure-vacuum relief valves on the tank roof vents. The use of internal floating roofs in fixed-roof tanks is discussed in Section 4.2.2.

For add-on control applications, vapors are contained in the tank until the internal tank pressure attains a preselected level. Upon reaching this level, a pressure switch activates a blower to collect the vapors from the tank and transfer the vapors through piping to the add-on control device. As a safety precaution, flame arrestors normally are installed between the tank and control device. Other safety devices may be used such as a saturator unit to increase the vapor concentration above the upper explosive limit. Add-on control devices for organic vapors are discussed in Section 4.3.

Fixed-roof tanks can be designed to operate safely at internal pressures up to 35 kPa (2.5 psig).[5] The use of pressure relief valves to control organic air emissions from a 38 m^3 (10,000 gal) fixed-roof tank storing volatile organic liquids has been investigated using emission models.[6] This analysis estimated that using pressure relief valves set at 35 kPa reduces breathing and working losses from a fixed-roof tank storing high-volatility organic liquids by 20 to 45 percent. However, many existing fixed-roof tanks are designed to operate at atmospheric pressure and cannot be pressurized. Therefore, use of high-pressure relief valve settings for organic air emission control is limited to tanks specifically built to design specifications for operating at elevated internal pressures.

Fixed-roof tanks require no energy to operate. Use of fixed-roof tanks at TSDF produces no secondary air or cross-media impacts.

4.2.2 Tank Floating Roofs

Floating roofs are used extensively in the petroleum refining, gasoline marketing, and chemical manufacturing industries to control organic air emissions from tanks storing volatile organic liquids. A tank floating roof is basically a disk-shaped structure (termed a "deck") with a diameter slightly less than the inside tank diameter that floats freely on the surface of liquid stored in the tank. A seal is attached around the outer rim of the deck to cover the open annular space between the deck and inside tank wall. The seal mechanism is designed to slide against the tank wall as the liquid level in the tank is raised or lowered. There are two general types of tank floating roofs: external floating roofs and internal floating roofs.

Floating roofs are appropriate for TSDF hazardous waste storage tanks and certain treatment tanks where the presence of the floating cover would not interfere with the treatment process. Treatment tanks equipped with surface mixing or aeration equipment cannot use floating roofs. Also, because floating roofs are in direct contact with the hazardous waste, the materials selected to fabricate the deck and seals must be compatible with the waste composition. This may prevent the use of floating roofs in tanks containing certain types of hazardous waste (e.g., highly corrosive wastes).

An external floating roof consists of a single- or double-layer steel deck that moves within the walls of an open-top tank (see Figure 4-1).[7] Pontoon sections often are added to the deck to improve floatation stability. Because the top surface of the deck is exposed to the outdoors, the external floating roof design must include additional components for rainwater drainage and snow removal to prevent the deck from sinking, and for cleaning the inside walls of the tank above the deck to protect the sliding seal mechanism from dirt. A variety of seal types (e.g., metallic shoe seal, liquid-filled seal, or resilient foam-filled seal) and seal configurations (e.g., mounted above liquid surface, mounted on liquid surface) can be used for external floating roofs.[8] Small openings are required on the deck for various fittings such as vents, inspection hatches, gage wells, and sampling ports.

An internal floating roof consists of a steel, stainless steel, aluminum, or fiberglass-reinforced plastic deck that is installed inside a fixed-roof tank (see Figure 4-1).[9] Many internal floating roof designs can be retrofitted into existing fixed-roof tanks. Because the fixed roof shelters the deck from weather, internal floating roofs do not need additional components for rainwater drainage or for seal protection. An internal floating roof is equipped with the same types of deck fittings used on an external floating roof, but normally uses a simpler deck seal mechanism (e.g., a single resilient foam-filled seal or wiper seal).[10] Vertical guide rods are installed inside the tank to maintain deck alignment. The internal tank space above the deck must be vented to prevent the accumulation of a flammable vapor mixture.

Floating roof tanks significantly reduce but do not eliminate organic air emissions. Organic vapor losses termed "standing losses" occur at the deck seals and fitting openings. The imperfect fit of the deck seals allows gaps that expose a small amount of the liquid surface to the atmosphere. Small quantities of vapors that collect in the small openings under the deck can leak from the deck fitting openings. Standing losses can be reduced by installing secondary deck seals, selecting appropriate pressure-relief valve settings, and using tight-gasketed and bolted covers on all other fittings. Additional organic vapor losses termed "withdrawal losses" occur from evaporation of the liquid that wets the inside tank wall as the roof descends during emptying operations.

No emission source test studies of full-sized tanks equipped with floating roofs have been conducted because of the complexity of erecting an enclosure around a tank. However, emission test studies of full-sized floating roof components sponsored by the American Petroleum Institute (API) were conducted using a pilot-scale tank.[11] The results of these studies in combination with other data have been used by API and EPA to develop empirical models that estimate external and internal floating roof tank standing and withdrawal losses.[12]

For the development of volatile organic liquid storage New Source Performance Standards (NSPS), EPA analyzed the emission reduction effectiveness of using floating roof tanks compared to fixed-roof tanks using the empirical models.[13] The percentage of reduction in emissions varies with the tank characteristics (e.g., tank size, vapor pressure of the material stored in the tank). A model tank was selected for the NSPS analysis that has a volume of 606 m^3 (160,000 gal), contains a volatile organic liquid having a vapor pressure of 6.9 kPa (1 psia), and operates with 50 turnovers per year. The analysis concluded that, depending on the type of deck and seal system selected, installing an internal floating roof tank in a fixed-roof tank will reduce volatile organic emissions by 93 to 97 percent. The analysis also concluded that a similar level of emission reduction can be achieved using an external floating roof tank.

Because many tanks at TSDF are smaller than 606 m^3 (160,000 gal) and contain hazardous wastes having vapor pressures less than 6.9 kPa (1 psia), a separate analysis was performed to estimate the effectiveness of using internal floating roofs to suppress TSDF organic air emissions. A detailed description of this analysis is presented in Appendix H, Section H.2.1. For this analysis, the model tank capacity of 76 m^3 (20,000 gal) was used with five different waste compositions that are representative of the range of hazardous wastes managed at TSDF. Installing internal floating roofs is estimated to reduce TSDF fixed-roof tank organic air emissions by 74 to 82 percent. Converting an open-top tank to a fixed-roof tank and installing an internal floating roof is estimated to reduce emissions by 96 to 99 percent.

Floating roof tanks require no energy to operate. Use of floating roof tanks at TSDF produces no secondary air or cross-media impacts.

4.2.3 Pressure Tanks

Pressure tanks are structurally designed to operate safely at internal pressures above atmospheric pressure. Consequently, pressure tanks operate as closed systems and do not emit organic air emissions at normal storage conditions or during routine filling and emptying operations. Pressure-relief valves on the tanks open only in the event of improper operation (e.g. overfilling the tank) or an emergency (e.g., exposure to excessive heat).

There are two general pressure tank classes: tanks with internal pressure operating ranges not exceeding 204 kPa (2 atm) termed "low-pressure tanks," and tanks with operating pressure greater than 204 kPa termed "high-pressure tanks".[14] The design and shape of the pressure tank depends on the internal pressure operating range. Fixed-roof tanks can be designed to operate at pressures up to 35 kPa (2.5 psig). Above this pressure, noded spheroid and noded hemispheriod shapes normally are used for low-pressure tanks. Horizontal cylinder and spheroid shapes generally are used for high-pressure tanks.

Pressure tanks are closed systems and require no energy to operate. Use of pressure tanks at TSDF produces no secondary air or cross-media impacts.

4.2.4 Floating Membrane Covers

Similar to using a fixed-roof tank to manage hazardous waste, placing a cover over a surface impoundment reduces the release of volatile organics contained in the waste by preventing waste mixing due to wind blowing across the unit. One type of cover available for application to surface impoundments is a floating membrane cover. A floating membrane cover consists of large sheets of synthetic, flexible membrane material that float on the surface of a liquid or sludge. Individual, standard-dimension sheets can be seamed or welded together to form covers applicable to any size of surface impoundment.

Floating membrane covers have been used for many years to cover the surface of potable water reservoirs. More recently, use of floating membrane covers has been extended to applications that require the cover be airtight, as in anaerobic sludge lagoons. One example of a state-of-the-art floating membrane cover installation is the successful operation since 1987 of a floating membrane cover on a 2.8 ha (7 acre) surface impoundment used as an anaerobic digester.[15,16] This cover is required to be airtight because a vacuum is pulled from under the cover to extract the methane gas formed by the anaerobic process. The cover is fabricated from 2.5 mm

(100 mil) thick high-density polyethylene (HDPE). Although HDPE is buoyant in water, foam floats are placed under the membrane sheet to provide additional floatation and to form channels for collecting the methane. Two blowers are used to pull a vacuum (maximum of 0.25 kPa or 1 in. of water column) under the cover to extract the methane that accumulates in the gas collection channels. The collected gas is vented to a system of three flares.

Overall performance of the floating membrane cover in airtight applications as demonstrated by the 2.5 mm HDPE cover described above is good. No leaks have occurred in the HDPE seams. An initial problem with leaking around access hatch lids on the cover was corrected by installing positive seal hatch lids. To prevent the cover from sinking because of rainwater accumulating on top of the cover, the cover is fabricated with sufficient excess materials to form troughs that collect rainfall. Plastic drainage pipes are placed in the troughs and connected to a pump that is periodically operated to drain the accumulated rainwater off the cover. Also, emergency gas vents are installed on the cover to prevent any buildup of gas under the cover should the gas collection system blowers fail to operate. These vents consists of short lengths of open-ended pipes that extend a short distance below the liquid surface during normal operation. The liquid seal prevents gases from being discharged through the vent. Should a sufficient quantity of gas collect under the cover causing the cover to bulge above the liquid surface, the vent inlet is lifted out of the liquid, allowing the gas to be vented and the cover to return to its normal position contacting the liquid surface.

Surface impoundments used for hazardous waste treatment are exempt from the RCRA land disposal restrictions (40 CFR Part 268) if the treatment residues that do not meet specific treatment standards are removed from the impoundment for subsequent management within 1 yr of placement in the impoundment. The application of floating membrane covers to these TSDF surface impoundments will require that the cover allow for impoundment cleaning. Because a floating membrane cover is heavy (e.g., 2.5 mm HDPE weighs over 2 kg/m^2 or approximately 10 ton/acre[17]), routine removal of the entire cover is impractical. Therefore, waste residues will need to be removed with the cover in place, requiring a sludge pumping or other type of system to be installed on the bottom of the impoundment at the same time the floating membrane cover is installed. This requirement may prevent the use of a floating membrane cover for those TSDF surface impoundment applications where the residues on the impoundment bottom can only be removed by draining the impoundment and scraping the material out of the impoundment using heavy construction equipment (e.g., bulldozer, power shovel).

The application of a floating membrane cover to a TSDF surface impoundment will require the cover to be made of a material that is resistant to chemical and biological degradation from compounds in the waste while also having good strength characteristics to resist tearing due to wind stresses and long-term weather exposure. Floating membrane covers for water reservoir and anaerobic digester applications have been fabricated using HDPE or chlorosulfonated polyethylene (more commonly known as Hypalon, a registered trademark of E.I. du Pont de Nemours & Co., Inc.) for the membrane material. Because these materials have also been used for lining hazardous waste landfills and surface impoundments, they are candidate materials for TSDF surface impoundment floating membrane covers--provided the material is effective in controlling organic emissions.

The effectiveness of using a floating membrane cover for organic emission control is a function of the amount of leakage from the cover fittings and seams as well as the losses resulting from the permeation of the membrane material by volatile organic compounds contained in the waste. The successful application of floating membrane covers to anaerobic sludge impoundments demonstrates that leakage from fittings and seams can be reduced to very low levels by using a membrane material with adequate thickness, installing proper seals on cover fittings and vents, and following good installation practices to ensure the seams are properly welded and to prevent tearing or puncturing the membrane material. Consequently, for a properly installed floating membrane cover, the organic emission control effectiveness is expected to be determined primarily by the permeability of the cover to the organic constituents in the waste.

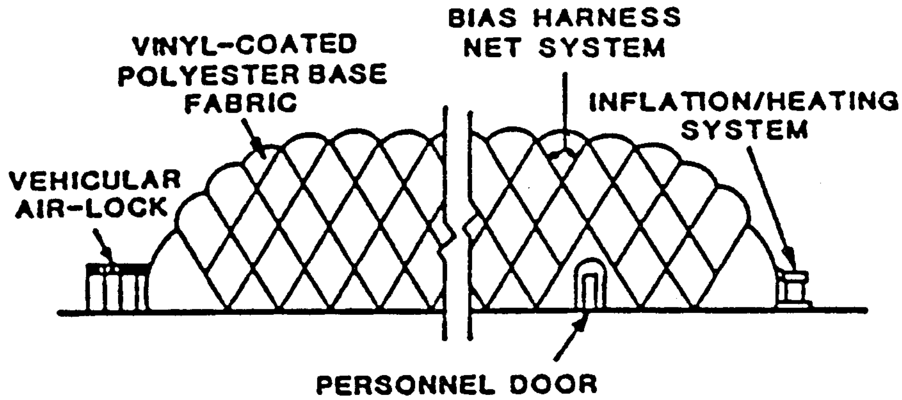
Permeability is a measure of how well a membrane material resists allowing the organics to pass through the membrane. Permeation of a membrane material is a three-step process that involves the adsorption of an organic by the material, diffusion of the organics through the material, and evaporation of the organics on the air side of the membrane. The permeability of a floating membrane cover is a function of the organic composition and concentration of the waste managed in the surface impoundment as well as cover materials composition and thickness.

No source test data are available to measure the effectiveness of a floating membrane cover in controlling organic emissions from a surface impoundment. However, an indication of the effectiveness of using floating membrane covers applied to representative TSDF surface impoundments can be estimated using theoretical mass transfer relationships. These estimates suggest that a flexible membrane cover fabricated from HDPE can be an effective organic emission control for hazardous waste managed in TSDF surface impoundments. For example, the organic emission control levels estimated for a 2.5 mm HDPE floating membrane cover range from approximately 50 percent to over 95 percent depending on the organic constituents in the waste and the waste retention time in the surface impoundment. The estimate procedure and calculations are described in Appendix H, Section H.1.2. This procedure provides only an approximation of the effectiveness of using floating membrane covers to control organic emissions because certain assumptions must be made that simplify the actual mass transfer conditions that occur in surface impoundments. Improved estimates of the organic emission control effectiveness of using floating membrane covers will be possible when the results from ongoing laboratory tests to measure the organic permeability of potential membrane materials become available.

The only secondary air or cross-media impacts from application of floating membrane covers would be any impacts attributed to the intermittent operation of the small electric-powered or gasoline-powered pumps used to drain rainwater off the cover.

4.2.5 Air-Supported Structures

An air-supported structure is a plastic-reinforced fabric shell that is inflated and, therefore, requires no internal rigid supports. Figure 4-2 shows the major air-supported structure components.[18] The structure shape and support is provided by maintaining a positive interior pressure



Source: Air Structures International, Inc.

Figure 4-2. Typical air-supported structure.

(i.e., the interior pressure is greater than the external atmospheric pressure).

Large electric-motor driven fans are used to blow air continuously or intermittently through the structure and out a vent system. The interior pressure is maintained at a constant 10 to 15 kPa (1.25 to 1.5 inch of water) for structure inflation. Adequate air changes are necessary to prevent the organic vapor concentrations inside the structure from exceeding the lower explosive limits. A standby blower system consisting of internal combustion engine driven fans normally is installed to keep the structure inflated and ventilated in the event of an electrical power outage. The vent system can discharge directly to the atmosphere or be connected to an add-on control device.

Large areas can be enclosed by erecting an air-supported structure. Structures are commercially available ranging in widths from 24 to 91 m (80 to 300 ft) wide and lengths from 24 to 137 m (80 to 450 ft).[19] For larger areas, a number of modules can be connected together. Air-supported structures have been used as enclosures for conveyors and coke ovens, open-top tanks, and material storage piles. A 4,000 m^3 (1 acre) aerated wastewater treatment lagoon at a specialty chemical manufacturing plant has been covered by an air-supported structure for more than 4 years.[20] Thus, air-supported structures offer good potential as a suppression device for TSDF surface impoundments that cannot use floating membrane covers (e.g., surface treatment impoundments using surface-mounted aeration equipment).

The fabric used for the air-supported structure depends on the size of the structure, design requirements (e.g., wind and snow loadings), and type of chemicals to which the fabric's inner side will be exposed. Polyvinyl-fluoride-coated polyester fabric would likely be the material of current choice for TSDF applications because of the fabric's good resistance to deterioration from chemical, weather, or ultraviolet sunlight exposure. The service life of the fabric ranges from 2 to 12 years depending on the site-specific conditions.

Anchoring the air-supported structure likely will be accomplished by bolting the edges of the fabric to a continuous, grade-level concrete footing or beam installed around the perimeter of the surface impoundment.

Entrance into an air-supported structure is through airlocked doors. These doors can be sized to allow earth-moving equipment to be used inside the structure for impoundment cleaning operations.

The use of air-supported structures to enclose TSDF surface impoundments can result in excessive condensation and high temperatures inside the structure. An air-supported structure's interior temperatures typically are 5 to 11 °C (10 to 20 °F) above the ambient temperature.[21] Consequently, during hot summer days, temperatures inside an air-supported structure can exceed 42 °C (110 °F). Depending on the severity of these conditions, workers entering the structure may need to follow additional safety procedures and be restricted as to the period of time they may remain inside the structure. Also, any equipment operating inside the structure may require more frequent repair or replacement because of accelerated rust and corrosion of the equipment components.

The effectiveness of an air-supported structure in controlling organic air emissions primarily depends on the amount of leakage from the structure and whether the structure vent system is connected to an add-on control device. Air-supported structure leaks are usually confined to areas around airlocks, doors, and anchor points. Leak checks were performed at the air-supported structure operating at the specialty chemical manufacturing plant (refer to Appendix F, Section F.2.1.1). A soap solution was sprayed around the structure base and fittings to locate leaks, and measurements were made using a portable hydrocarbon analyzer. Few leaks were found, and the sizes of the leaks ranged from 2 to 40 ppm. The operating experience at this facility indicates that proper installation and maintenance of the air-supported structure can limit leakage to very low levels.

Because of the very low leakage levels attainable, almost all of the organic vapors contained by an air-supported structure will be ultimately discharged through the structure's vent system. Therefore, connecting the vent system to one of the add-on control devices discussed in Section 4.3 will result in an overall organic air emission control efficiency for TSDF applications using an air-supported structure that is approximately equivalent to the efficiency of the control device. These add-on control devices are capable of achieving control efficiencies in excess of 95 percent.

Operation of an air-supported structure consumes large quantities of electricity to maintain the positive interior pressure. For example, the existing air-supported structure covering a 4,000 m^3 aerated wastewater treatment lagoon uses fans with a combined power rating of 26 kW (35 hp) for structure inflation and ventilation.[22] Annual electricity consumption to operate continuously a standard 26 kW fan is approximately 250,000 kWh. Application of air-supported structures to TSDF emission sources increases demand for electricity and, consequently, would contribute to nationwide electricity consumption impacts.

Any other air emissions, wastewater effluents, or solid wastes associated with the use of air-supported structures at TSDF, are determined by the type of add-on control device used in conjunction with the enclosure. Add-on control device secondary air and cross-media impacts are discussed in Section 4.3.

4.2.6 Flexible Membrane Covers

The flexible membrane cover is the analogous organic suppression control to the floating membrane cover (described in Section 4.2.4) but for application to wastepiles. A flexible membrane cover is simply a large sheet of a synthetic, flexible membrane material that is placed over the top of a wastepile. Like a floating membrane cover, individual, standard-dimension sheets of the membrane material can be seamed or welded together to form covers applicable to large wastepiles. The cover can be secured at the perimeter using earth fill or another type of mechanical anchoring system (e.g., cables attached to concrete piers). To obtain access to the waste for addition or removal of material, the entire cover is lifted off the wastepile or a section of the cover is folded back.

The material used to fabricate a flexible membrane cover to TSDF applications needs to be resistant to chemical and biological degradation from compounds in the waste while also having good strength and durability characteristics to withstand the wear and tear of repeated handling and weather exposure. No source test data are available to measure the effectiveness of a flexible membrane cover in controlling organic emissions from a wastepile. The effectiveness of the flexible membrane cover in controlling organic emissions is expected to be similar to that of a floating membrane cover.

Flexible membrane covers require no energy to operate. Use of flexible membrane covers at TSDF produces no secondary air or cross-media impacts.

4.2.7 Rigid Membrane Covers

Rigid membrane covers consist of plastic-reinforced fabric that is stretched over a rigid structural support system such as an aluminum frame or a mast with tensioned cables.[23] The fabric is supported above the waste material so that a vapor space is formed between the waste surface and the cover. Used with an add-on control device, this type of cover provides an alternative to an air-supported structure for a TSDF surface impoundment.

Any non-organic air emissions, wastewater effluents, or solid wastes associated with the use of rigid membrane covers at TSDF is determined by the type of add-on control device used in conjunction with the cover. Add-on control device secondary air and cross-media impacts are discussed in Section 4.3.

4.2.8 Rigid Structures

A rigid structure is a permanent building that is designed to confine air emissions from storage or processing operations. The configuration and design of the building depend on the process requirements and site conditions. Steel-frame construction with metal or reinforced fiberglass panels most likely would be used for TSDF applications.

Existing applications of rigid structures to TSDF have been for particulate matter and odor control from hazardous waste fixation processes.[24,25,26] These buildings are vented to wet scrubber control devices. Other potential TSDF applications for rigid structures are to confine air emissions from drum storage and processing operations.

Any non-organic air emissions, wastewater effluents, or solid wastes associated with the use of rigid structures at TSDF is determined by the type of add-on control device used in conjunction with the structure. Add-on control device secondary air and cross-media impacts are discussed in Section 4.3.

4.3 ADD-ON CONTROLS

Add-on controls are processes applied to captured organic vapors vented from TSDF emission sources. These controls serve to reduce organic air emissions by destroying organics in the gas stream or extracting organics from the gas stream before discharging the gas stream to the atmosphere. Add-on controls for organic air emissions are classified into four broad categories: combustion, adsorption, condensation, and absorption. General background information about these types of add-on controls is available in Reference 27. The type of add-on control best suited for a particular TSDF emission source depends on the size of the source and the characteristics of the hazardous waste managed by the TSDF source.

Combustion destroys the organics in the gas stream by oxidation of the compounds to primarily carbon dioxide and water. Because essentially all organics will burn, combustion add-on controls are applicable to all TSDF emission sources for which the organic vapors can be captured. However, combustion add-on controls will likely be used for those TSDF emission sources where recovery of the organics is not practical or desirable. Combustion add-on controls are thermal vapor incinerators, catalytic vapor incinerators, flares, boilers, and process heaters.

Adsorption, condensation, or absorption processes can be used to extract the organics from the gas stream. All of these processes are capable of achieving very high levels of organic removal efficiencies. However, adsorbers or condensers are likely to be less expensive than absorbers for application to TSDF emission sources.

The type and magnitude of the secondary air and cross-media impacts associated with add-on controls varies depending on the type of control. However, all add-on control devices use electric-motor driven equipment such as fans, blowers, and pumps. The electricity required to operate the control device is supplied by the local electric utility or perhaps an existing on-site cogeneration unit. Thus, add-on control device operation increases demand for electricity, which in turn increases any air, water, and solid waste impacts associated with the power plants that supply the electricity. The types and quantities of these impacts varies depending on the technology used to generate the electricity (e.g., fossil-fuel-fired steam boiler, gas turbine, hydroelectric, or nuclear power plants) and, for combustion power plants, the type of fuel burned (e.g., natural gas, coal, municipal solid waste).

4.3.1 Carbon Adsorbers

Adsorption as applied to air pollutant control is the process by which organic molecules in a gas stream are retained on the surface of solid particles. The solid most frequently used is carbon that has been processed or "activated" to have a very porous structure. This provides many surfaces upon which the organic molecules can attach, resulting in a high rate of organic removal from a gas stream as it passes through a bed of carbon.

Activated carbon has a finite adsorption capacity. When the carbon becomes saturated (i.e., all of the carbon surface is covered with organic material), there is no further organic air emission control because all of the organic vapors pass through the carbon bed. At this point (referred to as "breakthrough"), the organic compounds must be removed from the carbon before organic air emission control can resume. This process is called desorption or regeneration.

For most air pollutant control applications, regeneration of the carbon in the adsorber is performed by passing steam through the carbon bed. The steam heats the carbon particles, which releases the organic molecules into the steam flow. The resulting steam and organic vapor mixture is condensed to recover the organics and separate the water for discharge to a wastewater treatment unit. An alternative method for regenerating the carbon is to reduce the pressure of the atmosphere surrounding the carbon particles. Vacuum regeneration is used for special carbon adsorber applications when direct recycling of the recovered organics is desired such as vapor recovery at gasoline tank truck loading terminals. A detailed description of carbon adsorption and desorption mechanisms is available in Reference 28.

Two types of carbon adsorption systems most commonly used for air pollutant control are: fixed-bed carbon adsorbers and carbon canisters. A fluidized-bed carbon adsorption system has been developed, but currently is not commercially available.

Fixed-bed carbon adsorbers are used for controlling continuous, organic gas streams with flow rates ranging from 30 to over 3,000 m^3/min (1,000 to over 100,000 ft^3/min). The organic concentration can be as low as several parts per billion by volume (ppbv) or as high as 25 percent of the lower explosive limit for the vapor stream constituents. The major components of a fixed-bed carbon adsorber system are one or more carbon bed units to adsorb the organics, a condenser to convert the desorbed organics and steam mixture to a liquid, a decanter to separate the organic and aqueous phases, and blowers to cool and dry the carbon beds following desorption.

Fixed-bed carbon adsorbers may be operated in either intermittent or continuous modes. For intermittent operation, the adsorber removes organics only during a specific period of the day. Intermittent mode of operation allows a single carbon bed to be used because it can be regenerated during the off-line periods. This mode of operation would be suitable for TSDF emission sources that operate one 8 to 10 hour shift per day such as a waste fixation unit. For continuous operation, the unit is equipped with two or more carbon beds so that at least one bed is always available for adsorption while other beds are being regenerated. This mode of operation would be suitable for TSDF emission sources that are in operation 24 hours per day such as tanks and surface impoundments.

Carbon canisters differ from fixed-bed carbon adsorbers. First, a carbon canisters is a very simple add-on control device consisting of a 0.21 m^3 (55 gal) drum with inlet and outlet pipe fittings (see Figure 4-3).[29] A typical canister unit is filled with 70 to 90 kg (150 to 200 lb) of activated carbon. Second, use of carbon canisters is limited to controlling low volume gas streams with flow rates less than 3 m^3/min (100 ft^3/min).[30] Third, the carbon cannot be regenerated directly in the canister. Once the activated carbon in the canister becomes saturated by the organic vapors, the carbon canister must be removed and replaced with a fresh carbon canister. The spent carbon canister is then recycled or discarded depending on site-specific factors.

For a carbon canister to be an effective organic air emission control device, the canister must be replaced promptly when carbon breakthrough first occurs. An automated, continuous organic analyzer could be used to signal when carbon breakthrough occurs but is expensive relative to the total capital cost of the carbon canister unit. Manual monitoring of

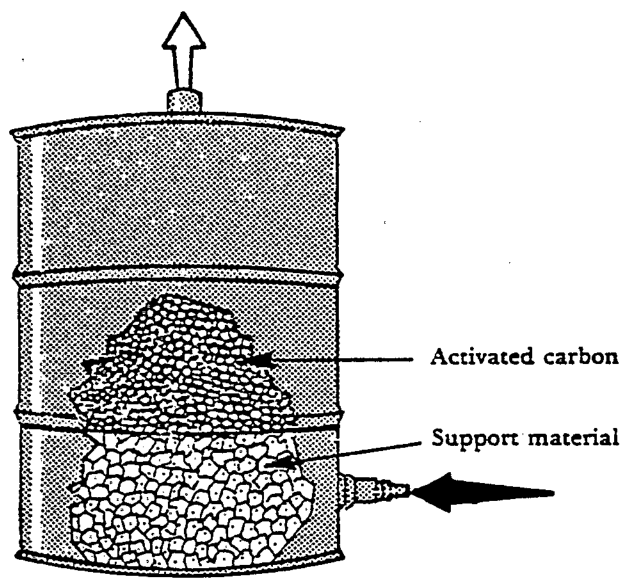


Figure 4-3. Carbon canister unit.

carbon breakthrough can be conducted by a facility worker checking periodically to see whether the organic concentration at the canister outlet has increased significantly.[31] A colorimetric detection test or a portable instrument that measures organic concentration can be used to check the canister outlet concentration. An alternative to monitoring is to replace the carbon canister regularly based on a maintenance schedule. The replacement interval would be a specified number of operating hours less than the number of operating hours at which carbon breakthrough first occurs.

The design of a carbon adsorption system depends on the inlet gas stream characteristics including organic composition and concentrations, flow rate, and temperature. Good carbon adsorber performance requires that (1) the adsorber is charged with an adequate quantity of high-quality activated carbon; (2) the gas stream receives appropriate preconditioning (e.g., cooling, filtering) before entering the carbon bed; and (3) the carbon beds are regenerated before breakthrough occurs.

Emission source test data for 12 full-sized, fixed-bed carbon adsorbers operating in industrial applications has been compiled by EPA for a study of carbon adsorber performance.[32] The analysis of these data concluded that for well-designed and operated carbon adsorbers continuous organic removal efficiencies of at least 95 percent are achievable over long periods. Several units have been shown to continuously achieve organic removal efficiencies of 97 to 99 percent.

An equivalent level of performance for carbon canisters applied to TSDF emission sources is indicated by the results of an emission source test conducted on carbon canisters installed on the neutralizer tanks for a wastewater treatment system at a specialty chemicals plant (refer to Appendix F, Section F.2.2.1.2). This device was designed for odor control and not organic removal. However, 100 percent removal was measured for 1,2-dichlorobenzene, benzene, toluene, chlorobenzene, and chloroform. Overall organic removal efficiencies measured for various hydrocarbon categories ranged from 50 to 99 percent.

High moisture content in the gas stream can affect carbon adsorber performance for gas streams having organic concentrations less than

1,000 ppm.[33] At these conditions, water molecules compete with the organic compounds for the available adsorption sites on the carbon particles. Consequently, the carbon bed working capacity is decreased. Above an organic concentration of 1,000 ppm, high moisture does not significantly affect performance. Thus, to obtain good adsorber performance for gas streams with a high relative humidity (relative humidity greater than 50 percent) and low organic concentration (less than 1,000 ppm) requires preconditioning the gas stream upstream of the carbon bed. This can be accomplished using a dehumidification system, installing duct burners to heat the gas stream, or diluting the gas stream with ambient air. For TSDF applications, these gas stream conditions would most likely occur at locations where a carbon adsorber is used in conjunction with an air-supported structure enclosing an aerated surface impoundment containing dilute aqueous hazardous waste.

Carbon bed operating temperature can also affect carbon adsorber performance. Excessive bed temperatures can result due to the release of heat from exothermic chemical reactions that may occur in the carbon bed.[34] Ketones and aldehydes are especially reactive compounds that exothermically polymerize in the carbon bed. If temperatures rise too high, spontaneous combustion will result in carbon bed fires. To avoid this problem, carbon adsorbers applied to gas streams containing these types of compounds must be carefully designed and operated to allow sufficient airflow through the bed to remove excess heat.

Carbon adsorption control devices produce two types of cross-media impacts: (1) wastewater effluent from the condensation of steam used to regenerate spent carbon; and (2) solid waste from periodic replacement of spent carbon. The magnitude of these impacts will depend primarily on the type of carbon adsorption systems used (e.g., fixed-bed carbon adsorbers versus carbon canisters), the type of carbon regeneration used (e.g., steam regeneration versus vacuum regeneration), and the spent carbon canister management practices used (e.g., regenerate carbon or direct disposal of carbon).

Most fixed-bed carbon adsorbers used for TSDF organic air emission control are expected to use conventional low-pressure steam regeneration.

After passing through the carbon bed, the steam is condensed and passed through a decanter or distillation column to separate the condensed organics from the water. A wastewater effluent containing small quantities of water soluble organics is produced. Also, the carbon cannot be regenerated indefinitely. Gradual deactivation and attrition of the carbon in the fixed-bed adsorber requires the carbon be replaced with fresh carbon approximately once every several years. The spent carbon is either recycled by returning it to the vendor for processing or discarded in the appropriate disposal facility as determined by the spent carbon's waste classification.

The waste classification of the spent carbon used for air pollutant control applications will depend on the type of waste managed in the TSDF unit that is being controlled by the carbon adsorption system. The spent carbon from a particular TSDF control application may be determined to be a hazardous waste if it exhibits any of the four hazardous waste characteristics as defined by the Resource Conservation and Recovery Act (RCRA), Part 261 Subpart C. If the spent carbon is determined to be nonhazardous, it may be possible to dispose the carbon in a municipal solid waste landfill depending on the rules and policies affecting disposal at the landfill. Otherwise the spent carbon from many TSDF will need to be disposed in a hazardous waste landfill or incinerator.

The steam required for fixed-bed carbon adsorber regeneration most likely will be supplied by an on-site industrial boiler. Production of the steam required for regeneration creates secondary air emission impacts due to the boiler air emissions. Because natural gas or distillate fuel oil commonly is the type of fuel burned in industrial boilers, these impacts primarily are expected to be increases in nitrogen oxides (NO_x) and carbon monoxide (CO) emissions.

Spent carbon canisters can be either recycled or discarded.[35] The type of spent carbon canister management practice used at a specific TSDF location will depend on site-specific factors. Recycling involves removing the spent carbon from the canister, regenerating the carbon, and then repacking the canister with regenerated carbon plus any necessary makeup carbon. If disposal is selected, the spent carbon and canister are sent to an appropriate disposal site depending on the waste classification.

4.3.2 Thermal Vapor Incinerators

Thermal vapor incineration is a controlled oxidation process that occurs in an enclosed chamber. Figure 4-4 shows a simplified diagram of a thermal vapor incinerator. One type of thermal vapor incinerator consists of a refractory-lined chamber containing one or more discrete burners that premix the organic vapor gas stream with the combustion air and any required supplemental fuel. A second type of incinerator uses a plate-type burner firing natural gas to produce a flame zone through which the organic vapor gas stream passes. Packaged thermal vapor incinerators are commercially available in sizes capable of handling gas stream flow rates ranging from approximately 8 to 1,400 m^3/min (300 to 50,000 ft^3/min).[36]

Organic vapor destruction efficiency for a thermal vapor incinerator is a function of the organic vapor composition and concentration, combustion zone temperature, the period of time the organics remain in the combustion zone (referred to as "residence time"), and the degree of turbulent mixing in the combustion zone. Field emission testing and combustion kinetic modeling analyses have been conducted to evaluate thermal vapor incinerator organic destruction efficiencies.[37-41] These analysis results indicate that thermal vapor incineration destroys at least 98 percent of non-halogenated organic compounds in the vapor stream at a temperature of 870 °C (1,600 °F) and a residence time of 0.75 seconds. If the vapor stream contains halogenated compounds, a temperature of 1,100 °C (2,000 °F) and a residence time of 1 second is needed to achieve a 98 percent destruction efficiency.

Incinerator performance is affected by the heating value and moisture content of the organic vapor stream, and the amount of excess combustion air. Combustion of organic vapor streams with a heating value less than 1.9 MJ/m^3 (50 Btu/ft^3) usually requires the addition of supplemental fuel (also referred to as auxiliary fuel) to maintain the desired combustion temperature.[42] Above this heating value, supplemental fuel may be used to maintain flame stability. Although either natural gas or fuel oil can be used as supplemental fuel, natural gas is preferred. Supplemental fuel requirements can be decreased if the combustion air or organic vapor stream is preheated.

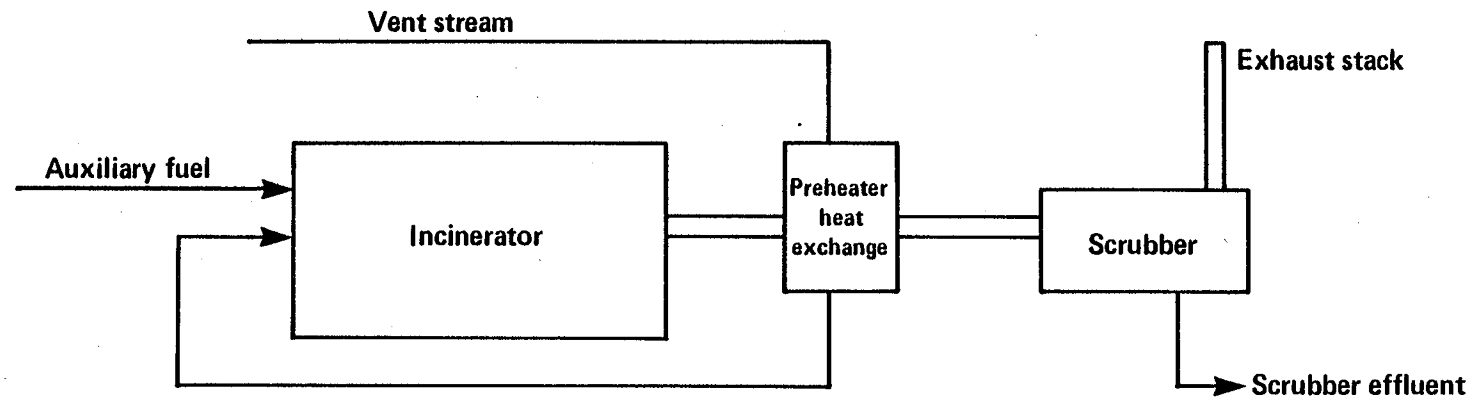


Figure 4-4. Schematic diagram of thermal incinerator system.

Thermal vapor incinerator exhaust gases are comprised mainly of carbon dioxide and water. Using good thermal vapor incinerator design and operating practices limits CO and unburned hydrocarbon emissions to very low levels. However, the combustion temperature levels required to achieve good organic vapor destruction efficiency also promote the oxidation of molecular nitrogen in the combustion air to produce NO_x air emissions.

The quantity of NO_x emitted from a thermal vapor incinerator is affected by peak temperatures in the incinerator combustion zone, quantity of excess combustion air used for incineration, and period of time combustion gases are exposed to the peak temperatures. Additional quantities of NO_x can form if the vapor stream contains nitrogen compounds. A series of EPA-sponsored source tests on three thermal vapor incinerators used to control organic emissions from air oxidation plants measured incinerator outlet NO_x concentrations ranging from 8 to 200 ppmv.[43] For vapor streams not containing nitrogen compounds, the measured NO_x concentrations were less than 30 ppmv.

If compounds containing halogens are present in the organic vapor stream, hydrogen chloride (HCl) will be formed when the vapors are incinerated. Similarly, the presence of sulfur compounds in the vapor stream results in the formation of sulfur oxides. These acid gases can be controlled by venting the thermal vapor incinerator exhaust gases through a wet scrubber. Water is normally used as the scrubbing agent increasing the TSDF wastewater effluent discharge to an on-site wastewater treatment unit or to a sewer for treatment by a publicly owned treatment works (POTW). To meet effluent discharge requirements, it may be necessary to neutralize the scrubber wastewater prior to discharge to the TSDF wastewater system. This is normally accomplished by adding a caustic (e.g., sodium hydroxide) to the wastewater producing small quantities of salts that must be disposed as hazardous waste.

4.3.3 Catalytic Vapor Incinerators

Catalytic vapor incineration is essentially a flameless combustion process. Passing the organic vapor stream through a catalyst bed promotes oxidation of the organics at temperatures in the range of 320 to 650 °C (600 to 1,200 °F).[44] Temperatures below this range slow down or stop the oxidation reactions resulting in low destruction efficiencies. Temperatures above this range shorten catalyst life or may even cause catalyst failure. Oxidation of vapor streams with a high organic content can produce temperatures well above 650 °C (1,200 °F). Consequently, high organic concentration vapor streams may not be suitable for catalytic incineration.

Figure 4-5 shows a simplified diagram of a catalytic vapor incinerator. The device consists of a chamber where the gas stream vented from the emission source is heated to the desired reaction temperature by mixing the organic vapors with hot combustion gas from natural gas-fired burners. The heated gas mixture then flows through the catalyst bed. The catalyst is composed of a porous inert substrate material that is plated with a metal alloy containing platinum, palladium, copper, chromium, or cobalt. A heat exchanger is installed to preheat the vapor stream and, hence, reduce the amount of fuel that must be burned.

Organic vapor destruction efficiency for catalytic vapor incinerators is a function of organic vapor composition and concentration, catalyst operating temperature, oxygen concentration, catalyst characteristics, and the ratio of the volumetric flow of gas entering the catalyst bed to the volume of the catalyst bed (referred to as "space velocity"). Destruction efficiency is increased by decreasing the space velocity. However, a lower space velocity increases the size of the catalyst bed and, consequently, the incinerator capital cost. For a specific catalyst bed size, increasing the catalyst bed temperature allows a higher space velocity to be used without impairing destruction efficiency.

A series of studies have been sponsored by EPA to investigate the destruction efficiency of catalytic vapor incinerators used to control organic and hazardous air pollutants.[45,46] The results of these studies concluded that destruction efficiencies of 97 to 98 percent are achievable.

The destruction efficiency is reduced by the accumulation of particulate matter, condensed organics, or polymerized hydrocarbons on the catalyst. These materials deactivate the catalyst by permanently blocking the active sites on the catalyst surface. If the catalyst is deactivated, the volatile organics in the gas stream will pass through the catalyst bed

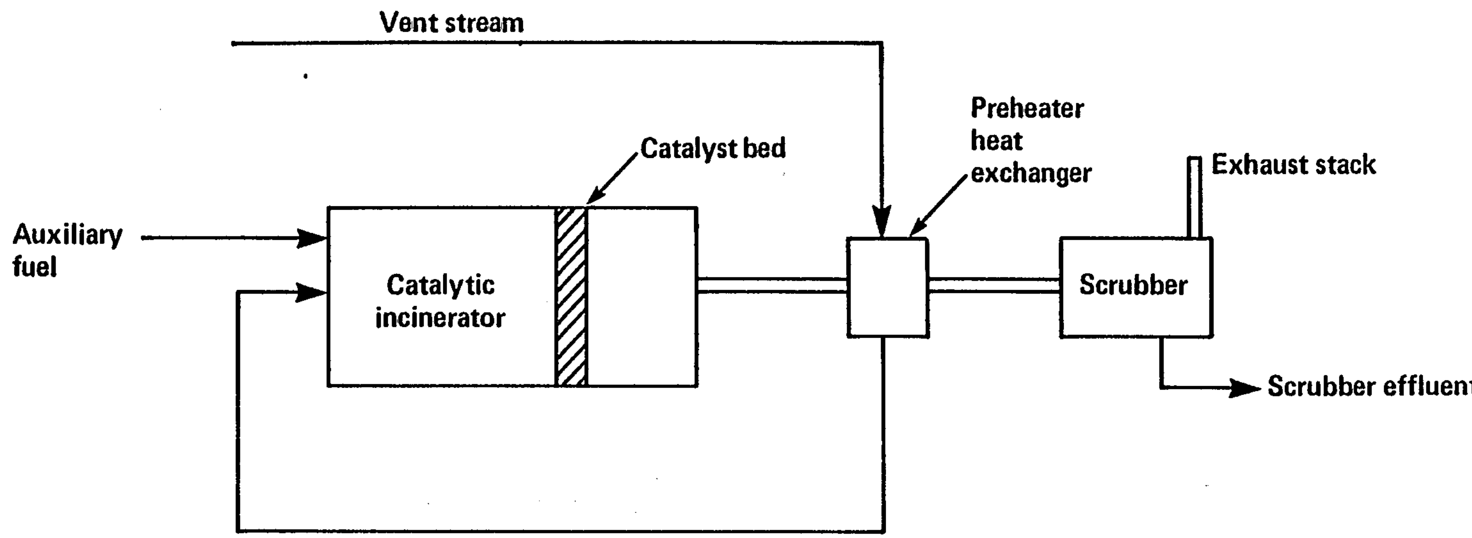


Figure 4-5. Schematic diagram of catalytic incinerator system.

unreacted or form new compounds such as aldehydes, ketones, and organic acids. Catalysts can also be deactivated by compounds containing sulfur, bismuth, phosphorous, arsenic, antimony, mercury, lead, zinc, tin, or halogens.

Catalytic vapor incinerators do not have the magnitude of NO_x air emission impacts or potential HCl and sulfur oxide air emission impacts associated with thermal vapor incineration because of lower operating temperatures and applicability restrictions. Catalytic vapor incinerators' operating temperatures are significantly lower than the temperatures required for significant NO_x formation from molecular nitrogen in the air (above 1,600 °C [2,900 °F]).[47] Small quantities of NO_x may form in the auxiliary burner flame zone. Also, the catalysts are very susceptible to rapid deactivation by halogens or sulfur. Consequently, catalytic vapor incineration will not likely be selected to control TSDF organics vapor streams containing halogen or sulfur compounds.

Using catalytic vapor incineration does produce small solid waste impacts. The incinerator catalyst must be periodically replaced with fresh catalyst because of gradual deactivation of the catalyst over time. The spent catalyst materials are either returned to a catalyst vendor for recycling or disposed as a solid waste. Because the catalyst formulations currently used contain heavy metals, spent catalyst materials will need to be disposed as a hazardous waste.

4.3.4 Flares

Unlike vapor incinerators, a flare is an open combustion process. The ambient air surrounding the flare provides the oxygen needed for combustion, Consequently, a flare does not require blowers to provide combustion air. To achieve smokeless flare operation, turbulent mixing of the organic vapor stream with the ambient air at the flame zone boundary can be "assisted" by injecting steam or air at the flare tip or by releasing the gas stream through a high velocity nozzle (i.e., a nozzle with a high pressure drop). Flares are used extensively to burn purge and waste gases from many industrial processes such as petroleum refinery process units, blast furnaces, and coke ovens.

Figure 4-6 shows a diagram of a typical steam-assisted flare configuration.[48] The knockout drum is used to remove entrained liquids from the

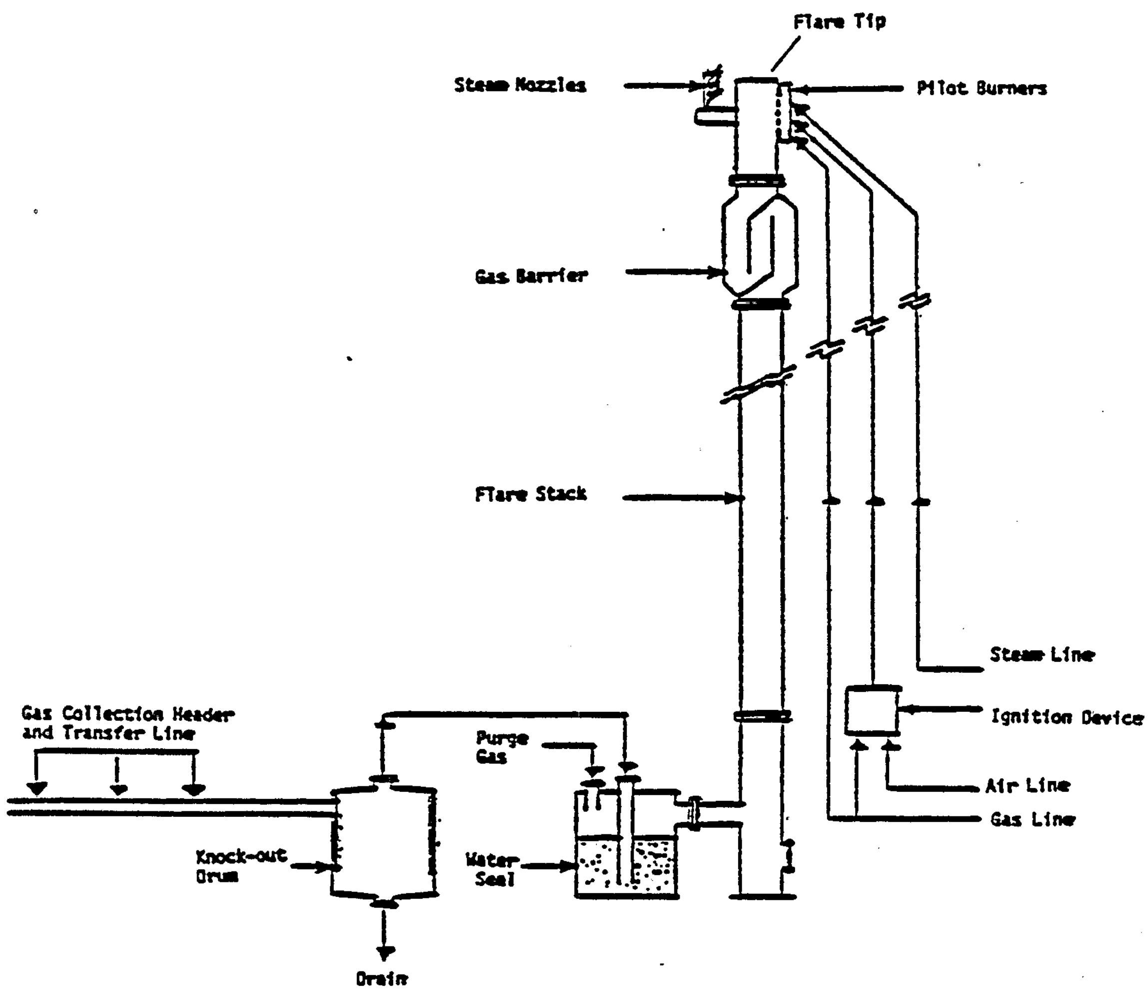


Figure 4-6. Steam-assisted elevated flare system.

organic vapor stream. A water seal is used to prevent air intrusion into the flare stack. A pilot burner fired with natural gas is used to ignite the waste gases.

Flares without assist continuously burn the vapors from the emission source. A flare equipped with a steam, air, or pressure assist operates on an intermittent basis. Steam-assisted flares typically are used for burning large volumes of waste gases released from a process unit during an upset or emergency condition. Air-assisted flares are less expensive to operate than steam-assisted flares. However, air-assisted flares are not suitable for large gas volumes because the airflow is difficult to control when the gas flow is intermittent. Pressure-assisted flares normally are used for applications requiring ground-level operation.

A series of flare destruction efficiency studies has been performed by EPA.[49,50] Based on the results of these studies, EPA concluded that 98 percent combustion efficiency can be achieved by steam-assisted and air-assisted flares burning gases with heat contents greater than 11 MJ/m^3 (300 Btu/ft^3). To achieve this efficiency level, EPA developed a set of flare design guidelines.[51] The guidelines specify flare tip exit velocities for different flares types and waste gas stream heating values.

Because flaring is a combustion process, using a flare to destruct organic vapors also produces NO_x emissions. However, flare NO_x emissions are very low. Measurements obtained during EPA-sponsored testing of two flares used to control hydrocarbon emissions from refinery and petrochemical processes indicate that NO_x concentrations in the flared gases are less than 10 ppmv.[52]

Application of flares to TSDF emission sources are not expected to produce HCl and sulfur oxide air emission impacts. Flares are not recommended for organic vapor streams containing halogens or sulfur compounds. The acid gases formed from these compounds during combustion causes severe corrosion and premature wear of flare tips. Thus, flares are not likely to be selected to control TSDF organic vapor streams containing halogen or sulfur compounds.

Steam-assisted flares with high steam rates emit high-pitched sounds that are considered annoying by many people. The use of this type of flare at a TSDF may create a noise nuisance impact especially if a residential neighborhood is located near the TSDF.

4.3.5 Boilers and Process Heaters

A boiler or process heater can be used for organic vapor destruction. The organic vapor stream is either (1) premixed with a gaseous fuel and fired using the existing burner configuration, or (2) fired separately through a special burner or burners that are retrofitted to the combustion unit.[53] Industrial boilers and process heaters currently are being used to burn vent gases from chemical manufacturing and petroleum refining process units.

A series of EPA-sponsored studies of organic vapor destruction efficiencies for industrial boilers and process heaters was conducted by premixing waste materials with the fuel used to fire representative types of combustion devices.[54,55,56] The destruction efficiency was determined based on the waste constituent concentrations measured in the fuel feed and stack gases using a gas chromatograph. The results of one study indicated that the destruction efficiency for an industrial boiler firing fuel oil spiked with polychlorinated biphenyls (PCB) was greater than 99.9 percent. A second study investigated the destruction efficiency of five process heaters firing a benzene vapor and natural gas mixture. The results of these tests showed 98 to 99 percent overall destruction efficiencies for C_1 to C_6 hydrocarbons.

Industrial boilers and process heaters are located at a plant site to provide steam or heat for a manufacturing process. Because plant operation requires these combustion units to be on-line, boilers and process heaters are suitable for controlling only organic vapor streams that do not impair the combustion device performance (e.g., reduce steam output) or reliability (e.g., cause premature boiler tube failure).

4.3.6 Condensers

Condensation is the process by which a gas or vapor is converted to a liquid form by lowering the temperature or increasing the pressure. This process occurs when the partial pressure for a specific organic compound in the vapor stream equals its partial pressure as a pure substance at operating conditions. For air pollutant control applications, cooling the gas stream is the more cost-effective method of achieving organic condensation.

There are two major types of condensers: surface condensers and contact condensers. In a surface condenser, the coolant does not contact the vapors or the condensate. In a contact condenser, the coolant and vapor stream are physically mixed together inside the vessel and exit the condenser as a single stream. For the TSDF applications, a contact condenser would not likely be used because the combined organic/coolant condensate creates additional treatment and disposal requirements.

A shell-and-tube-type heat exchanger is used for most surface condenser applications (see Figure 4-7).[57] The gas stream flows into a cylindrical shell and condenses on the outer surface of tubes that are chilled by a coolant flowing inside the tubes. The coolant used depends on the saturation temperature or dewpoint of the particular organic compounds in the gas stream. The condensed organic liquids are pumped to a tank. Additional information about condenser equipment and operations is available in References 58 and 59.

The volatile organic removal efficiency for a condenser is dependent upon the gas stream organic composition and concentrations as well as the condenser operating temperature. Condensation can be an effective control device for gas streams having high concentrations of organic compounds with high-boiling points. However, condensation is not effective for gas streams containing low organic concentrations or composed primarily of low-boiling point organics. At these conditions, organics cannot readily be condensed at normal condenser operating temperatures.

Appendix F, Section F.2.2.3, summarizes the results of a field evaluation of a condenser used to recover organics from a steam stripping process used to treat wastewater at a plant manufacturing ethylene dichloride and vinyl chloride monomer. The measured condenser removal efficiencies for specific organic constituents ranged from a high value of 99.5 percent for 1,2-dichloroethane to a low value of 6 percent for vinyl chloride.

Use of surface condensers for TSDF organic air emission control will likely produce no cross-media or secondary impacts other than any impacts attributed to electricity consumption. Because the coolant does not contact the condensate, organic condensate is not contaminated and can be

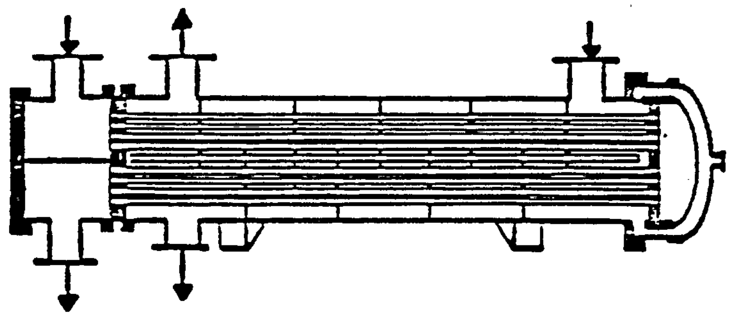


Figure 4-7. Schematic diagram of a shell-and-tube surface condenser.

readily recycled instead of being disposed. Electricity is required to power the coolant and condensate pumps.

4.3.7 Absorbers

Absorption as applied to air pollutant control is the process by which organic molecules in a gas stream are selectively removed by a liquid solvent (referred to as the "absorbent"). This process may occur by a physical or chemical mechanism. For physical absorption, the organic compounds dissolve in the absorbent. For chemical absorption, the organic compounds react with the absorbent or with reagents dissolved in the absorbent. The combined organic and absorbent mixture is then processed further to separate the organics and absorbent.

To achieve high organic control efficiencies using absorption, intimate mixing of the organic vapors with the absorbent is required. Several different types of equipment are available that achieve good contact between the gas and the absorbent. Absorbers include packed towers, plate or tray towers, spray towers, and venturi scrubbers. Background information about these devices is available in Reference 60.

The relatively low organic concentrations in the vent streams from many TSDF emission sources would require long contact times and large quantities of absorbent for effective emission control. This increases the size of the absorber vessel required as well as the absorber operating costs. Furthermore, the organics and absorbent are physically mixed together inside the absorber vessel, and exit as a single stream that creates additional hazardous waste treatment and disposal requirements. Consequently, application of an absorber to a TSDF emission source is generally more expensive than using a adsorption, combustion, or condensation add-on control device. Thus, it is expected that absorbers will not be selected for TSDF organic air emission control except perhaps at a TSDF location where a unique combination of waste characteristics and site-specific factors make an absorber the better choice for an add-on control device.

4.4 ORGANIC REMOVAL AND HAZARDOUS WASTE INCINERATION PROCESSES

4.4.1 Steam Stripping

Steam stripping involves the fractional distillation of volatile organics from a less volatile waste material. It is a commercially proven process and currently is used to remove organics from dilute aqueous liquids such as chemical manufacturing process wastewater. Several references discuss steam stripping in detail, including a steam-stripping manual published by EPA,[61] discussions of the theory and design procedures,[62-65] and discussions of applicability to hazardous wastes.[66-69]

The basic operating principle of steam stripping is the direct contact of steam with the waste, which results in the transfer of heat to the waste and the vaporization of the more volatile organic compounds. The vapor is condensed and separated (usually decanted) from the condensed water vapor. Final control of organics is accomplished by recycling or incinerating the condensed organic layer. A simplified diagram of a steam stripper is shown in Figure 4-8.

Batch steam stripping is used extensively in the laboratory and in small production units where a single unit may have to serve for many mixtures. Large installations also use batch steam stripping if the material to be separated contains solids, tars, or resins that may foul or plug a continuous unit. Batch steam stripping is also used to treat materials that are generated from a cyclical or batch process.[70] Batch processing may offer advantages at TSDF because the unit can be operated to optimize organic removal for a particular type of waste. For example, the same unit may be used to remove volatiles from a batch of wastewater, from a waste containing solids, or from a high-boiling organic matrix. The heat input rate and fraction boiled over can be varied for each waste type to obtain the recovery or removal desired for the specific batch of waste.

Continuous steam stripping requires a feed stream that is a free-flowing liquid with a negligible solids content. Solids, including tars and resins, tend to foul the column trays or packing and heat exchangers. Consequently, wastes containing solids may require removal of the solids prior to processing through a continuous steam stripper. Unlike the batch operation, a continuous steam stripper requires a relatively consistent feed composition to maintain a consistent removal efficiency from the waste material.[71] The continuous steam stripper may offer cost advantages over a batch operation for applications in which there is little variation in the type of feed and for relatively high volumes of waste materials.

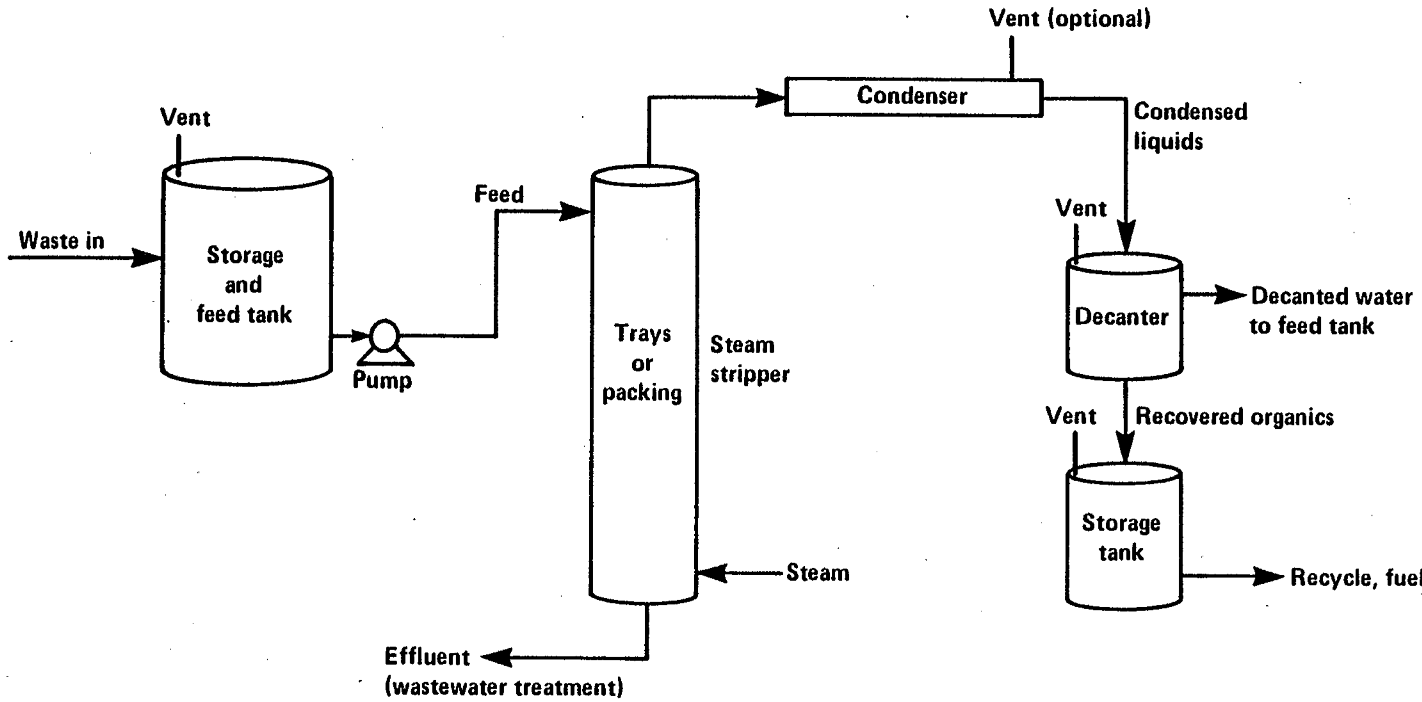


Figure 4-8. Schematic diagram of a steam stripping system.

The products and residues from steam stripping include the condensed vapors (condensate), noncondensible gases, and the treated waste or effluent. The condensate usually is decanted to remove any separate organic layer from the aqueous layer with recycle of the aqueous condensate back to the feed stream. The separate organic layer may be recovered and reused as product or fuel. If the condensate is a single phase of water containing dissolved organics, then additional treatment of the condensate may be necessary for ultimate control of organics. Most commercial processes rely on the formation of a separate organic phase and decanting for economical removal and recovery of organics. Noncondensibles in the overhead stream include gases dissolved in the waste material and very volatile compounds in low concentrations that are not condensed in the overhead system. The noncondensibles leave through the condenser or decanter vent and usually are vented to the atmosphere or to an incinerator. For example, vinyl chloride and chloroethane in one steam stripping test were found to pass through the condenser and were vented as noncondensibles to an incinerator.[72] The effluent from the steam stripper should be essentially free of the most volatile compounds; however, semivolatiles and compounds that are relatively nonvolatile may still be present in the stripper bottoms or effluent and may require additional treatment for removal.

Steam stripping is applicable to most waste types that have a reasonably high vapor-phase concentration of organics at elevated temperatures (as measured by the vapor/liquid equilibrium coefficient). These waste types are commonly found in TSDF. Theoretically, wastes can be processed by batch steam stripping if they can be pumped into the unit and if they produce a residue that can be removed from the still. This batch operation may be applicable for waste streams generated in relatively low quantities. However, batch stripping of sludges with high solids content is not a technology that has been demonstrated and evaluated in full-scale units. Consequently, no design or performance data are available for batch stripping of sludges. Some of the difficulties associated with batch stripping of sludges include material handling problems, heat transfer in the unit, long cycle times, and unknown performance. All of these factors would affect the basic design and operation of the unit.

Preliminary treatment such as solids removal or pH adjustment are often used before wastewater is stripped in a continuous unit. Continuous steam stripping has been used routinely in the chemical industry to recover organics for recycle and to pretreat wastewater for organic removal prior to the conventional wastewater treatment process. Common steam stripping applications include recovery of ethylene dichloride, ammonia, sulfur, or phenol for recycle and removal of phenol, mercaptans, vinyl chloride, and other chlorinated compounds from wastewater.[73] Batch steam stripping appears to be more common at commercial TSDF because it is adaptable to different types of wastes that may be received in batches.[74] For any given waste type, pilot-scale evaluations or trials in the full-scale process may be required to optimize the operating conditions for maximum removal at the lowest cost.

Removal efficiencies on the order of 95 to 100 percent are achievable for volatile organics such as benzene, toluene, and one- or two-carbon chlorinated compounds.[75,76] Batch operations usually provide a single equilibrium stage of separation, and the removal efficiency is determined essentially by the equilibrium coefficient and the fraction of the waste distilled. The efficiency of a continuous system is related to the equilibrium coefficient and the number of equilibrium stages, which is determined primarily by the number of trays or height of packing. The organic removal efficiency also is affected by the steam input rate, column temperatures, and, in some cases, the pH. Temperature affects the solubility and partition coefficient of the volatile compound. The liquid pH also may affect the solubility and treatability of specific compounds, such as phenol. In principle, the removal efficiency in a multistage system can be designed to achieve almost any level. In practice, removal efficiencies are determined by practical limits in the column design (such as maximum column height or pressure drop) and cost. Consequently, steam stripping is difficult to characterize in terms of maximum achievable performance with respect to percent organic emission reduction or organic concentration in the treated waste.

Emission source tests for five steam stripping units are presented in Appendix F. Wastewater containing methylene chloride, chloroform, and carbon tetrachloride was treated by steam stripping at a chemical plant (Section F.2.3.1.1). An inlet concentration of approximately 6,000 ppm organics was reduced to less than 0.037 ppm for an overall removal efficiency of about 99.999 percent. The effluent from the stripper required no further treatment and was discharged directly to a river under a National Pollutant Discharge Elimination System (NPDES) permit.

The steam stripper at a second plant (Section F.2.3.1.2) was used to strip volatile organics from industrial wastewater. The major component, 1,2-dichloroethane, was removed from the wastewater at an efficiency of 99.998 percent. The removal of total organics, which generally included chlorinated compounds with one to two carbon atoms, averaged 99.8 percent.

The test at a third chemical manufacturing plant (Section F.2.3.1.3) evaluated the removal of nitrobenzene and nitrotoluene from wastewater. These compounds are less volatile than the compounds in the wastewater at the first plant. The removal efficiency for nitrobenzene and 2-nitrotoluene ranged from 91 to 97 percent with an overall organics removal of 92 percent.

The steam stripper at a fourth chemicals manufacturing plant (Section F.2.3.1.5) is used to remove relatively volatile compounds (methylene chloride, chloroform, and carbon tetrachloride) from wastewater. The removal of the major component, methylene chloride, was 99.99 percent. The removal of total organics was 98 percent.

Four batches of waste were evaluated in a batch steam stripping process used to reclaim organic solvents (Section F.2.3.1.4). The types of compounds present in the waste included both very volatile compounds and some considered to be semivolatiles because of their solubility in water. The removal of the most volatile compounds was on the order of 99 percent with occasionally lower values for specific compounds (e.g., 91 percent for acetone, 87 to 94 percent for 1,1,1-trichloroethane, and 74 percent for ethyl benzene). The removal of total organics from the batches ranged from 94 to 99.8 percent.

At a solvent recycling plant (Section F.2.3.4.1), tests were conducted on two batches of waste processed through a batch steam distillation unit. In the first batch, removal of individual compounds ranged from 36 to

92 percent and total organics removal was 76 percent. In the second batch, removal of individual compounds ranged from 12 to 91 percent and total organics removal was 91 percent. In this latter batch, a major portion of the total organic content of the waste consisted of the most volatile compound.

The steam required for steam stripping most likely is supplied by an on-site industrial boiler. Increasing process steam production will increase boiler air emission impacts.

4.4.2 Air Stripping

Air stripping is a process that uses forced air to remove volatile compounds from a less volatile liquid. The contact between air and liquid can be accomplished in spray towers, mechanical or diffused-air aeration systems, and packed towers.[77] Packed tower air strippers are preferred for TSDF organic air emission control because the vapor-laden air can be sent to a control device, whereas the other devices rely upon dilution in ambient air to avoid environmental problems. In packed towers, the liquid to be treated is sprayed into the top of a packed column and flows down the column by gravity. Air is injected at the bottom of the column and rises countercurrent to the liquid flow. The air becomes progressively richer in organics as it rises through the column and is sent to a control device to remove or destroy organics in the air stream. See Figure 4-9 for a schematic of a typical air stripping system with gas-phase organic emission control.

The principle of operation is the equilibrium differential between the concentration of the organics in the waste and the air with which it is in contact. Consequently, compounds that are very volatile are the most easily stripped. The packing in the column promotes contact between the air and liquid and enhances the mass transfer of organics to the air. The residues from air stripping include the organics-laden air that must be treated and the water effluent from the air stripper. This effluent will contain very low levels of the most volatile organic compounds; however, semivolatile compounds that are not easily air stripped may still be present and may require some form of additional treatment before final disposal. The process does not offer a significant potential for recovery

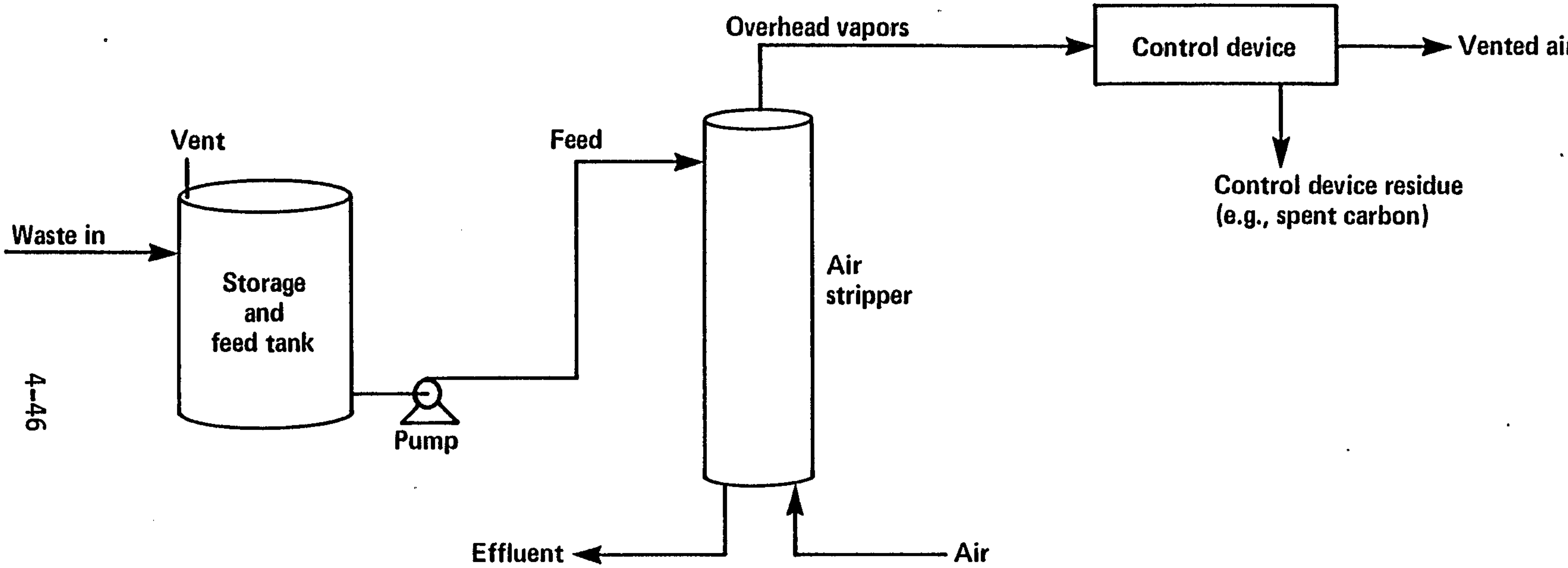


Figure 4-9. Schematic diagram of an air stripping system.

and reuse of organics. Condensers generally are not used to recover the stripped organics because of the large energy requirements to cool the large quantity of noncondensibles (primarily air) and to condense the relatively low vapor-phase quantities of organic compounds. Thermal and catalytic incinerators and carbon adsorption units are the most common control devices used for control of the overhead gas stream from air strippers. Fixed-bed carbon adsorption systems offer some potential for recovery of organics; however, the decision on type of control (organic destruction or recovery) is usually based on economics.

Air stripping has been used primarily on dilute aqueous waste streams with organic concentrations that range from a few parts per billion to hundreds of parts per million. The feed stream should be relatively free of solids to avoid fouling in the column; consequently, some form of solids removal may be required for certain aqueous hazardous wastes. In addition, dissolved metals that may be oxidized to an insoluble form should be removed. Equipment may be designed and operated to air-strip organics from sludges and solids in a batch operation; however, this application has not been demonstrated extensively and is not a common practice. The major industrial application of air stripping has been in the removal of ammonia from wastewater.[78] In recent years, the use of air strippers has become a widely used technology in the removal of volatile compounds from contaminated groundwater.[79,80]

Packed towers can achieve up to 99.9 percent removal of volatiles from water.[81] The major factors affecting removal efficiency include the equilibrium between the organics and the vapor phase (usually measured by Henry's law constant for dilute aqueous wastes) and the system's design, which determines mass transfer rates. Removal efficiency increases as the equilibrium coefficient increases; consequently, the extent of removal is strongly affected by the type of waste and the volatility of the individual organic constituents. Mass transfer rates (and removal efficiency) are also a function of the air:water ratio, height of packing, and type of packing.[82] The operating temperature is also an important variable that affects efficiency because of its direct effect on the vapor/liquid equilibrium. Higher temperatures result in higher vapor-phase concentrations of organics and higher removal rates. Air strippers have operational difficulties in freezing weather that may require heating the input waste stream, heating and insulating the column, or housing the operation inside an enclosure. Air strippers are typically designed to remove key or major constituents. Compounds more volatile than the design constituent are removed at or above the design efficiency, and less volatile compounds are removed at a lower efficiency. Numerous vendors are available for the design and installation of air strippers. As is the case with steam strippers, these vendors usually require pilot-scale tests on the actual waste material to design the column and to guarantee minimum removal efficiencies.

Emission sources associated with an air stripping operation include tank vents (storage or feed tanks, preliminary treatment tanks) and equipment used to transfer and handle the waste (pumps, valves, etc). The air leaving the stripping column usually is treated by incineration (with destruction efficiencies of 98 percent or higher) or carbon adsorption (with removal efficiencies of 95 percent or higher if carbon breakthrough is monitored). The choice between incineration and carbon adsorption depends on the specific conditions at the facility. For example, high relative humidity in the air stream leaving the air stripper may adversely affect the adsorption capacity of a carbon bed. This could be avoided by choosing incineration. However, if the air stream contains chlorinated organics, the incinerated air stream may need to be scrubbed to remove HCl, leading to higher costs. In this case, it might be better to choose carbon adsorption and design to avoid the humidity problem.

The effluent from the air stripper may be an emission source for semivolatiles that are not removed efficiently, especially if subsequent processing includes placement in an evaporation pond or disposal impoundment. Air stripping could be used to reduce organics from wastewater prior to a wastewater treatment operation.

An air stripper was evaluated at a Superfund site (Section F.2.3.2.1) where it is used to remove organics from the leachate collected at the site. The evaluation focused on optimizing the removal efficiency for organic components that represented a relatively wide range in volatility.

During one test, the removal of the most volatile constituents (1,2,3-trichloropropane and xylene) ranged from 88 to 98 percent. The removal of semivolatiles such as aniline, phenol, methylphenol, and ethylbenzene ranged from 53 to 70 percent. The removal of total organics averaged 99 percent.

Any air emissions, wastewater effluents, or solid wastes associated with the use of air stripping at TSDF are determined by the type of add-on control device used in conjunction with the air stripping unit. Section 4.3 discusses add-on control device cross-media and secondary impacts.

4.4.3 Thin-Film Evaporation

Thin-film evaporators (TFE) are designed to promote heat transfer by spreading a thin-layer film of liquid on one side of a metallic surface while supplying heat to the other side.[83] The unique feature of this equipment is the mechanical agitator device, which permits the processing of high-viscosity liquids and liquids with suspended solids. However, if solid particles are large, a coarse filtration operation may be required to pretreat the waste stream going to the TFE. The mechanical agitator promotes the transfer of heat to the material by exposing a large surface area for the evaporation of volatile compounds and agitates the film to maintain the solids in suspension without fouling the heat transfer area. Heat can be supplied by either steam or hot oil; hot oils are used to heat the material to temperatures higher than can be achieved with saturated steam (>100 °C). TFE can be operated at atmospheric pressure or under vacuum as needed based on the characteristics of the material treated. A TFE is illustrated in Figure 4-10.

The two types of mechanically agitated TFE are horizontal and vertical. A typical unit consists of a motor-driven rotor with longitudinal blades that rotate concentrically within a heated cylinder. The rotating blade has a typical tip speed of 9 to 12 m/s and a clearance of 0.8 to 2.5 mm to the outer shell. In a vertical design, feed material enters the feed nozzle above the heated zone and is transported mechanically by the rotor and grating down a helical path on the inner heat transfer surface while the volatile compounds are volatilized and leave the evaporator on the top. The vapor-phase products from TFE are condensed in a condenser, and the bottom residues are collected for disposal.

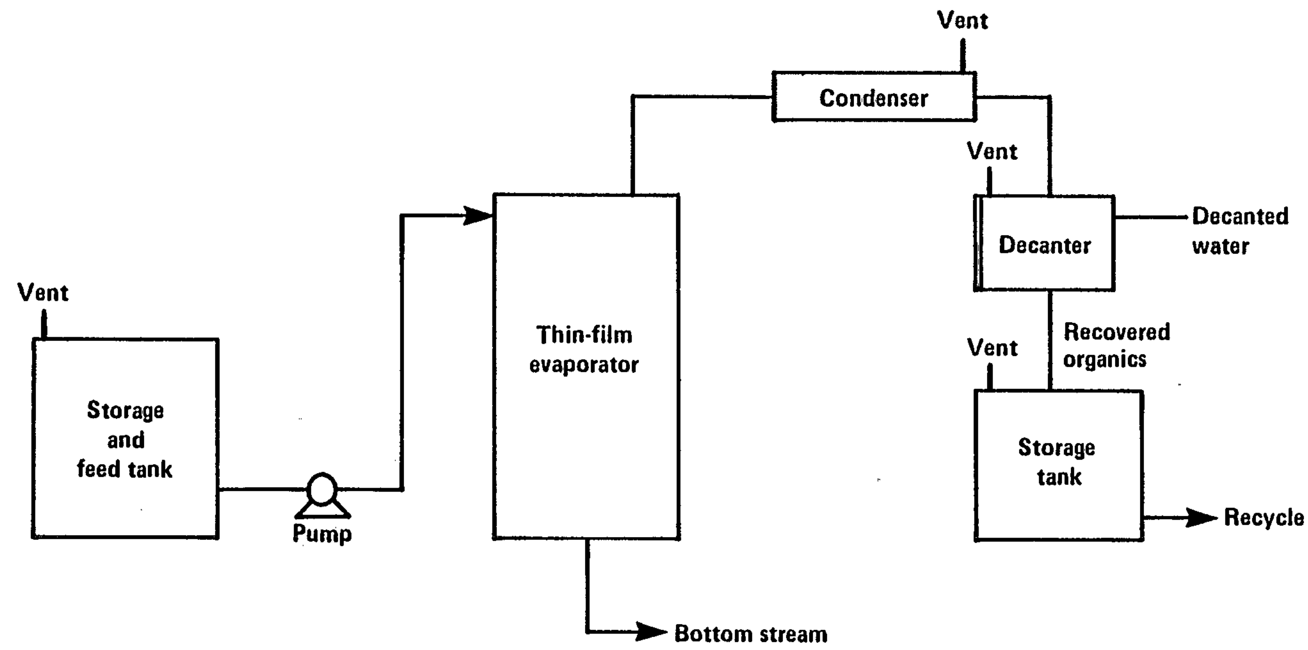


Figure 4-10. Schematic diagram of a thin-film evaporator system.

TFE have been used widely for many years in a number of applications such as processing of chemicals, pharmaceuticals, plastics, and foods.[84] Because of their unique features, their use in chemical and waste material processing has expanded rapidly. The flexibility in operating temperature and pressure add potential to TFE for recovering low-boiling-point organics from a complex waste matrix.

Although TFE can be used to remove varying levels of organics from a waste stream, when applied to hazardous petroleum refinery sludges, the most suitable mode of operation is to evaporate the water and volatiles and leave most of the hydrocarbons that are less volatile than water.

With this mode of operation, the TFE bottom residue contains only low concentrations of both volatile and semivolatile organic compounds and thus has a low potential for air emissions after ultimate disposal. This mode of operation was used during a pilot-scale test discussed below. Waste forms suitable for TFE treatment include organic liquids, organic sludge/ slurry, two-phase aqueous/organic liquids, and aqueous sludges. TFE would not be used as a means of treating dilute aqueous waste because of the high water content in the waste.

Although TFE technology is readily available, as with other organic removal techniques, a pilot-plant study is usually conducted before full-scale operation to determine the suitability of the TFE for pretreating a particular waste stream and to identify optimal operating conditions. The EPA recently sponsored a pilot-scale test to assess the performance of a TFE in removing organics from the different types of petroleum refining wastes.[85] In that study, 98.4 to 99.99 percent of the volatile and 10 to 75 percent of the semivolatile compounds were removed from the sludge. These results suggest that a TFE can be used to reduce organics substantially in refinery sludges that are currently land treated. No commercial-scale TFE installations have been identified that process the types of wastes normally handled by TSDF. However, two installations of TFE used to recover organics from waste streams have been documented in the literature and may have some relevance for TSDF operations.[86] In one installation (Section F.2.3.3.3), a hazardous waste recycling plant operates a TFE under vacuum to separate approximately 95 percent of a feed stream that consists of waste oils, a small amount of solids, and approximately 5 percent organics. In that operation, toluene is removed from the oily wastes at less than 85 percent efficiency while both chloroform and methylene chloride are removed at greater than 99 percent efficiency. However, that installation reportedly has significant organic air emissions through the vacuum pump vent although no estimate was given for the magnitude of the emissions. At another organic solvent reclamation and recycling plant (Section F.2.3.3.2), a TFE operating at atmospheric pressure was able to remove approximately 76 percent of the acetone and 30 percent of the xylene from a contaminated acetone waste. Air samples from the process vent at that operation indicated that air emissions were negligible. At a solvent recycling plant (Section F.2.3.3.1), a TFE showed removal efficiencies of 45 to 99 percent for individual volatile and semivolatile compounds and yielded a total organic removal efficiency of 74 percent.

Factors likely to affect or limit the applicability or removal efficiency of TFE include:

- Large changes in the properties of the waste being treated, which could cause fouling of the TFE unit.
- The requirement for separation of water and condensed organics when water is evaporated from the waste stream, which adds to the operating expense of the unit.

The steam required for thin film evaporation most likely is supplied by an on-site industrial boiler. Increasing process steam production will increase boiler air emission impacts.

4.4.4 Batch Distillation

Batch distillation is a commonly used process for recovery of organics from wastes. Its principal use is for recovery of valuable organic chemicals for recycling or reuse and the re-refining of waste oil as discussed later in this section. Examples of its use show that it can be applied to wastes and reduce the organic air emission potential of those wastes by separating the volatile compounds from the wastes. Although it has been applied to aqueous wastes, it has been more typically applied to predominantly organic wastes.

The simplest form of distillation is a batch operation that consists of a heated vessel (called the pot), a condenser, and one or more receiving tanks. This process is identical in principle to batch steam stripping except that the waste charge is heated indirectly instead of by direct steam injection. The waste material is charged to the pot and heated to boiling; vapors enriched in organics are removed, condensed, and collected in receiving tanks. The distillation is continued to a cutoff point determined by the concentration of organics in the condensate or the concentration of organics remaining in the batch. A common modification is to add a rectifying column and some means of returning a portion of the distillate as reflux (see Figure 4-11). Rectification enables the operator to obtain products from the condensate that have a narrow composition range. Different distillate cuts are made by switching to alternate receivers, at which time the operating conditions may be changed. If the distillate is collected as one product, the distillation is stopped when the combined distillate reaches the desired average composition.[87] Several references are available that discuss the design and operation of batch distillation units.[88-94] The batch still is operated at a temperature determined by the boiling point of the waste, which may increase with the time of operation. The distillation can be carried out under pressure or under vacuum. The use of vacuum reduces the operating temperature and may improve product recovery, especially when decomposition or chemical reaction occurs at higher temperatures.

Batch distillation provides a means for removing organics from a waste matrix and recovery of the organics by condensation for recycle, sale as product, or for fuel. The products and residues include the condensate that is enriched in organics and recovered, noncondensibles that escape through the condenser vent, and the waste residue that remains in the pot. The noncondensibles are composed of gases dissolved in the waste and very volatile organic compounds with relatively low-vapor phase concentrations. The waste material after distillation may have been concentrated with high-boiling-point organics or solids that are not removed with the overhead vapors. These still bottoms may be a free-flowing liquid, a viscous slurry, or an organic material that may solidify upon cooling. If the

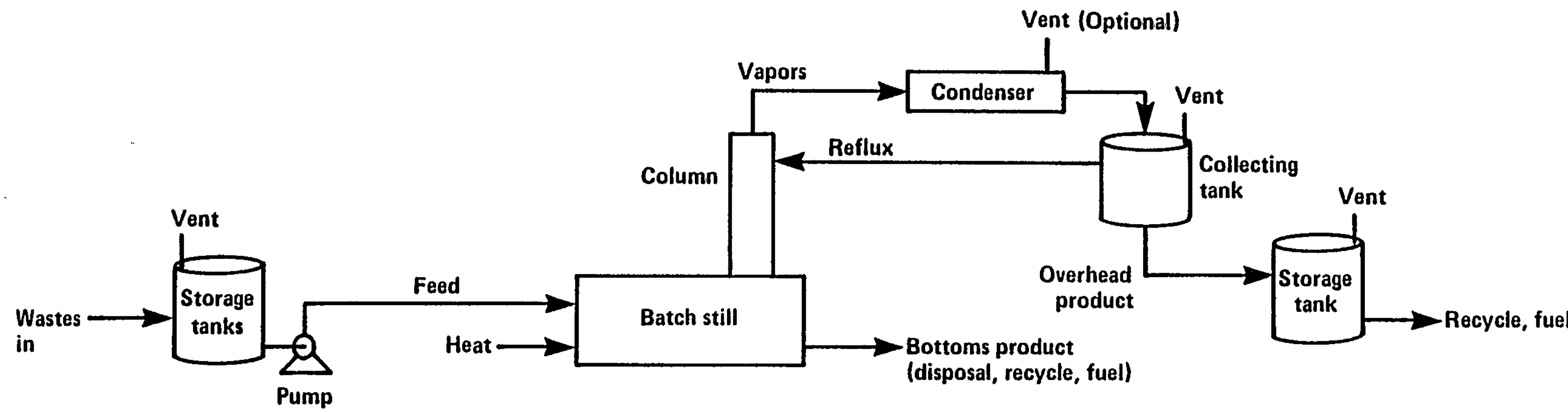


Figure 4-11. Schematic diagram of batch distillation with fractionating column.

waste material contains water, a separate aqueous phase may be generated with the condensate. This phase may be returned to the batch or processed with additional treatment to remove organics or other contaminants.

Batch distillation may be used for wastes that have a significant vapor-phase concentration of organics at the distillation temperature. If the waste can be pumped and charged to the still pot and the residue can be removed from the pot, then the waste is likely to be treatable for organic removal by this process. Such wastes include dilute aqueous wastes (the operation would be similar to batch steam stripping), aqueous or organic sludges, or wastes with volatiles in a high-boiling-point organic solvent or oil. The batch distillation of sludges has not been demonstrated and evaluated in full-scale units; consequently, the processing of sludges in a batch distillation unit is subject to the same limitations described for the batch steam stripping of sludges (Section 4.4.1). Batch distillation has been used to remove organics from plating wastes, phenol from aqueous wastes, recovery and separation of solvents, and re-refining of waste oils.[95,96] The applicability of batch distillation for a specific waste type can be evaluated by a simple laboratory distillation to assess potential organic recovery. As with other organic removal techniques, the process may require optimization in a pilot-scale or full-scale system for different types of wastes to determine operating conditions that provide the desired distillate composition or percent removal from the waste.

Batch stills usually are operated as a single equilibrium stage (i.e., with no reflux); consequently, the organic removal efficiency is primarily a function of the vapor/liquid equilibrium coefficient of the organics at distillation temperatures and the fraction of the waste boiled over as distillate. The use of a rectifying section yields an overhead product with a composition that can be controlled by the operator. The removal efficiency for various waste types can be highly variable because of the dependence on both properties of the waste (e.g., organic equilibrium) and the operating conditions that are used. Emission tests were conducted on a batch unit at a plant engaged in the reclamation of contaminated solvents and other chemicals.[97] The test results (summarized in Appendix F, Section F.2.3.4.2) indicate organic removal efficiencies on the order of 99.4 to

99.97 percent for organics, including compounds such as methyl ethyl ketone, 2,2-dimethyl oxirane, methanol, methylene chloride, isopropanol, and carbon tetrachloride. Results for a second distillation unit at the same site processing contaminated solvents showed organic removal efficiencies ranged from 97 percent (for xylene and ethyl benzene) to 99.9 percent (for trichloroethane). These results demonstrate that batch distillation has been used successfully to remove organics from aqueous and organic wastes or solvents.

The steam required for batch distillation most likely is supplied by an on-site industrial boiler. Increasing process steam production will increase boiler air emission impacts.

4.4.5 Dewatering

As used herein, dewatering refers to solid-liquid separation achieved by filtration or centrifugation. Such devices normally are characterized according to the force used to achieve the desired separation. At TSDF, solid-liquid separation most often is achieved by filtration rather than centrifugation. Filtration is achieved by passing the waste stream through a filtering medium, often a textile product, using force that may be applied in any of several ways. Press-type filters consist of a series of plates covered with a filtering medium and enclosed in a frame. Separation is achieved by filling the void spaces between plates with the input material and then applying pressure to force the plates together and generate the desired separation. Examples of this type of filter include plate and frame, recessed plate, and pressure leaf filters.[98] Filtration force also may be applied by using atmospheric pressure on one side of the filter medium while the other side is maintained at greater or lesser than atmospheric pressure. Examples of this type of filter include rotary drum vacuum and rotary drum pressure filters. In rotary drum vacuum filters, the driving force is achieved by reducing the pressure inside a rotating drum to below atmospheric. The drum is covered with a filter medium that builds up a cake of solids that contributes to filtration efficiency. The rotary drum pressure filter uses the reverse principle of applying greater than atmospheric pressure to the inside of the rotating drum. In these filters, the filtering medium is inside the drum. Advantages of the vacuum filter include its adaptability to continuous operation and the ease with which the filter material can be cleaned and maintained.[99] In recent years, belt filter presses have become one of the more widely used types for many applications. These filters use a combination of gravity and pressure to apply force across the filter medium. In belt filter presses, the input stream is applied to a horizontal moving belt that is covered with filter material. Gravity forces cause partial separation of the liquid from the solids in the stream. As the belt continues to move, it approaches a second moving belt, and the two move along together over a series of rollers that force the belts closer and closer together, creating pressure on the material between the two belts. The belts separate for solids removal, and the filter medium separates from the underlying supporting web. At this point, the filter medium can be washed continuously. The ease of continuous washing is one of the primary advantages of the belt filter press.[100] Other advantages include the adaptability to continuous operation and the higher throughputs handled relative to other types of filters. Exit streams from a filtering or dewatering operation include the filtrate, which is mostly free of solids, and the filter cake, which generally has a sufficiently low moisture content to be handled using solids handling techniques. A schematic diagram of a dewatering system is illustrated in Figure 4-12.

Dewatering is applicable to any waste stream that consists of a sludge or slurry such as petroleum refinery sludges. When used for this application, toxic metals remain in the filter cake, which could continue to be land treated or may be fixated and landfilled, while the liquid passes through a separation process where oil (which will contain a large fraction of the organics) is recovered for recycle. Little data have been identified that can be used to estimate the emission reduction achieved by dewatering. However, Chevron Research Company has conducted tests that indicate as much as 90 percent of the oil in refinery sludges can be recovered by dewatering and that oil recovery is improved substantially if the filtration or centrifugation step is followed by a drying step.[101] At an EPA-sponsored test at a Midwest refinery, oil removal using a belt filter was found to be 78 percent for an API separator sludge and 66 percent for a

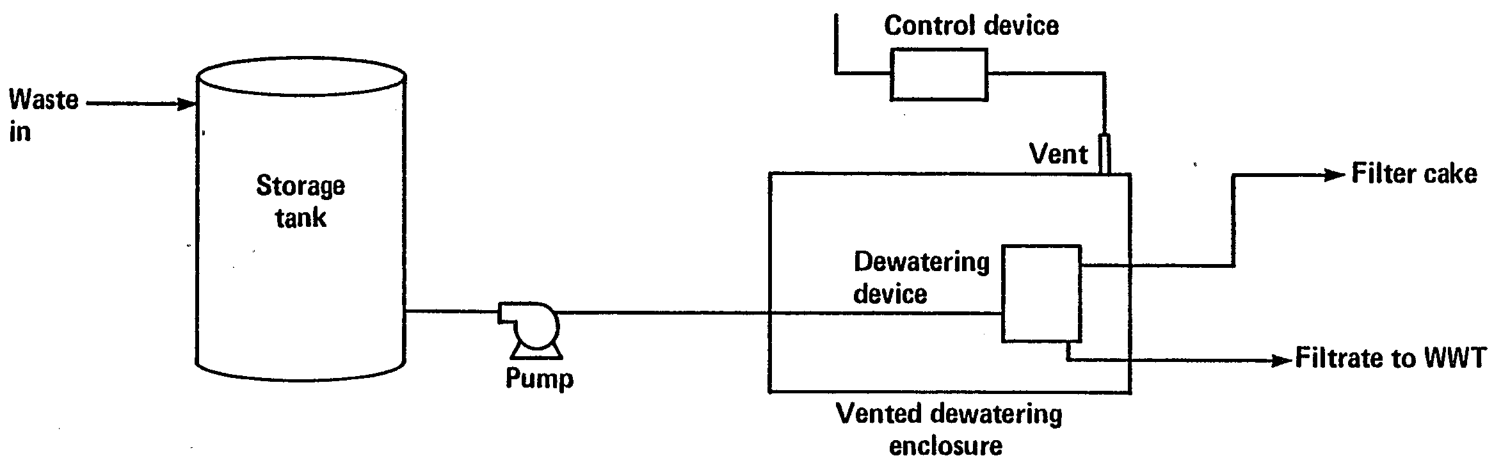


Figure 4-12. Dewatering system with enclosed dewatering device.

dissolved air flotation (DAF) float.[102] If the recovery efficiencies obtained in the tests can be achieved in full-scale applications, an equivalent reduction in emissions from land treatment or landfill operations would be expected.

Emissions during dewatering would come from pumps, valves, storage, and other handling operations and also from any exposed waste surfaces at the dewatering device. At the test of the belt filter press cited above, measured air emissions were equal to 21 percent of the volatiles in the API separator sludge and 13 percent of the volatiles and 22 percent of the semivolatiles in the DAF float.

When vacuum filters are used, emissions would occur with the vacuum pump exhaust. Control of emissions could be achieved by enclosing the operation where necessary and venting the enclosure to one of the add-on control devices described in Section 4.3. Vacuum pump exhaust also could be controlled with an add-on control device.

Any air emissions, wastewater effluents, or solid wastes associated with the use of dewatering are determined by the type of add-on control device used in conjunction with the dewatering device. Add-on control device cross-media and secondary impacts are discussed in Section 4.2.

4.4.6 Hazardous Waste Incineration

Incineration is an engineered process that uses thermal oxidation of a bulk or containerized waste to produce a less bulky, toxic, or noxious material. Combustion temperature, residence time, and proper mixing are crucial in controlling operating conditions.[103,104] Of the several types of waste incineration systems, four are generally cited as being the most useful and having the greatest potential for application to wastes processed at TSDF. They are liquid injection, rotary kiln, fluidized-bed, and multiple-hearth incinerators. The type of incinerator selected for a particular installation depends on the waste type and composition as well as other factors such as whether the waste is in bulk or containerized.

Liquid injection incinerators are versatile and can be used to dispose of virtually any combustible liquid that can be pumped. The liquid waste must be converted to gas prior to combustion. This change is brought about in the combustion chamber and is generally expedited by increasing the waste surface area by atomization.[105] Liquid injection incinerators operate at temperatures between 820 and 1,600 °C. Gas-phase residence times range from 0.1 to 2 s.

Rotary kilns are versatile units that can be used to dispose of solids, liquids, slurries, and gaseous combustible wastes. Rotary kilns are long, cylindrical rotating furnaces lined with firebrick or other refractory material in which solids are combusted by themselves or are incinerated by combustion of an auxiliary fuel or liquid wastes. Combustion temperatures range from 870 to 1,600 °C depending on the waste material characteristics.[106] Solids residence time varies from seconds to hours, depending on the type of waste. Unless the kiln is very long (i.e, provides a larger residence time), some type of secondary burning chamber usually is required to complete combustion of the solid waste. The heat release per unit volume is generally quite low, but the rotary kiln provides a method of mixing solids with combustion air and can be operated at temperatures in excess of 1,400 °C that are unavailable in other types of systems.

A fluidized-bed incinerator consists of a bed of inert granular material fluidized by hot air onto which the waste and auxiliary fuel is injected.[107] The waste in turn combusts and returns energy to the bed material; thus, heat release per unit volume is generally higher than for other types of incinerators. Fluidized-bed incinerators operate at temperatures below the softening point of the bed medium, usually around 450 to 850 °C.[108] The residence time is generally around 12 to 14 s for a liquid waste and longer for solid wastes. This type of incinerator is suited particularly to heavy sludge and to certain types of organic/inorganic mixtures. The inorganic material will stay in the bed and can be removed as ash. Scrubbing of flue gases usually is required to remove fine particulates, and subsequent flue gas treatment is required for halogen, sulfur, and phosphorus compounds.

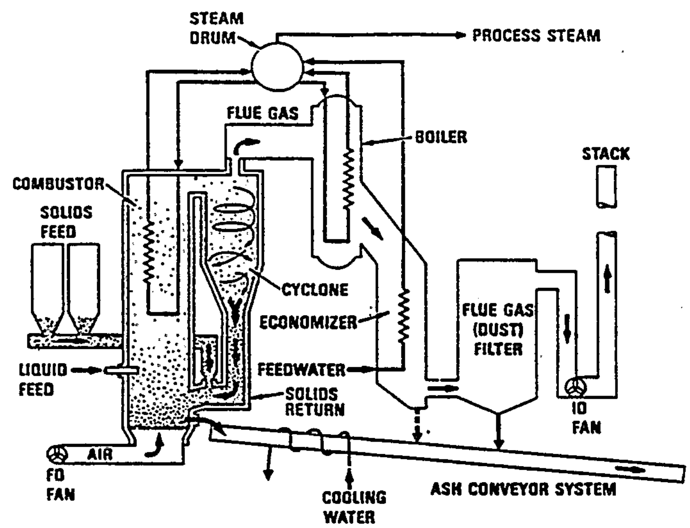
The multiple-hearth incinerator was designed for the incineration of low heat content waste such as sewage sludge. It generally uses large amounts of auxiliary fuel and is large in size. A multiple-hearth unit generally has three operating zones: the uppermost hearths where feed is dried (350 to 550 °C), the incineration zone (800 to 1,000 °C), and the cooling zone (200 to 350 °C).[109] Exit gases have good potential for heat recovery, being around 300 to 600 °C. Temperatures on each hearth can be maintained using supplemental fuel. Multiple-hearth units may be suitable for hazardous sludge disposal, although it may be necessary to add an afterburner to destroy unburned hydrocarbons that volatilize on the uppermost hearths. Several incinerator types are shown in Figure 4-13.

The cost of operating an incinerator can be reduced by recovering and using the heat generated by the combustion of waste. Primary heat recovery can be employed by using the incinerator exhaust to preheat the incoming waste stream. Secondary heat recovery, such as a waste heat boiler, can also be used if the production process can make use of the steam generated. Heat recovery is shown in the incinerator illustration in Figure 4-13.

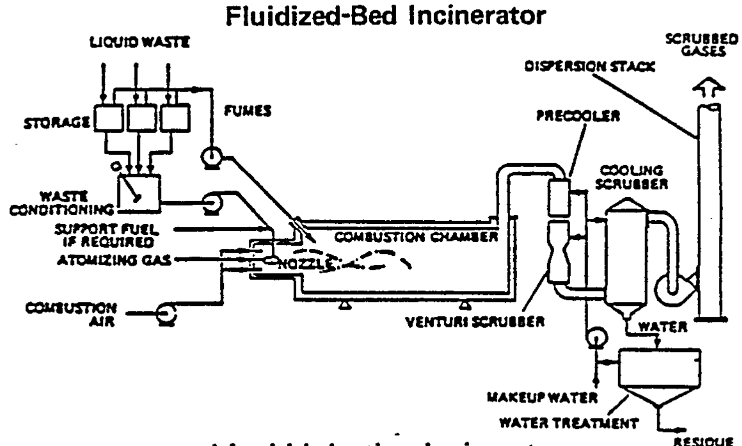
Incineration under proper control and using proper techniques will provide total destruction of all forms of hazardous organic wastes.[110] There are two basic types of wastes: (1) combustible wastes, which will sustain combustion without auxiliary fuel; and (2) noncombustible wastes, which usually contain large amounts of water or other inert compounds and will not sustain combustion without auxiliary fuel. Organic liquid and sludge are most suitable for incineration because of their heat content. Aqueous sludge, two-phase aqueous/sludge, and organic-containing solids may be incinerated with auxiliary fuel to destruct hazardous organics. Dilute aqueous waste would not be suitable for direct incineration because of its high water content.

Of the four types of incineration, liquid injection and rotary kiln have been proven to destruct hazardous waste and to be commercially available; fluidized-bed and multiple-hearth are less frequently used technologies. However, fluidized-bed incinerators may have greater potential because of their compact design, which results in relatively low capital cost, and their general applicability to solids, liquids, gases, and wastes containing inorganics.[111]

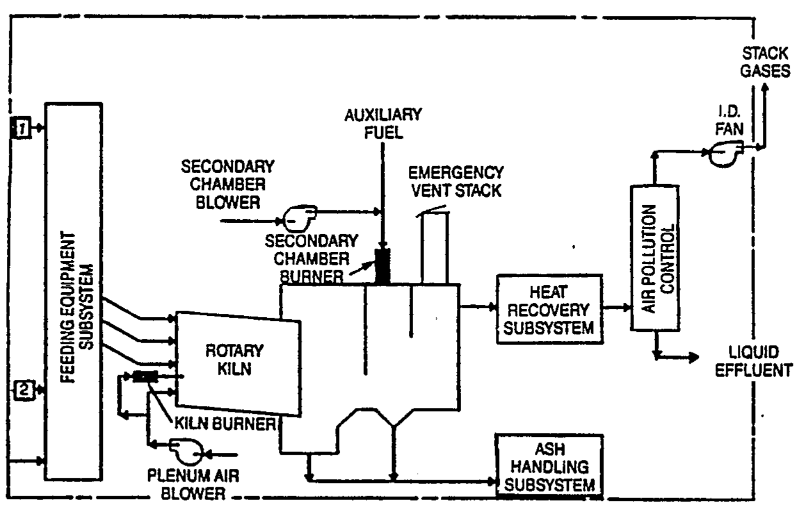
Air emission standards of performance for incinerators burning hazardous waste have been established by EPA.[112] Existing standards require that each incinerator (1) achieve a destruction and removal



Fluidized-Bed Incinerator



Liquid Injection Incinerator



Rotary Kiln Incinerator

Figure 4-13. Hazardous waste incinerators.

efficiency (DRE) of 99.99 percent for each principal organic hazardous constituent (POHC) designated for each waste stream; (2) have hydrogen chloride (HCl) emissions not to exceed the larger of 1.8 kg/h (4 lb/h) or 1 percent of the HCl in the incinerator exhaust gas upstream of any emission control device; and (3) have total particulate matter emissions not to exceed 0.18 grams per dry standard cubic meter (0.08 grains/dscf). Additional standards are being developed by EPA to improve the control of toxic metals, HCl, carbon monoxide, and residual organics.

To meet Federal and State standards, complex air pollution control systems are installed on hazardous waste incinerators. These control systems include the use of wet or dry scrubbers in conjunction with fabric filter or electrostatic precipitator control devices. Control system operation results in the production of solid wastes and, if a wet scrubber is used, wastewater effluents. Additional solid waste is produced by the incombustible material or ash that is removed from the incinerator and must be disposed as a hazardous material.

4.5 PROCESS MODIFICATIONS

4.5.1 Petroleum Refinery Waste Coking

Delayed coking is a process used in some petroleum refineries to recover useful products from the heavy ends of the raw petroleum. In this process, the feed stream enters a fractionator where gas oil, gasoline, and lighter fractions are flashed off and recovered. The fractionator bottoms are combined with a recycle stream and heated to reaction temperatures of 480 to 580 °C in the coker heater. The vapor-liquid mixture from the heater then enters the coke drum, where the primary coking reaction takes place. The coke drum provides the proper residence time, pressure, and temperature for coking. In the coke drum, the vapor portion of the feed undergoes further cracking as it passes through the drum, and the liquid portion undergoes successive cracking and polymerization until it is converted to vapor and coke.[113] Coking units consist of at least two coke drums so that one can remain online while coke is removed from the other.

In removal of coke from the drum, steam is first injected into the drum to remove hydrocarbon vapors, which are cooled to form a steam-hydrocarbon mixture. This is followed by water injection to cool the coke and allow removal. When the coke is cooled sufficiently, a high-pressure water jet is used to cut the coke into pieces that are then removed from the coke drum.

Coking is an alternative to the land treatment or landfilling of petroleum refinery hazardous wastes according to the requirements specified in the Federal Register.[114] Coke produced from petroleum refinery hazardous wastes is exempt from regulation as a hazardous waste, if the waste is coked at the facility where the waste is generated. In addition, the coke cannot exhibit any of the characteristics of a hazardous waste.

Refinery sludges can be introduced to a delayed coking operation in one of two ways. In one process, sludge is injected into the coker during the cool-down period. In that process, the water content of the sludge contributes to cooling the coke while organics are cracked into products or polymerized into coke. Sludge solids are immobilized inside the coke.[115] This process currently is used at several refineries. In the second process, sludge is introduced into the coker as a part of the feed stream by injecting it into the blowdown system where it is vaporized and recycled. In that process, the amount of sludge that can be added to the feed stream must not exceed some small percentage of the total feed, and the sludge must undergo extensive dewatering prior to entering the coking operation.[116] Only one refinery is known to use this operation.

No emission measurement data were found for coking operations; however, because the entire operation is enclosed, organic air emissions are estimated to be quite low. Some emissions would be expected from transfer, storage, and handling operations associated with coking. Most of these would be expected to come from the transportation of sludge from the point of generation to the coking operation and from storage of sludge at the coker. Although no definitive data are available to permit estimates of the emission reduction that would be achieved by processing refinery sludges through a coker rather than land treating, reductions approaching 100 percent are expected. Increased emissions from the coking operation as a result of introducing wastes into the feed stream are estimated to be negligible.

Coking is a possible control option at refineries that produce fuel-grade coke. At refineries that produce high-quality, electrode-grade coke, the quality degradation caused by sludge injection may be unacceptable. For refineries that do not have an existing coking operation, coking would not be a practical emission control alternative.

Application of coking for TSDF organic air emission control essentially involves using refinery sludges as additional feed materials for an existing refinery process unit. Existing petroleum coking units are operated to improve overall refinery product yield and economics. Therefore, no cross-media or secondary impacts are attributed to the organic air emission reduction achieved by coking of petroleum refinery wastes.

4.5.2 Submerged Loading

Organic air emissions generated during TSDF waste loading operations are the primary source of evaporative emissions from waste containers (e.g., tank trucks and drums). Emissions occur when liquid or semiliquid wastes are poured into a container displacing--from inside the container to the ambient air--an equal volume of air that is saturated or nearly saturated with organics. The quantity of organics emitted is a function of the loading method and whether the container is clean before loading.

For splash loading, the influent pipe dispensing the waste is lowered only partially into the container. Consequently, the waste flows from the end of the pipe that is above the liquid level in the tank or drum. Significant turbulence and vapor-liquid contact occur when the falling liquid splashes on the surface of the liquid already in the container. This results in organic vapor generation and emission to the atmosphere through the container opening used for waste loading. Control of loading air emissions can be accomplished by using submerged loading. During submerged loading, the influent pipe opening is located below the liquid surface level. This position decreases turbulence and evaporation, and eliminates liquid entrainment.

The quantity of organic air emissions is also affected by the condition of the container prior to loading. If a clean container is used, only the vapors generated by the loading operation are emitted. However, if the container contains residue vapors from a previous wasteload, then additional emissions will be released when the container is filled.

No emission source test studies of TSDF container loading have been conducted. To estimate the effectiveness of submerged loading in suppressing organic air emissions, an emission model derived for estimating emissions from loading petroleum liquids into trucks, tank cars, and marine vessels was used. A complete description of the emission model, as well as the analysis, are presented in Appendix H, Section H.1.3. Use of submerged loading is estimated to reduce organic air emissions from TSDF waste loading operations by 65 percent.

Submerged loading of open area sources, such as surface impoundments or open-top tanks, is not considered a control technique unless it is used in conjunction with covers or enclosures over the source. If the loading is changed from above to below the liquid surface in the absence of covers or enclosures, organics that would have been emitted during filling are instead emitted quickly from the open liquid surface by wind blowing across the source. However, if the open-top tank is covered or if the impoundment is enclosed, then emissions may be generated from the displacement of vapor by liquid. In this case, submerged loading may reduce emissions as described above for containers, and would provide additional control of organic air emissions.

There are no cross-media or secondary environmental impacts associated with submerged loading.

4.5.3 Subsurface Injection

Subsurface injection is a land treatment practice in which waste is injected directly into the soil. The process could be used to apply wastes to a land treatment site in lieu of surface application. In subsurface injection, as opposed to surface application, there is no pooling of liquid on the soil surface and thus potentially less opportunity for the material to be emitted to the atmosphere. However, in a field study to evaluate the relative air emissions from land treatment plots using surface application and subsurface injection, no difference in emissions was evident.[117] Therefore, subsurface injection is not currently being considered for air emission control.

4.5.4 Waste Fixation Mechanical Mixing

As a result of the RCRA land disposal restrictions, many liquid, slurry, and sludge types of hazardous wastes are now treated at TSDF using a waste fixation process so that the waste can be disposed in a hazardous waste landfill. Waste fixation, also referred to as waste solidification or stabilization, is a chemical process in which the free water in the waste reacts with a binder (i.e., cement) to form a solid material that immobilizes specific metal and organic contaminants in the waste for which treatment standards have been set.

Waste fixation involves first mixing the waste with the binder material. The binder can be either an inorganic or organic material. The prevalent TSDF industry practice is to use the least expensive binder material locally available (usually cement kiln or lime kiln dust). Typically, the waste and binder are mixed together in proportions to produce a moist, soil-like material. Following mixing, the mixture is cured by holding the mixture for a sufficient period of time (usually 24 to 48 h to allow the mixture to harden. The waste is then tested, and if it meets the appropriate treatment standards, the waste is transferred to a landfill. More information about TSDF waste fixation practices is presented in References 118 and 119.

Organic emissions from waste fixation occur when organics in the waste volatilize and are released to the atmosphere during mixing and curing. Results from a laboratory study of waste fixation suggest that the majority of organic emissions occur during the mixing of the waste and the binder.[120] For this study, organic emissions were measured for bench-scale simulations of waste fixation processes. Approximately 60 to 90 percent of the volatile organics in the waste were emitted during mixing of the waste and binder. The percentage varied depending on the type of binder used. The bulk of the remainder of the volatile organics was emitted during the curing step.

The simplest mixing procedure used at TSDF involves placing the waste into an open-pit or open-top tank, dumping the binder into the waste, and mixing the materials using heavy construction equipment such as a backhoe. A similar procedure is used, but on a smaller scale, for fixating waste directly in a drum. For this operation, a worker manually adds the fixative into the open-top drum containing the waste and mixes the materials with a small auger or blender. At some TSDF, open mixing of the waste and fixative has been replaced by enclosed mechanical mixing devices such as a pug mill and a ribbon blender.

Observation of waste fixation operations at sites throughout the United States indicates that mechanical mixers effectively control air emissions from the mixing of the waste and binder.[121-126] The mixer enclosure can be vented directly to an add-on control device. Controlling organic emissions is demonstrated by the use of carbon adsorption systems in combination with particulate controls on pug mills at two waste fixation facilities.[127,128] These controls have been installed to meet State or local air emission regulations.

4.6 WORK PRACTICE MODIFICATION

4.6.1 Housekeeping in Drum Storage Areas

Drum storage is the temporary holding of liquid, semisolid, or solid wastes until treatment and/or disposal can be undertaken. Drums can be stored on concrete pads that have a perimeter curb and gutter for secondary containment. Secondary containment is required at any drum storage area (40 CFR 264.175), and spilled or leaked waste and accumulated precipitation must be removed from the sump or collection area in as timely a manner as necessary to prevent overflow of the collection system.

Typically, drums are sealed and in good condition during storage; therefore, the potential for breathing emissions is assumed to be negligible. However, drums may rupture and leak hazardous wastes during storage or transfer. Management and technical practices not only cause spillage, they also determine what fraction is available for volatilization. Because RCRA requires that container storage areas be inspected weekly for container leaks and deterioration (40 CFR 264.174), a 50-percent loss of the volatiles to the atmosphere from the spilled waste was selected for emission estimating purposes; the remaining 50 percent are recovered as a result of implementing RCRA spill response actions.

Two control options are considered appropriate for reducing emissions from drum storage: one option is to vent the existing enclosed drum storage areas through a fixed-bed carbon adsorption system (see Section 4.2.2 for more detail). The other control option is to use an open secondary containment area, conduct daily inspections and maintenance, and have a policy to clean up spills within 24 hours of discovery. This option is an adaptation of the proposed 1986 RCRA tank regulations (40 CFR 264.196). Leak detection of stored drums is accomplished by visual inspection on a daily basis. In case of a spill or leak, sorbent material is used to clean up the spillage, or the spillage is collected in a collection sump for transfer to a drum for treatment or disposal. This policy of daily inspection with cleanup within 24 hours decreases the fraction of volatiles lost to the atmosphere. The magnitude of the reduction will depend on operating practices, waste type, and volatiles concentration; however, no data are available that quantify the emission reduction achieved by this method. Because it is estimated that these housekeeping practices are already used at most TSDF, no credit for an emission reduction was included in the estimates of nationwide emissions.

4.6.2 Leak Detection and Repair

Waste transfer operations often involve pumping waste through pipelines into a variety of waste management process units. This pumping creates the potential for equipment leak (fugitive) emissions from pump seals, valves, pressure-relief valves, sampling connections, and open-ended lines and flanges. Leaks from these types of equipment are generally random occurrences that are independent of temperature, pressure, and other process variables. However, these leaks do show a correlation with the vapor pressure of the material in the line. For example, monthly inspection data from the synthetic organic chemicals manufacturing industries (SOCMI) show that 8.8 percent of the seals on pumps handling light liquids have leaks and only 2.1 percent of the seals on pumps handling heavy liquids have leaks.[129] Light liquids are defined as those containing at least 20 percent by weight of organic compounds having a vapor pressure greater than 10 mm Hg.

An effective method for controlling fugitive emissions is to implement a routine leak detection and repair program (i.e., periodic inspection and maintenance). Leaks can be detected by individual component surveys, which may be carried out independently or may be a part of activities such as area (walkthrough) surveys, fixed-point monitoring, and visual inspection. Leaks can be repaired by adjusting the tightness of parts in pumps, valves, pressure-relief valves, closed-loop sampling, and capping or plugging open-ended lines or by replacing faulty devices. The use of portable organic vapor detection instruments during individual component surveys is considered to be the best method for identifying leaks of organics from valves and pump seals;[130] use of such instruments constitutes the only type of leak detection method for which a control efficiency has been quantified.

The control efficiency of individual component surveys depends on: (1) action level or leak definition, (2) monitoring interval or frequency, (3) achievable emission reduction of maintenance, and (4) interval between detection and repair of the leak. Background information developed by EPA to support standards for SOCMI fugitive emissions indicates that a monthly inspection and repair program of systems handling light liquid reduces fugitive emissions from pumps by 61 percent and from valves by 46 percent.[131] The study also shows that closed-loop sampling and capping open-ended lines provide 100 percent control of these emission sources. Considering the similarity between SOCMI sources and TSDF sources, these practices are expected to give equivalent reductions at TSDF. Nationwide emission reductions were estimated based on the above emission reductions along with the estimated relative numbers of pumps, valves, sampling connections, and open-ended lines in the waste management system. Combined, these control techniques provide weighted control efficiencies of 70 percent for systems handling light liquids and 78 percent for systems handling heavy liquids.

4.7 SUMMARY OF CONTROL TECHNOLOGIES SELECTED FOR CONTROL OPTION ANALYSES

A control option is a combination of control technologies applied to TSDF emission source categories to reduce nationwide TSDF organic air emissions. The selection of control options and estimates of the nationwide organic air emission, health risk, environmental, and cost impacts of options are discussed beginning in Chapter 5.0.

Table 4-2 lists the types of control technologies that are selected in Chapter 5.0 for reducing organic air emissions from each TSDF emission source category. Table 4-3 shows the emission reduction efficiencies used in the nationwide impacts analysis for specific control options applied to specific emission sources.

TABLE 4-2. EMISSION CONTROL OPTIONS USED FOR SELECTING TSDF CONTROL OPTIONS[a]

Management process source category	Control options[b]		
	Suppression	Add-on	Process modification/work practices
Quiescent surface impoundment[c]	X		
Storage or treatment	X	X	
Disposal	No direct controls; pretreat to remove organics or incinerate wastes[d]		
Dumpster storage	X		
Quiescent (storage or treatment) tank			
Uncovered	X		
	X	X	
Covered		X	
Waste fixation			
Pit	X	X	X
Enclosed mechanical mixer		X	
Aerated/agitated surface impoundment (treatment)	X	X	
Aerated/agitated uncovered tank (treatment)	X	X	
Land treatment	No direct controls; pretreat to remove organics, incinerate, or coke wastes[e]		
Active landfill	X		
Closed landfill	X		
Wastepile	X		
Equipment leaks			
Pumps, valves, and pressure-relief valves			X

(continued)

TABLE 4-2 (continued)

Management process source category	Control options[b]		
	Suppression	Add-on	Process modification/work practices
Equipment leaks (con.)			
Sampling connections			X
Open-ended lines	X		
Drum storage with enclosure[f]		X	
Drum and tank truck loading			X
Spills			X
Organic compound removal devices		X	
All TSDF process/emission sources		X	

TSDF = Transfer, storage, and disposal facilities.

HW = Hazardous waste.

[a]The development of control strategies is discussed in Chapter 5.0.

[b]Emission control options are of four types; examples of each control type are given in Table 4-1. Specific control options evaluated in this study are identified in Table 4-3.

[c]Includes treatment impoundments that are dredged annually and that are thus exempt from land disposal restriction regulations.

[d]Disposal surface impoundments function via evaporation. Direct controls such as covers inhibit evaporation.

[e]Coking is a control option only at refineries that have an existing coking operation and that meet the conditions specified in a November 1985 Federal Register notice.[132]

[f]Drums and containers are stored in a building that can be vented to a control device.

TABLE 4-3. EMISSION CONTROL EFFICIENCIES USED IN ESTIMATING NATIONWIDE IMPACTS OF CONTROL OPTIONS

Management process source category	Control device	Waste form[b]	Effect on organic emissions,[a] %			
			Capture[c]	Suppression	Removal	Control
Quiescent surface impoundment[d]	Floating synthetic membrane	All	--	85	--	--
Storage or treatment	Air-supported structure vented to fixed-bed carbon adsorber[e]	All	100	95	--	--
Dumpster storage	Dumpster cover	All	--	99	--	--
Quiescent (storage or treatment) tank						
Uncovered	Fixed roof[f]	All	--	86.4-99.2	--	--
	Fixed roof with internal floating roof[f]	All	--	96.5-99.9	--	--
	Fixed roof vented to carbon canister[g] or existing combustion device	All	100	86.4-99.2	--	95
	Fixed roof vented to fixed-bed carbon adsorber[g]	All	100	99.3-99.96	--	--
Covered	Internal floating roof[f]	3,5,7	--	74-82	--	--
	Fixed-roof tank vented to carbon canister[g] or existing combustion device	All	--	--	--	95
	Fixed-roof tank vented to fixed-bed carbon adsorber[g]	All	100	95	--	--
Waste fixation						
Pit	Fixation with enclosed mechanical mixer with control device	All	100	--	--	95
Enclosed mechanical mixer	Fixation with enclosed mechanical mixer with control device	All	100	--	--	95
Aerated/agitated surface impoundment (treatment)	Air-supported structure vented to fixed-bed carbon adsorber[h]	All	100	95	--	--
Aerated/agitated uncovered tank (treatment)	Fixed roof vented to fixed-bed carbon adsorber	All	100	95	--	--
Land treatment	Waste coking	2	--	--	--	100
Closed landfill	30-mil HDPE cover	1	--	0	--	--
		2,3	--	99.7	--	--
		4,5,7	--	49.3	--	--

See notes at end of table.

(continued)

TABLE 4-3 (continued)

Management process source category	Control device	Waste form[b]	Effect on organic emissions,[a] %: Capture[c]	Suppression	Removal	Control
Wastepile	100-mil HDPE cover	1	--	0	--	--
		2,3	--	99.9	--	--
		4,5,7	--	84.8	--	--
	30-mil HDPE cover	1	--	0	--	--
Sampling connections		2,3	--	99.7	--	--
		4,5,7	--	49.3	--	--
Equipment leaks		Light liquid				
Pumps, valves, and		Heavy liquid				
pressure-relief valves	Leak detection and repair		--	70	--	--
			--	78	--	--
Sampling connections	Closed-loop sampling					
Open-ended lines	Caps or plugs					
Drum storage with enclosure[i]	Carbon adsorber	--	--	--	--	95
Drum and tank truck loading	Submerged loading	All	--	65	--	--
Spills	Housekeeping	All	--	60	--	--
Organic compound removal devices	Existing control device[j]	--	--	--	--	95
	Catalytic incinerator	--	--	--	--	98
	Condenser	--	--	--	--	98.4-99.99[k]
	Thermal incinerator	--	--	--	--	98
	Carbon adsorber	--	--	--	--	95

HDPE = High-density polyethylene.
TSDF = Transfer, storage, and disposal facilities.
HW = Hazardous waste.
-- = Not applicable.

[a]A control device may affect emissions in any of four ways. It may capture (or contain) emissions and pass them to an emission control device; it may suppress emissions by containing them or reducing the rate at which they leave the source; it may remove organics from the waste stream before the stream enters other waste management processes; or it may control emissions by destroying the organics or removing organics from a vent stream.

(continued)

TABLE 4-3 (continued)

[b]Waste form identification:
1 Organic-containing solid
2 Aqueous sludge/slurry
3 Dilute aqueous waste
4 Organic liquid
5 Organic sludge/slurry
6 Miscellaneous
7 Two-phase aqueous/organic.

[c]Capture efficiencies are based on application of the controls to the emission sources identified in Table 4-2.

[d]Includes treatment impoundments that are dredged annually and that are thus exempt from land disposal restriction regulations.

[e]Desorbed material is returned to impoundment.

[e]Efficiencies vary by compound volatility.

[f]The efficiency of a fixed-roof tank in suppressing emissions relative to an open tank varies depending on the characteristics of the waste and the operating parameters of the tank.

[g]A fixed roof applied to an open tank suppresses emissions by 86.4 to 99.2 percent. If the fixed roof is vented to a control device, the remaining emissions are reduced by 95 percent to give an overall emission reduction of 99.3 to 99.96 percent. If the control device is a fixed-bed carbon adsorber, desorbed material is returned to the tank so that the total emission reduction is by suppression. If the control device is a carbon canister or existing combustion device, the overall emission reduction consists of 86.4 to 99.2 percent suppression and 95 percent control.

[h]Desorbed material is returned to impoundment.

[i]Drums and containers are stored in a building that can be vented to a control device.

[j]An existing control device is defined as one of the add-on controls described in this chapter to which the source may be vented.

[k]Efficiencies vary by compound volatility.

Although the control types listed in Table 4-3 for the source category are typically applicable to the source category, there may be site-specific conditions that inhibit or prevent the use of a particular control type at a particular facility. Where there are several choices of control type with equivalent levels of performance for a specific source category, presumably the facility operator would choose the lowest cost type to apply. In some cases, there are significant differences in the costs of control for similar performance levels, but factors such as waste incompatibility or source size may prevent use of the least costly control. For this reason, "generic control devices" have been defined for tanks and waste fixation source categories for use in estimating nationwide emission reductions and control costs.

Table 4-4 defines the generic control devices used for the nationwide impacts estimates. Selection of the percentage weightings for each generic control device was made on the basis of engineering judgment, taking into account the application limitations of the different control technologies, relative costs, and information about current industry practice.

Venting a tank to an existing, on-site control device is generally less expensive than using an internal floating roof or venting to a carbon adsorber. However, not all TSDF have an existing control device suitable to receive the tank vent stream. Depending on number of tank turnovers and organic content of the waste, an internal floating roof will be less expensive than venting to a carbon adsorber. However, some wastes are not compatible with roof seal materials, so the internal floating roof is not always applicable either. With a low number of tank turnovers and low concentrations of low-volatility organics, carbon adsorbers can be cost-competitive with internal floating roofs (details of estimated emission reductions and control costs for the tank model units storing or treating model wastes are presented in Appendixes C and H). The percentage weightings presented in Table 4-4 for tank generic control devices were selected after considering the above factors.

The selection of the percentage weightings for waste fixation is based on TSDF site visits and contacts with TSDF operators. This information indicates that open pit fixation is the most frequently used waste fixation

TABLE 4-4. GENERIC CONTROL DEVICE DEFINITIONS[a]

Management process source category	Percentage weighting	Control technology
Quiescent (storage or treatment) tank		
Uncovered	50	Fixed roof plus internal floating roof
	25	Fixed roof plus venting to carbon canister or fixed-bed carbon adsorber
	25	Fixed roof plus venting to existing control device
Covered	50	Internal floating roof
	25	Vent to carbon canister or fixed-bed carbon adsorber
	25	Vent to existing control device
Waste fixation	70	Replace pit with mechanical mixer vented to fixed-bed carbon adsorber
	30	Vent existing mechanical mixer to fixed-bed carbon adsorber

[a]This table defines the combinations of control technology types used to estimate nationwide emission reductions and control costs for the listed source category.

[b]Percentage weightings show the percentages of each control option emission reduction and cost used to define overall emission reductions and costs for the particular combination of source category and control type.

process. Consequently, it is estimated that 70 percent of existing TSDF waste fixation operations will need to be converted to mechanical mixing-type operations before add-on controls can be applied.

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5.0 CONTROL OPTIONS

The purpose of this chapter is to describe control options considered in the selection of a basis for air emission standards to be proposed for treatment, storage, and disposal facilities (TSDF) under Section 3004(n) of the Resource, Conservation, and Recovery Act (RCRA) as amended. In addition, this chapter describes the "baseline" against which the nationwide impacts of control options were measured.

Five specific control options are described. These options are based on the use of add-on emission controls applied to individual emission sources. The estimated human health and environmental impacts of these five options are presented in Chapter 6.0. Cost impacts are presented in Chapter 7.0, and economic impacts are presented in Chapter 8.0. The option selected as the basis for the proposed standards, and the factors leading to the selection of that option, are discussed in the preamble to the proposed standards published in the Federal Register.

5.1 CONTROL OPTION CONCEPT

As discussed in Chapters 3.0 and 4.0, there are a variety of sources of organic emissions at TSDF and several types of emission controls that can be applied to many of these sources. The term "control option," as used here, refers to a unique combination of emission sources, emission controls, and action levels for applying the controls. Different options are developed and evaluated to estimate the impacts of potential regulations. It is important to recognize, however, that although a control option identifies specific emission controls to be applied to TSDF sources, a regulation written to implement the option may be in terms of performance standards that allow equivalent, or more effective, controls for compliance. The emission sources, controls, and action levels considered in developing control options, the selection of control options for detailed evaluation, and the impacts to be estimated for each option are discussed in the following sections.

5.2 EMISSION SOURCES, CONTROLS, AND ACTION LEVELS CONSIDERED IN DEVELOPING CONTROL OPTIONS

5.2.1 Emission Sources

TDSF emission source categories are shown in Table 5-1. Hazardous waste management processes with similar emission characteristics and potential emission controls are grouped together (e.g., storage and treatment quiescent tanks are combined into one source category). Landfills, wastepiles, and land treatment are shown grouped together under the category of "Land Disposal Units." This is because hazardous wastes entering these types of waste management units are regulated by the land disposal restrictions (LDR), which require treatment of a waste with best demonstrated available technology (BDAT) before it is placed in one of these units. It is presumed that this treatment will decrease the organic air emission potential of landfills, wastepiles, and land treatment, and therefore additional air emission controls for these sources were not considered in developing regulatory options. This presumption will be reviewed after all requirements under the LDR program are promulgated. Similarly, control of organic air emissions from ancillary equipment (pumps, valves, flanges, etc.) and certain process vents at TSDF is required by a separate rulemaking under RCRA Section 3004(n) proposed on February 5, 1987 (52 FR 3748), and therefore additional controls for these sources were not considered. More information on the LDR and the standards for emissions from equipment leaks and process vents is presented in Section 5.4.2.

Surface impoundments are also covered by the LDR, but are exempt from LDR requirements under certain conditions. Those impoundments not covered by the LDR would continue to have significant potential air emissions and, therefore, additional controls for surface impoundments are being considered under RCRA Section 3004(n).

5.2.2 Controls

As described in Chapter 4.0, there are a variety of control techniques available to reduce organic air emissions from TSDF. These include the

TABLE 5-1. TSDF EMISSION SOURCE CATEGORIES

Source category
Quiescent tanks (storage or treatment)
Quiescent impoundments (storage or treatment)
Non-quiescent tanks
Non-quiescent impoundments
Containers[a]
Waste fixation units
Ancillary equipment (pumps, valves, flanges, etc.)[b]
Spills[c]
Hazardous waste incineration[d]
Land disposal units: Landfills, wastepiles, and land treatment[e]

TSDF = Treatment, storage, and disposal facilities.

[a]Includes loading and storage. Containers are any portable device in which a material is stored, transported, treated, disposed, or otherwise handled.

[b]Separate standards for equipment leaks were proposed February 5, 1987 (52 FR 3748).

[c]Spills are regulated by 40 CFR Part 264, Subparts D and J, and by Part 265, Subparts D and J.

[d]Air emissions from hazardous waste incinerators are regulated by 40 CFR Part 264, Subpart O.

[e]All hazardous wastes placed in these sources must meet pretreatment requirements of the land disposal restrictions.

addition of engineering controls, such as covers and add-on control devices, and the use of waste treatment processes to remove organics directly from hazardous waste, thus reducing its air emission potential prior to placement in a waste management unit.

In selecting controls to serve as the bases of regulatory options, EPA considered how the standards being developed for air emissions would fit into the broad framework of regulations that affect the management of hazardous waste at TSDF. Regulations are currently in place, or are being developed, that are directed at hazardous waste disposal. These include the LDR, standards for equipment leaks and process vents from treatment processes, and standards for hazardous waste incinerators. In addition, RCRA-exempt wastewater treatment units are being addressed under the Clean Air Act. All of these regulations are designed to act together to protect public health and the environment from exposure to pollutants via both ground water and air from waste disposal units.

Considering that all hazardous waste must ultimately be disposed and that the LDR ensure that air emissions generated by hazardous waste disposal practices will be controlled, EPA has adopted a regulatory philosophy of emission containment for TSDF sources that manage waste prior to waste disposal. Under this philosophy, the focus is on applying controls that reduce the volatilization of organics from hazardous waste prior to disposal, where organics will either be destroyed or removed from the waste by treatment processes that are controlled for air emissions.

Consistent with the objective of containing potential organic emissions from hazardous waste prior to its disposal, the regulatory options selected for detailed evaluation as possible bases for standards involve primarily the use of suppression (covers) or suppression plus add-on control devices. However, this will not necessarily preclude the use of other, equally or more effective controls to meet the requirements of the proposed regulation. For example, each of the options under consideration consists of a combination of controls applied to TSDF emission sources plus an action level above which the controls must be applied. By incorporating an action level, each option would implicitly allow an owner or operator to use a waste treatment process to reduce the organic content of the waste managed to below the action level, in which case additional controls would not be required by the air standards.

5.2.3 Action Levels

To apply emission controls to waste management processes with regard to the emission potential of the wastes managed, the regulatory control options developed for TSDF air emission standards include an "action level" above which controls must be applied. Action levels can be used as a mechanism for prioritizing emission sources within a waste management facility for control and for excluding sources that have lower emission potential. Action levels can be expressed in several formats (e.g., in terms of volume throughput, capacity, or measured or calculated emissions). An action level based on waste volatile organic concentration (as measured by an appropriate test method) is appropriate for TSDF sources such as open tanks, surface impoundments, containers, and waste fixation, where hazardous waste can be exposed directly to the ambient air, sunlight, and wind. For completely enclosed sources, such as covered quiescent tanks, a more appropriate indicator of emissions, and thus a more appropriate format for an action level, is the vapor pressure of the waste.

In developing control options for TSDF air emission standards, EPA incorporated two types of action levels. For all sources except covered quiescent tanks, the action level associated with the option is based on the volatile organic content of the waste at the point of generation. For covered quiescent tanks, the action level above which additional controls (e.g., vent to control device) would be required is based on the vapor pressure of the waste contained in the tank.

5.3 SELECTION OF CONTROL OPTIONS

Five control options were selected for detailed evaluation that illustrate the various combinations of action levels and controls that could be applied to TSDF emission sources. All of the options selected would be expected to result in significant reductions in organic emissions, and associated human health and environmental impacts. They are also used in later chapters to illustrate how the impacts of TSDF control options are estimated. These five options are described in Table 5-2.

TABLE 5-2. TSDF AIR EMISSION CONTROL OPTIONS[a]

Source category	Option 1 (applied when VO > 0 ppm)	Option 2 (applied when VO > 500 ppm)[b]	Option 3 (applied when VO > 500 ppm)	Option 4 (applied when VO > 1,500 ppm)	Option 5 (applied when VO > 3,000 ppm
Quiescent tanks (storage or treatment)	Cover, vent to control[c]	Cover, vent to control[c]	Cover	Cover, vent to control[c]	Cover, vent to control[c]
Quiescent impoundments (storage or treatment)	Cover, vent to control	Cover, vent to control	Cover	Cover, vent to control	Cover, vent to control
Non-quiescent tanks	Cover, vent to control	Cover, vent to control	Cover, vent to control	Cover, vent to control	Cover, vent to control
Non-quiescent impoundments	Cover, vent to control	Cover, vent to control	Cover, vent to control	Cover, vent to control	Cover, vent to control
Containers	Cover/submerged loading[d]	Cover/submerged loading[d]	Cover/submerged loading[d]	Cover/submerged loading[d]	Cover/submerged loading[d]
Waste fixation	Cover, vent to control	Cover, vent to control	Cover, vent to control	Cover, vent to control	Cover, vent to control
Other sources					
Ancillary equipment[e]	--	--	--	--	--
Spills[f]	--	--	--	--	--
Incineration[g]	--	--	--	--	--
Land disposal units[h]	--	--	--	--	--

TSDF = Treatment, storage, and disposal facility.
VO = Volatile organics.
-- = Not applicable.

[a]The strategies presented in this table are for use in illustrating how impacts associated with controls are calculated in later chapters. They will not necessarily be the basis for developing standards for proposal.

[b]Action level is based on volatile organic content of waste entering the facility as measured by a test method, except as noted for covered quiescent tanks. If volatile organic content of waste is above action level, then controls are required for all sources as shown.

[c]Quiescent tanks must be covered when volatile organic content of waste is above 500 ppm. Emissions from covered tanks must be vented to a control device when the waste in the tank has a true vapor pressure equal to or greater than 1.5 psia.

[d]Submerged fill required for drum and terminal loading; covers required for dumpsters.

[e]Required by TSDF air standards for equipment leaks and process vents.

[f]This source currently is regulated under 40 CFR 264 and 265, Subparts D and J.

[g]This source currently is regulated under 40 CFR 264 and 265, Subpart O.

[h]Landfills, wastepiles, and land treatment.

Options 1, 2, 4, and 5 are distinguished from one another by the number of sources requiring control; the number of sources requiring control is determined by the volatile organic concentration action level. In control option 1, the concentration action level is 0; that is, controls would be required on all waste streams containing detectable amounts of volatile organics. For control options 2, 4, and 5, the concentration action levels are 500 ppm, 1,500 ppm, and 3,000 ppm, respectively. Unless it is demonstrated that the waste being handled is below the volatile organic concentration action level, all of the following controls would be required: (1) covers or enclosures and submerged loading techniques would be required to control emissions from container loading operations and for dumpsters, (2) covers and control devices would be required for surface impoundments, and (3) covers and control devices would be required for tanks unless the tank is non-aerated and it is demonstrated that the vapor pressure of the waste in the tank is below the vapor pressure action level. In this case, covers alone would be required. If an owner or operator wishes to demonstrate that the vapor pressure of a waste stream is below the vapor pressure action level, he would have to perform a vapor pressure test using an appropriate test method.

The types of covers that could be used on tanks to meet the standards include fixed roofs, internal floating roofs, and external floating roofs. Covers that could be used for surface impoundments include air-supported structures. Control devices that could be used include carbon adsorption units, vapor incinerators, and flares.

Control option 3 has an action level of 500 ppm, the same as option 2, but differs from the other options in that covers alone may be used on non-aerated tanks and surface impoundments without the need for a vapor pressure test. The controls specified for this option are the same as described above for all sources except non-aerated surface impoundments and non-aerated tanks. Under this option, non-aerated surface impoundments could use floating synthetic membranes as a means of complying with the proposed standard.

The nationwide impacts that will be estimated for control options selected for detailed evaluation and the baseline to which the impacts of options will be compared are discussed below.

5.4 BASELINE FOR NATIONWIDE IMPACTS ESTIMATES

The baseline provides a perspective from which the impacts of adopting control options can be evaluated. Chapter 3.0 of this document presents nationwide uncontrolled TSDF organic emissions; i.e., emissions with current existing controls and before the adoption of additional nationwide control requirements. However, there are regulations that affect TSDF air emissions that are, or will be, in place when the RCRA 3004(n) standards being developed in this rulemaking are promulgated. The baseline against which the potential impacts of the 3004(n) standards are measured should reflect these other regulatory requirements if they affect TSDF nationwide.

Federal regulatory requirements that affect TSDF nationwide include the land disposal restrictions (proposed and promulgated under RCRA Section 3004(m)) and TSDF air standards for process vents and fugitive emissions (proposed February 5, 1987, under RCRA Section 3004(n)). There are other Federal requirements applicable to TSDF, such as the RCRA Corrective Action Program (implemented under RCRA Section 3004(u)), but these are site-specific rather than nationwide control requirements.

Also, there are standards that apply to TSDF emission sources at the State level. However, these are limited and vary widely from State to State. A survey of State programs indicated that 12 States have established generic volatile organic compounds (VOC) standards that might affect TSDF emission sources. Thirty States have standards applicable to storage tanks, 17 States have standards for terminal loading, and 9 States have standards for hazardous waste landfills. For those States that do have standards, there are differences in how VOC is defined, making it difficult to compare requirements from State to State.

After the review of Federal and State standards applicable to TSDF, it was concluded that the baseline for the RCRA Section 3004(n) standards under development should reflect the impacts of the LDR and the TSDF air standards for process vents and equipment leaks. Due to the limited applicability and lack of uniformity in State standards, they should not be included in the baseline.

More information on how the impacts of the LDR and the TSDF process vent and equipment leak standards will be simulated in the baseline is presented below.

5.4.1 Land Disposal Restrictions

The Hazardous and Solid Waste Amendments (HSWA) of 1984 mandate a number of actions that EPA must take to reduce the threat of hazardous waste to human health and the environment. These actions include restricting hazardous wastes from land disposal. The EPA is currently developing regulations (referred to as "land disposal restrictions") that will require that hazardous wastes be treated to reduce concentrations of specific chemicals or hazardous properties before the waste may be placed in a land disposal unit. The affected land disposal units include surface impoundments, wastepiles, landfills, and land treatment operations. Surface impoundments used for treatment of hazardous wastes are exempt from the LDR if treatment residues are removed annually. The waste treatment technologies required to reduce chemical concentrations before land disposal are referred to as best demonstrated available technologies (BDAT). The restrictions express BDAT as a performance standard that requires wastes to be treated before entering a land disposal unit (to reduce the waste's toxicity or mobility). The wastes must be treated to levels that can be achieved by use of the best technologies commercially available.

The EPA is developing the LDR in stages. Waste-specific prohibitions on land disposal have been promulgated for certain spent solvent wastes (40 CFR 268.30); dioxin-containing hazardous wastes (40 CFR 268.31); the "California list" wastes (40 CFR 268.32); the "First Third" set of listed wastes (40 CFR 268.33); the "Second Third" set of listed wastes (40 CFR 268.34); and, recently, the "Third Third" set of listed wastes (55 FR 22520, June 1, 1990). The TSDF air emission standards being developed in this current rulemaking would be promulgated after the date that LDR are in effect for all wastes identified or listed as hazardous as of November 8, 1984. Therefore, the LDR are considered a part of the baseline against which the potential impacts of the 3004(n) standards are measured.

The LDR for many listed wastes have only recently been finalized and many of the treatment standards are expressed as performance standards for certain constituents in the treatment residue rather than as specific technology requirements. Therefore, EPA is not certain at this time as to how the LDR will ultimately impact TSDF air emissions. For the nationwide impacts analysis, EPA first needed to forecast the approaches TSDF owners and operators would most likely choose to implement the LDR for specific wastes types. Using available information, EPA made certain assumptions regarding the general or average response of the hazardous waste management industry to compliance with the LDR. The following assumptions were developed concerning the manner in which TSDF will respond to the restrictions for purposes of estimating overall baseline impacts for the air standards:[1]

- All wastes currently land-treated (except organic-containing solids) will be incinerated. Solids will be fixated.
- All organic liquids and sludge/slurries that are currently sent to landfills and wastepiles will be incinerated or steam-stripped.
- All dilute aqueous liquids and aqueous sludge/slurries are fixated and landfilled.
- All surface impoundments will continue to operate as impoundments and be dredged annually or will be converted to uncovered tanks. In both cases, it is assumed that there will be no change in emission, emission reductions, or cost of control.
- All fixation processes will yield a solid waste product rather than a nonliquid such as sludge. This assumes an increase in the degree of fixation that will increase emissions from the treatment process.

The technology assumptions listed above may not be sufficient to comply with the LDR treatment standards for all TSDF. However, on a nationwide basis, it is likely that they represent the general or average response of the hazardous waste management industry. Therefore, it is a reasonable basis for the calculation of baseline emissions against which the nationwide impacts of potential air standards under RCRA Section 3004(n) are evaluated.

5.4.2 TSDF Air Standards for Equipment Leaks and Process Vent Control

To address concerns about air emissions from the treatment processes expected to be used to comply with the land disposal restrictions, EPA promulgated air emission standards under RCRA Section 3004(n) to reduce organic emissions vented from the treatment of hazardous wastes by distillation, fractionation, thin-film evaporation, solvent extraction, steam stripping, and air stripping, as well as from leaks in certain piping and equipment used for hazardous waste management processes (55 FR 25454, June 21, 1990). Sources of process vent emissions from treatment units include process condenser vents, and distillate receivers, surge control vessels, product separators, and hot wells, if process emissions are vented through these vessels. Equipment leak sources include pumps, valves, pressure-relief devices, compressors, open-ended lines, and sampling connections. These standards apply to hazardous wastes containing greater than 10 percent organics. Specific requirements include reduction of process vent emissions to less than 1.4 kg/h (3 lb/h) and 2.8 Mg/yr (3.1 tons/yr) or reduction of facility process vent emissions by 95 percent; and a leak detection and repair program for equipment leaks.

To simulate the impact of these standards on the baseline, all process vents and equipment leak emissions at facilities handling wastes containing greater than 10 percent organics are assumed to be controlled as part of the baseline.

5.4.3 New Source Performance Standards (NSPS) for Volatile Organic Storage Vessels

Under the authority of the Clean Air Act, EPA has promulgated standards of performance in 40 CFR Part 60 for storage vessels that contain volatile organic liquids (VOL), and that are constructed or modified after July 23, 1984. These standards require that tanks larger than 75 m^3 (about 20,000 gal) containing VOL be equipped with air pollution controls if the vapor pressure of the stored organic liquid is greater than the specified levels. The controls required by the standards are shown in Table 5-3.

The EPA views the controls required by the NSPS as minimum controls for any large tank containing organic hazardous waste, regardless of the date of construction of the tank. Accordingly, the NSPS control requirements for VOL storage vessels are included as minimum baseline control requirements for tanks in the standards proposed for hazardous waste TSDF under RCRA Section 3004(n). An exception to this is the NSPS requirement for any tank greater than 75 m^3 and containing an organic liquid with a vapor pressure greater than 76.6 kPa. This requirement is not included in

TABLE 5-3. CONTROL REQUIREMENTS UNDER THE CLEAN AIR ACT FOR VOLATILE ORGANIC LIQUID STORAGE VESSELS[a]

Tank size	Vapor pressure of stored liquid	Controls required
From 75 m^3 up to 151 m^3 (from 19,789 to 39,841 gal)	From 27.6 kPa to 76.6 kPa	One of the following: (1) Fixed roof plus internal floating roof; (2) External floating roof; (3) Closed vent system plus a control device; or (4) A system equivalent to those described in (1) - (3).
	Equal to or greater than 76.6 kPa	A closed vent system plus a control device.
Equal to or greater than 151 m^3 (greater than 39,841 gal)	From 5.2 up to 76.6 kPa	One of the following: (1) Fixed roof plus internal floating roof; (2) External floating roof; (3) Closed vent system plus a control device; or (4) A system equivalent to those described in (1) - (3).
	Equal to or greater than 76.6 kPa	A closed vent system plus a control device.

[a]Source: 40 CFR Part 60, Subpart Kb.

the proposed TSDF standards because EPA does not expect wastes managed at TSDF to have vapor pressures near or above this value.

The EPA believes that most existing tanks at TSDF are smaller than the sizes regulated by the NSPS for VOL storage vessels. Consequently, including the NSPS requirements for VOL storage in the proposed standards for TSDF under RCRA 3004(n) should have little or no additional impacts. However, making the NSPS control requirements part of the baseline for the TSDF standards would ensure that any existing large tanks used for the management of hazardous waste at TSDF are controlled at least as effectively as new tanks.

5.5 REFERENCE

1. Industrial Economics, Inc., and ICF Incorporated. Regulatory Analysis of Proposed Restrictions on Land Disposal of Hazardous Wastes. Prepared for U.S. Environmental Protection Agency. Washington, DC. December 27, 1985. p. 4-20 through 4-22 and exhibits.

6.0 NATIONAL ORGANIC EMISSIONS AND HEALTH RISK IMPACTS

The nationwide organic air emission and health risk impacts associated with each of the treatment, storage, and disposal facility (TSDF) control options identified in Chapter 5.0 are discussed in this chapter. The primary emphasis of Chapter 6.0 is to present the approach for assessing these impacts by using the control options as a guide for discussion and presentation. Both beneficial and adverse environmental impacts are assessed. Table 6-1 summarizes these nationwide impacts; presented are the nationwide estimates of TSDF organic emissions, cancer incidence, and maximum lifetime risk for the five control options as well as the uncontrolled and baseline scenarios. Comparisons to the baseline situation are also made to provide a relative measure of the effectiveness of or degree of control required under the five options. More detailed information on the emissions and health risks associated with implementation of the control options are provided in Sections 6.1 and 6.2. The nationwide emission reduction for each control option is tabulated in Section 6.1. Impacts on human health, assessed as cancer incidence and maximum lifetime risk of contracting cancer, are presented in Section 6.2. Impacts on water quality, solid waste, energy, and other environmental concerns are presented in Section 6.3.

6.1 ORGANIC EMISSION IMPACTS

This section presents the nationwide impacts on TSDF organic air emissions for five control options and includes a description of how emissions under the uncontrolled, baseline, and controlled scenarios were estimated. A tabular presentation of the estimated emission reductions from affected waste management units is also included. As discussed in Chapter 5.0, the baseline case assumes that Resource Conservation and Recovery Act (RCRA) land disposal restrictions and the 1987 proposed TSDF air emission

TABLE 6-1. SUMMARY OF NATIONWIDE ORGANIC AIR EMISSIONS AND HEALTH RISK IMPACTS FOR UNCONTROLLED, BASELINE, AND FIVE CONTROL OPTIONS[a]

Control case	Emissions, 10^3 Mg/yr[b]	Emission reduction from baseline, 10^3 Mg/yr	Percent reduction, %	Cancer incidence,[c] incidence/yr	Incidence reduction from baseline incidence/yr	Maximum lifetime risk, MLR
Uncontrolled	1,800	--	--	130	--	2×10^{-2}
Baseline	1,800	--	--	140	--	2×10^{-2}
Option 1[d]	92	1,700	95	5.9	130	5×10^{-4}
Option 2	98	1,700	95	6.4	130	5×10^{-4}
Option 3	130	1,670	93	8.4	130	5×10^{-4}
Option 4	140	1,660	92	14	130	8×10^{-4}
Option 5	180	1,620	90	16	120	9×10^{-4}

TSDF = Treatment, storage, and disposal facility.
-- = Not applicable.

[a]This table shows impacts from controlling the following TSDF source categories: quiescent tanks (storage or treatment), quiescent impoundments (storage or treatment), non-quiescent tanks, non-quiescent impoundments, containers, and waste fixation units.

[b]Refer to Table 6-2 for nationwide emissions by source.

[c]Refer to Table 6-3 for nationwide cancer incidence by source.

[d]Control options 1 through 5 apply to wastes containing organics at concentrations greater than the action level associated with the particular option. They entail covers and control devices for tanks (including waste fixation) and impoundments, submerged loading of drums, and covers for dumpsters. For covered storage and quiescent treatment tanks, venting to a control device is required if the vapor pressure of the waste in the tank exceeds 10.3 kPa (1.5 psi) for control options 1, 2, 4, and 5. No control devices are applied to covered storage and quiescent treatment tanks in control option 3.

standards (52 FR 3748) are in effect. Control options 1 through 5 represent the potential "controlled" cases. Data are presented for these seven scenarios to allow comparison of the impacts of the control options to current and to 1987 proposed standards on TSDF organic air emissions nationwide.

Chapter 3.0 of this document, "Industry Description and Air Emissions," provides nationwide estimates of uncontrolled emissions by TSDF management process. Nationwide emissions were computed using the computerized Source Assessment Model (SAM) by first identifying all process source categories listed in the Industry Profile (described in Appendix D.2.1). Once these categories were identified, their emissions were calculated by multiplying the organic quantity of each waste stream by an emission factor specific to the particular management process and the wastes being processed (see Appendix D, Section D.2.4.1). Emissions per process per TSDF then were summed to yield a nationwide uncontrolled emission estimate.

To calculate the quantity of emissions reduced by applying organic emission controls, the control technologies described in Chapter 4.0 were applied to the appropriate waste management processes (source category) as required by one of five control options. Control options 1-5 apply to wastes containing organics at concentrations greater than the action level associated with the option. They entail covers and control devices for tanks (including waste fixation) and impoundments, submerged loading of drums, and covers for dumpsters. For covered storage and quiescent treatment tanks, venting to a control device is required only if the vapor pressure of the waste in the tank exceeds 10.3 kPa (1.5 psi) for control options 1, 2, 4, and 5. No control devices are applied to covered storage and quiescent treatment tanks for control option 3.

The magnitude of nationwide organic emissions associated with each option was calculated using the SAM. In short, this consisted of adjusting the uncontrolled and baseline emissions by the control efficiency of the control technology required under each particular option, for each TSDF process stream at each facility nationwide. Summation of results provides an estimate of emissions per control option. Table 6-2 presents the nationwide results by emission source resulting from implementation of each

TABLE 6-2. NATIONWIDE TSDF EMISSIONS FOR THE UNCONTROLLED, BASELINE, AND AFTER CONTROL OPTIONS[a]

Source category	Uncontrolled emissions, 10^3 Mg/yr	Baseline emissions,[b] 10^3 Mg/yr	Emissions after control options,[c] 10^3 Mg/yr				
			1	2	3	4	5
Quiescent tanks (storage or treatment)	800	810	3.4	5.6	25	8.8	10
Quiescent impoundments (storage or treatment)	210	210	43	44	62	74	95
Non-quiescent tanks	440	440	23	23	23	25	31
Non-quiescent impoundments	74	74	4.4	4.5	4.5	7.5	12
Containers[d]	85	85	7.4	7.4	7.4	7.9	7.9
Waste fixation units	2.1	180	11	11	11	19	19
Subtotal[e]	1,600	1,800	92	96	130	140	180
Other sources							
Wastepiles[f]	0.13	0.03	0.03	0.03	0.03	0.03	0.03
Landfills[f]	40	2.1	3.8	3.8	3.7	3.4	3.4
Incineration[g]	0.88	1.1	1.1	1.1	1.1	1.1	1.1
Land treatment[h]	73	0	0	0	0	0	0
Spills[i]	0.43	0.42	0.43	0.43	0.43	0.43	0.43
Equipment leaks[j]	--	--	--	--	--	--	--
Subtotal[e]	110	3.7	5.4	5.4	5.3	5.0	5.0
TOTAL[e]	1,700	1,800	98	100	140	150	180

See notes at end of table.

(continued)

TABLE 6-2 (continued)

TSDF = Treatment, storage, and disposal facility.

[a]Estimated values for each source category should not be used or viewed independently because some control technologies may suppress emissions or reduce emissions that will impact sources downstream.

[b]With TSDF proposed air standards (for process vents and equipment leaks) and land disposal restrictions in place.

[c]Control options 1 through 5 entail covers and control devices for tanks (including waste fixation) and impoundments, submerged loading of drums, and covers for dumpsters. Control option 1 applies to wastes containing greater than 0 ppm of organics; 2, 500 ppm; 3, 500 ppm; 4, 1,500 ppm; and 5, 3,000 ppm of organics. For covered storage and quiescent treatment tanks, venting to a control device is required in control options 1, 2, 4, and 5, if the vapor pressure of the waste in the tank exceeds 10.3 kPa (1.5 psi).

[d]Containers' source category includes drum storage, dumpster storage, and loading. The control options do not apply additional controls to drum and dumpster storage because they are currently controlled by existing regulations (40 CFR Parts 264 and 265, Subpart I).

[e]The sum of each column of data does not equal the subtotal and total values because of rounding.

[f]The control options do not apply additional controls to these sources because they are controlled by the land disposal restrictions. The emission estimates for landfills change under the control options because certain sources handling the wastes prior to landfilling are controlled, which suppresses emissions and results in slightly higher organic concentrations in the landfilled wastes.

[g]Uncontrolled incinerator emissions include emissions from wastes that are routinely incinerated with stack exhaust gas emission controls. These sources are currently regulated under 40 CFR 264, Subpart O. The uncontrolled emission scenario does not include wastes that are or would be incinerated as a result of implementing the RCRA land disposal restrictions. The baseline and control options do, however, account for the incinerator emission resulting from the land disposal restrictions. The emission scenarios are explained in Chapter 5.0.

[h]Land treatment emissions for the baseline and control options are "0" because the land disposal restrictions are assumed to require pretreatment for volatile organic removal prior to land treatment.

[i]The control options do not apply additional controls for spills because they are controlled under existing Part 264 and 265 RCRA regulations.

[j]Emission numbers for equipment leaks are currently being revised. These total values do not include value for equipment leaks.

control option by source category. Because the specific design and operating characteristics of each waste management process are not widely available, nationwide distributions of process design and operating parameters were used in estimating TSDF emissions. Therefore, it is appropriate that nationwide TSDF emissions and impacts are used in the comparison of the various control options. As noted in Chapter 3.0, the estimation of TSDF emissions in this document involved the use of the TSDF air emission models as presented in the March 1987 draft of the air emission models report rather than the December 1987 version of the report.

Comments have been received providing additional information on the concentration of organics in biologically active treatment processes and the aeration parameters used for the model units.[1] Proposed revisions to the aerated units and the biodegradation model were evaluated in a sensitivity analysis to determine the effect on the nationwide impacts presented in this document.[2] The results of the analysis showed that the combined effects of the proposed changes had only a minor effect (less than 5 percent) on nationwide impacts. Consequently, the impacts presented for emissions and incidence, although based on the original biodegradation model and material balance in Appendix C, Equation C-5, would not change significantly with the revisions that were proposed to improve the modeling approach.

Nationwide uncontrolled organic air emissions were estimated at about 1.7 million Mg/yr; baseline emissions were 1.8 million Mg/yr. Quiescent tanks used for storage or treatment are the largest uncontrolled emitters nationwide under these two scenarios. Land treatment sources have zero emissions for the baseline and controlled cases because the land disposal restrictions will require pretreatment to remove volatile organics prior to land treatment. The control options do not apply to drum storage because this source is controlled by existing regulations (CFR Parts 264 and 265, Subpart I). Similarly, wastepiles and landfills are not controlled under the options because they are controlled by the land disposal restrictions.

Emission reductions from baseline for the five control options range from 1.6 million Mg/yr (control option 5) to 1.7 million Mg/yr (control option 1). Control options for quiescent tanks yield the highest emission reductions. Some sources such as landfill and incineration processes show an increase in emissions when a control option is applied. These increases occur because (1) emissions are suppressed from upstream controlled sources (i.e., the waste stream retains the organics that would have been emitted previously, which results in an increase in organics at the source of interest), and (2) when controls are applied, new emission sources are created such as pumps and valves (i.e., equipment leaks).

6.2 HUMAN HEALTH RISKS

Health risks posed by exposure to TSDF organic air emissions are presented in this section in three forms: annual cancer incidence (incidents per year nationwide resulting from exposure to TSDF organic air emissions), maximum lifetime risk (the highest risk of contracting cancer that any individual could have from exposure to TSDF emissions), and noncancer health effects (from acute and chronic exposures to noncarcinogenic chemical emissions from TSDF). Annual cancer incidence and maximum lifetime risk are used as an index to quantify health impacts for seven cases: (1) uncontrolled organic air emissions, (2) baseline air emissions, and (3) controlled emissions under the five options.

Detailed discussion on the development of the health effects data presented here are found in Appendixes E and J. In general, the methodology consists of four major components: estimation of the annual average concentration patterns of TSDF organic air emissions in the region surrounding each facility, estimation of the population associated with each computed concentration, estimation of exposures computed by summing the products of the concentrations and associated populations, and, finally, estimation of annual incidence and maximum lifetime risk, which are obtained from exposure and TSDF emission potency data.

6.2.1 Annual Cancer Incidence

For the estimates of TSDF incidence, the Human Exposure Model (HEM), which uses a basic EPA dispersion algorithm, was used to generate organic emission concentration patterns. The TSDF Industry Profile (see Appendix D.2.1) was accessed to identify facility locations for population pattern estimation within the HEM using 1980 census population distributions. The HEM was run for each TSDF using a fixed unit risk factor and a facility organic emission rate; as such, the HEM site-specific incidence results can be adjusted by the annual facility emissions generated from the SAM and the appropriate TSDF unit risk factor to give facility-specific estimates for the control option under consideration. A unique unit risk factor was derived for each option based on the emissions of specific carcinogens under that option (see Appendix E). The incidence results therefore reflect the level and composition of emissions resulting from a particular emission scenario or control option.

As shown in Table 6-3, incidence estimates indicate that an uncontrolled TSDF industry would lead to 130 cancer incidents per year nationwide; the baseline TSDF industry case would lead to 140 incidents. Control options 1 through 5 reduce the estimated number of cancer incidences by 89 to 95 percent from 140 in the baseline case to a range of 6.4 to 16 per year.

6.2.2 Maximum Lifetime Risk

Maximum lifetime risk (MLR) represents "individual" risk as opposed to the "aggregate" risk in the total nationwide cancer incidence and is intended to reflect the Nation's most exposed individual's chance of getting cancer if exposed continuously for 70 years to the highest annual average ambient concentration around a TSDF. As such, MLR reflects the highest risk that any person would have from exposure to TSDF emissions. MLR is calculated as a function of ambient organic concentration and the composite unit risk factor for TSDF organic emissions. For TSDF MLR estimates, the Industrial Source Complex Long-Term Model (ISCLT), a state-of-the-art air quality dispersion model, was used to generate the maximum annual average ambient organic concentration estimates (see Appendix J for a description of the model). In order to provide a more comprehensive analysis of maximum ambient concentrations, two TSDF were selected for detailed, rigorous analysis in making MLR estimates. The two facilities were selected on the basis of their estimated emissions and the TSDF management processes utilized at the facilities. The design and operating parameters and wastes managed at these two facilities were used in conjunction with the local meteorological conditions (standard climatological frequency of occurrence summaries) to estimate dispersion of emissions from each source at each facility on an annual basis. Multiplying the maximum annual average ambient concentration by the composite unit risk factor

TABLE 6-3. NATIONWIDE CANCER INCIDENCE FROM TSDF EMISSIONS BY SOURCE CATEGORY[a,b]
(Number of Cancer Incidences/Year)

Source category	Cancer incidence due to . . .		Cancer incidence after . . . Control options[d]				
	Uncontrolled emissions	Baseline emissions[c]	1	2	3	4	5
Quiescent tanks (storage or treatment)	81	81	0.48	0.72	2.6	1.6	1.8
Quiescent impoundment (storage or treatment)	9.2	9.3	1.3	1.4	2.2	5.7	6.0
Non-quiescent tanks	28	28	2.0	2.1	1.7	2.5	4.3
Non-quiescent impoundments	4.5	4.5	0.35	0.35	0.30	0.71	1.0
Containers[e]	7.9	7.9	0.84	0.86	0.72	0.99	0.84
Waste fixation units	0.14	11	0.94	0.95	0.80	2.0	1.8
Subtotal[f]	130	140	5.9	6.4	8.4	14	16
Other sources							
Wastepiles[g]	0.03	0	0	0	0	0	0
Landfills[g]	2.1	0.13	0.35	0.35	0.30	0.33	0.28
Incineration[h]	0.03	0.04	0.06	0.06	0.05	0.06	0.05
Land treatment[i]	0.6	0	0	0	0	0	0
Spills	0.05	0.04	0.06	0.06	0.05	0.06	0.05
Equipment leaks[j]	--	--	--	--	--	--	--
Subtotal[f]	2.8	0.21	0.47	0.47	0.40	0.45	0.38
TOTAL[f]	130	140	6.4	6.8	8.8	14	16

(continued)

TABLE 6-3 (continued)

TSDF = Treatment, storage, and disposal facility.

[a]This table shows nationwide cancer incidence by emission source. Each of the seven columns of incidence listed above is described in detail in Chapter 5.Ø. Development of incidence estimates is presented in Appendix E and is based on composite risk factors derived for each scenario.

[b]Estimated values for each source category should not be used or viewed independently because some control technologies may suppress emissions or reduce emissions that will impact sources downstream.

[c]With TSDF proposed air standards (for process vents and equipment leaks) and land disposal restrictions in place.

[d]Control options 1 through 5 entail covers and control devices for tanks and impoundments, submerged loading of drums, and covers for dumpsters. Control option 1 applies to wastes containing greater than Ø ppm of organics; 2, 5ØØ ppm; 3, 5ØØ ppm; 4, 1,5ØØ ppm; and 5, 3,ØØØ ppm of organics. For covered storage and quiescent treatment tanks, venting to a control device is required in control options 1, 2, 4, and 5, if the vapor pressure of the waste in the tank exceeds 1Ø.3 kPa (1.5 psi).

[e]Containers' source category includes drum storage, dumpster storage, and loading. The control options do not apply additional controls to drum and dumpster storage because they are currently controlled by existing regulations (4Ø CFR Parts 264 and 265, Subpart I).

[f]The sum of each column of data does not equal the subtotal and total values because of rounding.

[g]These sources are not controlled under the control options because they are currently controlled under other regulatory programs. The changes in estimates of incidence reflect the changes in the composite risk factor for each control option (see Appendix E). In addition, the increase in incidence for landfills reflects also a slight increase in emissions from higher organic concentrations in the landfilled wastes due to suppression controls applied to certain sources prior to landfilling.

[h]Uncontrolled incinerator emissions include emissions from wastes that are routinely incinerated with stack exhaust gas emission controls. These sources are currently regulated under 4Ø CFR 264, Subpart O. The uncontrolled emission scenario does not include wastes that are or would be incinerated as a result of implementing the RCRA land disposal restrictions. The baseline and five options do, however, account for the incinerator emission resulting from the land disposal restrictions. The emission scenarios are explained in Chapter 5.Ø.

[i]The cancer incidences associated with land treatment for the baseline and control options are "Ø" because the land disposal restrictions are assumed to require pretreatment of the waste prior to land treatment.

[j]Incidence numbers for equipment leaks are currently being revised. The total values do not include value for equipment leaks.

yields the maximum risk, given that someone is predicted to reside at that location. The unit risks from the various individual dispersed carcinogens are represented by a composite unit risk factor derived for each option for TSDF organic emissions. Pertinent information on the selected TSDF and unit risks is presented in Appendix J and Appendix E, respectively.

The results of the MLR calculations, shown in Table 6-4, indicate that the probability of contracting cancer is 2 x 10^{-2} for the baseline TSDF industry. For control options 1 through 5, these risks range from 5 x 10^{-4} to 9 x 10^{-4}. For all options, aerated units are the major sources contributing to the maximum ambient air concentrations associated with the MLR values.

6.2.3 Noncancer Health Effects Assessment--Acute and Chronic Exposures

A screening analysis of the potential adverse noncancer health effects associated with acute and chronic exposure to individual waste constituents emitted from the two selected TSDF was based on a comparison of relevant health data to the highest short-term (i.e., 15-min, 1-h, 3-h, and 24-h) or long-term (i.e., annual) modeled ambient concentrations for chemicals at each facility (see Appendix E). Modeled concentrations were estimated from the Industrial Source Complex-Short Term (ISCST) Model. Detailed information on this model and on modeled ambient concentrations of constituents at each facility is provided in Appendix J.

Results of this analysis indicate that adverse noncancer health effects are unlikely to be associated with acute or chronic exposure to the given ambient concentrations of individual chemicals at these two TSDF. Modeled short-term and long-term ambient concentrations were in most cases at least three orders of magnitude below health effects levels of concern. It should be noted that the health data base for many chemicals was limited, particularly for short-term exposures. The conclusions reached in this analysis should be considered in the context of the limitations of the health data, the uncertainties associated with the characterization of wastes at the two facilities, and the assumptions used in estimating emissions, ambient concentrations, and the potential for human exposure.

TABLE 6-4. MAXIMUM LIFETIME RISKS FROM TSDF EMISSIONS[a]

Control scenario	Maximum concentration, $\mu g/m^3$	Maximum risk[b]
Uncontrolled	1,700	2×10^{-2}
Baseline	1,700	2×10^{-2}
Option 1	43	5×10^{-4}
Option 2	43	5×10^{-4}
Option 3	47	5×10^{-4}
Option 4	60	8×10^{-4}
Option 5	81	9×10^{-4}

[a]This table shows the cancer risk of the individual in the United States most exposed to TSDF emissions over a 70-year period. Risk is presented for seven scenarios, which are described in detail in Chapter 5.0. Development of risk data is presented in Appendixes E and J.

[b]Based on the composite risk factors derived for each scenario as described in Appendix E.

6.3 OTHER ENVIRONMENTAL IMPACTS

The types of environmental impacts that potentially may result from the operation of control devices used to reduce TSDF organic air emissions were discussed in Chapter 4.0. Estimates of the magnitude of the secondary air and cross-media impacts associated with the different control options were prepared using an approach that applied energy conversion factors, air emission factors, and wastewater and solid waste generation rates to the results of the Source Assessment Model (SAM) control option analyses.

The secondary air and cross-media impact results are sensitive to the control device operating conditions used at TSDF (e.g., electricity source, type of fuel burned to produce steam, spent activated carbon management practices). To account for this sensitivity, a range of secondary air and cross-media impacts estimates was computed for each control option by defining two sets of TSDF control device operating conditions that provide an upper boundary estimate and a lower boundary estimate. This approach allows a range of values to be computed that spans the conditions most likely to occur at TSDF on a nationwide average basis. The two sets of TSDF control device operating conditions selected are summarized in Table 6-5.

A nine-step procedure was followed to estimate nationwide annual air emission, wastewater, solid waste, and energy impacts produced by the operation of the control devices selected for each control option. The procedure is outlined below:

1. Define the TSDF control device operating conditions.
2. Develop TSDF source category operation factors relating specific control device operating requirements (e.g., electricity demand, steam demand, activated carbon requirements) to the amount of hazardous waste managed.
3. Select energy conversion factors for electricity generation by fossil fuel-fired utility power plants and process steam production by industrial boilers.
4. Select air pollutant emission factors for utility boilers, industrial boilers, and hazardous waste incinerators.
5. Select wastewater and solid waste generation rate factors for utility power plants, carbon regeneration units, and hazardous waste incinerators.

TABLE 6-5. TSDF CONTROL DEVICE OPERATING CONDITIONS SELECTED FOR SECONDARY AIR AND CROSS-MEDIA IMPACT ESTIMATES

TSDF control device operating condition	Lower boundary	Upper boundary
Electricity		
Electicity source	Electric utility	Electric utility
Electric utility power plant mix	50% coal 25% natural gas 25% noncombustion	100% coal
Process steam		
Process steam source	Onsite industrial boiler	Onsite industrial boiler
Steam boiler fuel	100% natural gas	100% fuel oil
Carbon adsorption units		
Fixed-bed carbon unit regeneration yield	90%	80%
Spent carbon canister management practice	100% regenerated with 90% yield	100% direct landfill disposal

6. Obtain SAM results for each control option listing annual nationwide hazardous waste throughput (megagrams of waste per year) by TSDF source category.

7. Multiply control device operation factors times individual TSDF source category throughput to obtain annual electricity, steam, and carbon demand for each TSDF source category.

8. Add the individual source category demand values to obtain the total nationwide annual electricity, steam, and carbon demand for each control option.

9. Multiply the total annual electricity, steam, and carbon demand values by the appropriate energy conversion factors, air emission factors, and wastewater and solid waste generation rate factors to obtain nationwide annual secondary air and cross-media impacts.

Control device operation factors were developed for each TSDF source category using the control cost estimates presented in Appendix H. As part of these cost estimates, annual control device electricity, steam, and carbon consumption were computed to determine capital and annual control costs for individual TSDF model units defined for each TSDF source category. Each operation factor was calculated by dividing the control device annual consumption value by the annual hazardous waste throughput defined for the model unit.

Energy conversion factors were selected based on engineering judgment to be consistent with typical electric utility power generation and industrial process steam production practices. Fuel property and air emission factor values were selected from the EPA document <u>Compilation of Air Pollutant Emission Factors</u> (AP-42).[3] Wastewater and solid waste generation rates were computed for the defined TSDF control device operations and fuel property values. The specific values used for the secondary air and cross-media impacts calculations are listed in Appendix K.

Secondary air and cross-media impacts were estimated for each control option using the TSDF source category nationwide annual hazardous waste throughput values estimated by the SAM analyses. The nationwide secondary air pollutant emission impacts, wastewater discharge impacts, solid waste disposal impacts, and energy impact for the five control options are presented in Table 6-6.

TABLE 6-6. SUMMARY OF NATIONWIDE ANNUAL SECONDARY AIR AND CROSS-MEDIA IMPACT ESTIMATES FOR CONTROL OPTIONS 1 THROUGH 5[a]

Impacts	Option 1	Option 2	Option 3	Option 4	Option 5
Air emissions (Mg/yr)					
Carbon monoxide (CO)	170 - 180	140 - 150	70 - 80	50 - 60	30 - 40
Nitrogen oxides (NO_x)	1,200 - 1,700	1,000 - 1,500	500 - 700	400 - 600	200 - 300
Sulfur oxides (SO_x)	400 - 3,200	400 - 2,700	200 - 1,400	100 - 1,000	100 - 700
Particulate matter	40 - 110	40 - 100	20 - 60	10 - 40	10 - 20
Wastewater effluent (m^3/yr)					
Power plant[b]	23,000 - 47,000	22,000 - 45,000	9,000 - 16,000	8,000 - 16,000	5,000 - 11,000
Carbon regenerator	25,000 - 39,000	24,000 - 26,000	9,000 - 9,000	9,000 - 10,000	6,000 - 7,000
Solid waste (Mg/yr)					
Power plant ash[b]	9,000 - 17,000	8,000 - 16,000	3,000 - 7,000	3,000 - 6,000	2,000 - 4,000
Scrubber sludge[b]	14,000 - 28,000	13,000 - 26,000	6,000 - 11,000	5,000 - 9,000	3,000 - 6,000
Spent activated carbon	3,000 - 14,000	2,000 - 5,000	600 - 1,200	700 - 2,400	500 - 2,000
Energy impact (TJ/yr)	12,000 - 13,000	10,000 - 11,000	5,100 - 5,500	3,800 - 4,200	2,500 - 2,800

[a]Estimate range based on Source Assessment Model (SAM) analysis results for control options 1 through 5 and TSDF control device operating conditions listed in Table 6-5.

[b]Utility power plant impact due to generation of electricity required to operate TSDF control devices.

To provide a sense of the magnitude of the nationwide TSDF control device secondary air and cross-media impacts, the values presented in Table 6-6 can be compared to the impacts produced by a single coal-fired utility power plant. Recognizing that the TSDF control device impacts would not all occur at a single location, the order-of-magnitude of the nationwide control options 1 through 5 impacts is comparable to the air emission, wastewater, and solid waste impacts associated with a new 100-MW utility power plant burning a high-sulfur coal.

6.4 REFERENCES

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7.0 COSTS OF THE CONTROL OPTIONS

The purpose of this chapter is to present the methodology used to estimate nationwide costs of adopting each of the five control options described in Chapter 5.0 as the basis for regulation of air emissions from hazardous waste treatment, storage, and disposal facilities (TSDF). Estimated nationwide total capital investment (TCI; i.e., equipment purchase and direct and indirect installation costs) and total annual costs (TAC; i.e., costs of operating control technologies minus any energy or materials credits) are provided in a subsequent section of this chapter. In addition, the cost per unit of waste throughput for the control technologies identified in Chapter 5.0 as part of the control options is discussed and listed, and a general explanation of the methodology used to derive those unit costs is presented in this chapter. Supporting data are provided in Appendix H to this document, and other references to cost information are listed in that appendix.

Development of costs requires the presumption of a baseline level of emissions and emission control from which the control costs can be calculated. The baseline used for this effort is described in Chapter 5.0, Section 5.1, of this document. Costs to implement the control options are provided to permit a comparison of the resources that would be expended to reduce air emissions from TSDF using different combinations of controls and sources.

7.1 CONTROL COSTS DEVELOPMENT

Estimation of the nationwide costs of adopting a control option begins with estimation of the control costs for individual waste management units within a TSDF. Ideally, information about the design and operating characteristics (such as surface area and retention time for impoundments) of each waste management unit would be available to permit accurate estimates of control costs for that unit. Information at that level of detail is not available for each unit at each facility; generally, only waste throughput is known. For this reason, model units were developed. Rationale for the development of model units is given in Chapter 3.0, Section 3.2.1 (as relates to emission estimation) and Section C.2. Control cost estimates were developed for each of the model units (results are shown in Section C.2.3). The methodology for developing control costs for the model units is described partially in Section 7.1.1 and in detail in Appendix H.

To obtain nationwide costs from model unit costs requires a method of assigning a model unit cost to each waste management unit in each facility and then computing the sum. Given that only TSDF waste management unit throughput is known, the assignment of one of the defined model units to represent each TSDF waste management unit is not possible. Therefore, a weighted average model unit control cost--in essence, "national average model unit" control cost--was derived for each control applied to each TSDF waste management unit. These control costs, divided by the model unit throughput, provide cost factors that are used to generate control cost estimates for each TSDF facility. The discussions of weighted average model unit control costs and control costs as a function of throughput are given in Sections 7.1.2.2 and 7.1.2.1, respectively.

7.1.1 Methodology for Model Units

To estimate the nationwide cost impacts of implementing the five control options presented in Chapter 5.0, the estimated total capital investment and total annual costs were developed for each of the various control technologies applied in the control options. (A general discussion of these control technologies is contained in Chapter 4.0.) The control options describe the control technology for each source category in general terms, such as cover and vent to control device. The specific control technologies assumed to be applied to each source category for each option are defined in Chapter 5.0, Section 5.4.

A standardized cost estimating approach was developed for add-on and suppression-type control devices based on an EPA cost manual[1] and a series of articles by Vatavuk and Neveril.[2-7] These sources identified the total capital investment, annual operating costs (costs of operating control technologies minus capital recovery and energy credits), and the total annual costs (i.e., annualized costs) as the key elements of a cost estimate.

For each control technology applied in a control option, a detailed cost estimate was developed. The detailed cost estimate consisted of three standard cost tables. The first of the three cost tables lists the major equipment items associated with the control technology. The second table lists any auxiliary equipment required, instrumentation, sales tax and freight, plus direct and indirect installation charges. These first two tables are used to calculate total capital investment. The third table lists the direct operating costs, indirect operating costs, and energy credits used to calculate total annual costs. Examples of these three tables are presented in Appendix H.

The purchase cost, material of construction, and size of each major equipment item were obtained from vendor data, engineering handbooks, the literature, and currently operating commercial facilities. (Such sources are referenced in Appendix H.) The sum of the costs for the major equipment items is equal to the base equipment cost (BEC).

Using the base equipment cost, the purchased equipment cost (PEC) for the control technology is computed. Direct and indirect installation charges for each control technology are factored directly from the purchased equipment cost. For this analysis, the direct and indirect installation factors are based on information obtained from vendors, other cost estimates, data summarized in References 2 through 7, and engineering judgment based on typical TSDF wastes and operating practices. The costs for site preparation and buildings were based on vendor information and construction cost reference sources.[8] The sum of the purchased equipment cost, direct installation charges, and indirect installation charges are equal to the total capital investment (TCI).

The sum of direct and indirect operating expenses less capital recovery and energy credits is equal to the annual operating costs. The total annual cost is equal to the direct plus indirect operating costs less any energy credits.

To illustrate this cost approach for add-on control devices, Appendix H gives detailed cost analyses for control technologies used in the control option definitions in Chapter 5.0. Appendix H provides the rationale for the design, costing, and material and energy balances for TSDF control options. In addition, Appendix H provides sample calculations and other details of how each control was costed.

7.1.2 Derivation of Unit Costs to Estimate Nationwide Costs of Control Options

The estimation of nationwide costs of the control options makes use of a TSDF Industry Profile data base (assembled to aid in this effort and described in Appendix D) and the emission control costs for individual source category/emission control combinations whose development is discussed in Appendix H. The Industry Profile gives the waste throughput data used to assign throughputs to each TSDF waste management unit in each facility in the Nation. To facilitate the use of these two information sources, the total capital investment and annual operating cost for each of the model unit cost estimates were divided by the throughput of the model waste management unit (emission source) to obtain a cost (both total capital investment and annual operating cost) per unit of waste throughput. The following paragraphs discuss the development of the unit cost factors.

7.1.2.1 Costs as a Function of Throughput (Unit Cost Factors). As part of the effort to characterize the variety of TSDF operating practices, model TSDF waste management units were defined. The main purposes of the model units are to evaluate uncontrolled emissions from waste management processes, assess the reduction in air emissions when emission controls are applied, and estimate the costs of applying controls. Model units were defined for TSDF storage, transfer and handling, treatment, and disposal operations. The model units cover a range of waste management unit sizes (e.g., throughput, surface area, and tank volumes) and other characteristics that may impact air emissions. The entire set of model units is presented in Appendix C of this document. The approach to developing control costs discussed in Section 7.1.1 was applied to each of the model units listed in Appendix C for each of the individual unit emission controls.

The next step toward generating the control costs on a nationwide basis was to convert the costs of controls for the model units to a cost per unit of waste throughput; i.e., the costs of controlling emissions from each model unit were divided by the annual waste throughput of the model waste management unit to which the control was applied. These factors (referred to as unit cost factors), when multiplied by the waste throughput for a particular waste management unit, yield an estimate of the cost of air emission controls for that unit.

7.1.2.2 Development of Weighted Cost Factors. Data contained in the TSDF Industry Profile (described in Appendix D) are used to estimate annual waste throughput for each type of waste management unit at each TSDF. The Industry Profile, however, does not yield the exact size of each management unit, e.g., 758 m^3 of tank storage could be ten 75.8-m^3 tanks in one case, or one 758-m^3 tank in another case. Because there are economies of scale associated with emission control costs, the total control costs might be substantially different for these cases. To compensate for the lack of facility-specific unit size information, weighted unit cost factors were developed that account for the national size distribution of TSDF waste management units. Statistics on the national distribution of waste management unit sizes were used to weight the emission control costs for each model unit size defined in Appendix C (see Appendix H). This approach yields an approximation of the effects of economies of scale for the nationwide cost estimates.

Table 7-1 lists the unit cost factors used to estimate nationwide total capital investment and annual operating costs for each of the emission controls specified in the control options.

7.2 SUMMARY OF NATIONWIDE CONTROL COSTS FOR CONTROL OPTIONS

This section presents tabular summaries of the estimated nationwide total capital investment and total annual costs (annualized capital cost plus annual operating costs) for the five control options described in Chapter 5.0. Separate cost estimates are given for each TSDF source category.

The nationwide cost estimates were obtained by multiplying the quantity of wastes managed in each TSDF waste management unit (obtained from

TABLE 7-1. ESTIMATED TOTAL CAPITAL INVESTMENT AND TOTAL ANNUAL COST PER UNIT OF WASTE THROUGHPUT BY SOURCE CATEGORY FOR FIVE CONTROL OPTIONS[a]

Source category	Total capital investment, \$/Mg throughput[b]	Total annual cost, \$/Mg throughput[b]
Drum storage[c]	--	--
Dumpster storage	6.3-26	2.1-9.9
Storage tanks	9.7-28	4.9-15.0
Quiescent surface impoundments	1.9-2.6	0.87-4.8
Quiescent treatment tanks	0.22-1.2	0.14-0.58
Aerated/agitated tanks and impoundments	0.41-2.9	0.26-1.7
Wastepiles[c]	--	--
Landfills[c]	--	--
Waste fixation process units	12.3	5.1
Incineration[c]	--	--
Land treatment[c]	--	--
Spills[c]	--	--
Loading	0.49-0.94	0.09-0.18
Equipment leaks[c]	--	--

[a]Total capital investment includes all costs to purchase equipment, direct installation charges, and indirect installation charges. Total annual cost is the sum of the annual operating cost and the annualized capital costs. All costs are in January 1986 dollars.

[b]The unit costs were obtained from information presented in Appendix H. Where a cost range is given, the range represents cost variations due to differences in waste composition. Model waste compositions for which costs were derived are presented in Appendix C.

[c]These sources are not being controlled by the control options presented in this chapter. For further information, see Chapter 5.0.

the TSDF Industry Profile) by the unit cost factors listed in Table 7-1. The estimated costs for each TSDF were summed to produce national totals. Table 7-2 lists the estimated nationwide total capital investment and the estimated nationwide total annual cost, respectively, for each of the control options.

The estimated total capital investment for control options 1 through 5 ranges from a low value of $520 million for option 5 to a high value of $2.1 billion for option 1. The estimated total annual costs (i.e., annualized costs) for control options 1 through 5 range from a low value of $210 million for option 5 to a high value of $930 million for option 1.

The nationwide cost information presented in this chapter provides two means of comparing control options: capital and annual costs. Other means of comparing options are discussed in Chapter 5.0. Section 5.5 describes a methodology for ranking control options according to the relative health and environmental benefits achieved by the options.

7.3 COST EFFECTIVENESS OF CONTROL OPTIONS

Table 7-3 shows the cost effectiveness of the five control options. The cost effectiveness of a control option is defined as the total annual cost of applying controls to all emission sources covered by the option divided by the total emission reduction that would be achieved. Total annual cost is the annual operating cost plus the annual cost of capital required to purchase and install the controls. As shown, the cost effectiveness of options 1 through 5 varies from $130/Mg to $540/Mg of organic emission reduction.

Only a single aggregate cost effectiveness is presented for each TSDF control option. The cost effectiveness of controlling specific emission source categories covered by an option (e.g., the cost effectiveness of controlling storage tanks) is not presented. This is because emissions from TSDF sources are interrelated in many strategies and, consequently, it is potentially misleading to estimate the cost effectiveness on an emission source category basis.

For example, covering only the first of several TSDF waste management units (emission sources) in series will reduce organic emissions from the unit that is covered but may increase the emissions from the uncovered

TABLE 7-2. ESTIMATED NATIONWIDE TOTAL CAPITAL INVESTMENT AND TOTAL ANNUAL COST FOR FIVE CONTROL OPTIONS[a]

	Total capital investment, $\$10^6$					Total annual cost, $\$10^6$				
	Control option[c]					Control option[c]				
Source category[b]	1	2	3	4	5	1	2	3	4	5
Quiescent tanks (storage or treatment)	520	200	120	160	150	280	73	24	57	52
Quiescent impoundments (storage or treatment)	850	840	160	400	280	360	350	46	170	120
Non-quiescent tanks	19	18	18	9	5.0	12	11	11	6.0	3.0
Non-quiescent impoundments	32	29	29	14	9.0	15	13	13	7.0	4.0
Containers[d]	30	29	29	17	16	8.0	8.0	8.0	5.0	4.0
Waste fixation units	610	600	600	92	63	260	260	260	39	27
Total	2,100	1,700	960	690	520	930	710	360	290	210

[a]Total capital investment includes all costs to purchase equipment, direct installation charges, and indirect installation charges. Total annual cost is the sum of the annual operating cost and the annualized capital costs. All costs are in January 1986 dollars.

[b]Other sources, including wastepiles, landfills, incineration, land treatment, spills, and equipment leaks, are not being controlled by options listed in Chapter 5.0.

[c]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The control options are described in Chapter 5.0.

[d]Containers' source category includes drum storage, dumpster storage, and loading.

TABLE 7-3. NATIONWIDE TSDF COST EFFECTIVENESS OF FIVE CONTROL OPTIONS

Control option[b]	Cost effectiveness, $/Mg emission reduction
1	540
2	420
3	220
4	170
5	130

[a]This table presents total annual costs of control divided by organic emission reductions, i.e., cost effectiveness.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls. The control options are described in Chapter 5.0.

units downstream, resulting in no change in total facility emissions. The cost effectiveness of controlling the first unit may look attractive in isolation, but, as a practical concern, reduction in total facility emissions would not be achieved unless units downstream were controlled as well.

7.4 REFERENCES

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8.0 ECONOMIC IMPACTS

Chapter 5.0 describes five control options for organic air emissions from treatment, storage, and disposal facilities (TSDF). This chapter estimates the economic impacts of control options 1 through 5. For analytical purposes, it is useful to divide the affected facilities into those that only have hazardous waste storage facilities and those that also perform treatment or disposal services.

All control options examined are projected to have small impacts--less than 1 percent--on the unit cost of hazardous waste management services at facilities that treat and dispose of these wastes. These unit-cost increases will slightly raise the costs and prices of goods and services produced by the generating sectors. This will encourage a small amount of waste minimization. The capital costs will vary between $500 million and $2 billion for these facilities; annual compliance costs will vary between $200 million and $900 million. Small decreases are projected in the number of jobs at TSDF, so small that employment dislocations will probably be few if any. Similarly, while the projected reductions in waste generation could, in the aggregate, imply facility closures, it appears much more likely that the reductions will be distributed across all facilities and that the number of closures, if any, will be nominal.

The unit-cost increases for storage-only facilities are substantial for several sectors and options when viewed as a share of hazardous waste management costs. These cost increases translate into compliance costs of between $4 million and $31 million. However, storage facility closures again appear unlikely, even though there may be some economic pressures in that direction, because closing a permitted facility requires the firm to undertake a time-consuming and expensive process. This process is designed to ensure that liability rules are met and that the environment is protected from hazardous wastes.

8.1 INDUSTRY PROFILE

Before beginning the economic analysis, it is necessary to define the affected industry. The following sections discuss the activities of hazardous waste managers and describe the markets where they are active. The demanders and suppliers of these services are described, along with the factors underlying their production and consumption decisions. The size of firms operating the hazardous waste management facilities, along with other characteristics relevant to the economic analysis model, are also presented.

The demand for hazardous waste management services is a function of the production process. In the course of producing final goods or services, firms often produce hazardous waste. Because these production outputs are technically interdependent, they are referred to as "joint products."

The firms that produce hazardous wastes as joint products with their product or service represent more than 100 different Standard Industry Classification (SIC) codes. The hazardous wastes they produce represent more than 400 Resource Conservation and Recovery Act (RCRA) waste codes. Hazardous wastes include characteristic wastes, wastes from both specific and nonspecific sources, chemical products and intermediates, and discarded chemical products and residues.

Because these wastes are classified as hazardous under RCRA, they must be treated, stored, or disposed by a permitted TSDF. A generator can treat, store, or dispose, hazardous wastes on site if it has a permit, or hire a commercial TSDF to manage its hazardous wastes. To reduce the demand for hazardous waste management services, generators may reduce the level of waste generated. Generators may reduce output levels of the primary product or substitute other inputs in the production process to reduce waste and, hence, the need for waste management services.

The following industries generate wastes in their production processes and, therefore, produce not only their marketable commodity but also hazardous wastes:

- Mining
- Milling

- Manufacturing of chemicals and pharmaceuticals
- Manufacturing of primary and fabricated metals
- Manufacturing of cement
- Manufacturing of electrical and nonelectrical machinery
- Manufacturing of transportation equipment and instruments
- Electric and gas utilities
- Wholesale and retail sales
- Research labs, hospitals, university research centers
- Remainder of the economy, including government facilities.

On the supply side of the market for hazardous waste management services are many of the same firms that generate the hazardous waste and, therefore, appear on the demand side of the market. These firms provide "captive" onsite hazardous waste management services. In addition to these captive firms, a group of commercial firms specializes in managing hazardous materials. Section 8.1.1 describes the suppliers of hazardous waste management services in more detail.

8.1.1 The Supply Side

Hazardous waste management processes fall into three major categories: (1) treatment, (2) storage, and (3) disposal. Within each of these categories are further subcategories totaling 12 waste management processes. TSDF can be classified into four broad categories: (1) captive storage-only facilities; (2) commercial storage-only facilities; (3) captive TSDF; and (4) commercial TSDF. Storage-only facilities (captive or commercial) store the wastes using containers and/or tanks prior to treatment and disposal; TSDF (captive or commercial) include all facilities other than storage-only facilities (captive and commercial).

8.1.1.1 Hazardous Waste Management Processes. Hazardous Waste management services include storage, treatment, and disposal of wastes described in Table 3-1 and Table 3-2, Chapter 3.0. Twelve processes are identified.

The key storage processes include containers, tanks, wastepiles, and surface impoundments. The key treatment processes include tank treatment, surface impoundment treatment, incineration, and other treatment. The key disposal processes include injection wells, landfills, land application, and surface impoundments.

8.1.1.2 Costs of Hazardous Waste Management Processes. The costs of a hazardous waste management process include all annual costs (e.g., raw materials, utilities, labor, maintenance, and overhead) required to operate a plant. Typical plant sizes and typical operating practices were identified for each of the 12 management processes to develop generalized cost equations. The annualized average costs of hazardous waste management processes ($/Mg of waste managed) were estimated for each of the 12 waste management processes.

The operating costs of waste management processes were obtained from several sources, including studies by Booz-Allen and Hamilton; Research Triangle Institute; Industrial Economics, Inc.; Temple, Barker, and Sloane; and the National Council of the Paper Industry on Air and Stream Improvement. As with some of the other data, process costs reflect recent but not necessarily current values. For each of the 12 processes, model costs were developed for different plant sizes using available information on model and actual process expenditures. In this manner, cost estimates were determined for the different waste management processes.

The per-metric ton processing costs for the 12 different waste management processes were compared with values found in other sources to verify their reasonableness. The results of this comparison are presented in Table 8-1. As can be seen from the blank entries in the table, not every source gives costs estimates for each process technology. It is also evident from the tables that, in most cases, the RTI cost estimates are comparable to those of the other sources.

Finally, the cost functions were developed using unit costs developed for the 12 different waste management processes and several plant sizes. The estimated parameters of the cost functions are summarized in Table 8-2. These cost functions were used to compute costs for waste management operations in TSDF from which price adjustments resulting from the control options were estimated.

8.1.1.3 Identifying Directly Affected Facilities. From the Industry Profile discussed in Appendix D, 2,336 facilities were identified that

TABLE 8-1. COMPARISON OF UNIT COSTS PER METRIC TON[a]

Waste management practice baseline	Booz-Allen and Hamilton (1982 $)	RIA Mail Survey (1981 $)	Industrial Economics, Inc. (1984 $)	Temple, Barker, and Sloane, Inc. (1984 $)	NCASI (1983 $)	Cost range across sources	TSDF-RTI (ICF) (1882 $)
<u>Treatment options</u>							
Tank treatment	*	26.4 - 79.2	*	*	*	26.4 - 79.2	0.46 - 949
Other treatment	66.0 - 792	30.4 - 29.0	2.43 - 109	185 - 605	*	2.43 - 792	0.46 - 949[b]
Incinerator	396 - 792	132 - 700	145 - 630	100 - 300	*	100 - 792	109 - 238
Treatment impoundment	*	*	0.16 - 1.46	*	*	0.16 - 1.46	16.9 - 158
<u>Storage options</u>							
Container storage	*	*	*	106	*	106	290 - 578
Tank storage	*	*	5.28	106	*	5.28 - 106	290 - 578[c]
Wastepiles	*	*	153 - 860	51.2 - 726	*	516 - 860	6.15 - 74.8
Storage impoundment	*	*	0.38 - 3.75	103 - 1,100	*	0.38 - 1,100	16.5 - 90.0
<u>Disposal options</u>							
Land treatment	5.25 - 23.8	79.2	31.26 - 60.2	*	18.1 - 144	5.25 - 144	57.0 - 283
Landfill RCRA	33.0 - 75.0	5.41 - 136	106 - 150	50.0 - 517	*	5.41 - 517	53.8 - 575
Injection well	13.2 - 264	*	5.11 - 150	145 - 765	*	5.11 - 765	6.98
Disposal impoundment	*	4.56	166 - 315	*	*	4.56 - 315	16.5 - 90.1

* = Data not available from this source.

[a]This table presents the estimated unit costs from various sources for hazardous waste treatment, storage, and disposal options.[1-6]

[b]Other treatment costs are assumed equal to tank treatment.

[c]Tank storage costs are assumed equal to container storage.

TABLE 8-2. PARAMETERS OF THE UNIT COST FUNCTION[a]

Waste management practice baseline	Intercept	Slope
Treatment options		
Tank treatment	8.60	0.60
Other treatment	8.60	0.60
Incinerator	8.78	0.65
Treatment impoundment	8.70	0.56
Storage options		
Container storage	7.09	0.44
Tank storage	8.70	0.56
Wastepiles	7.58	0.26
Storage impoundment	7.09	0.44
Disposal options		
Land treatment	0	6.98
Landfill RCRA	9.43	0.50
Injection well	10.4	0.66
Disposal impoundment	8.70	0.56

[a]The unit cost function depends on the amount of waste processed and the type of waste management processes used. The function was estimated using the available data described in Table 8-1. The function was assumed a log-linear function, defined by: $C(Q) = a - b \ln(Q)$, where a and b are the estimated intercept and slope values, Q is the amount of waste processed, and 'ln' represents natural logarithm. The unit costs are truncated by the upper and lower bounds represented in the last column of Table 8-1. The estimation of the parameters of the cost functions are described in Reference 7.

performed some form of hazardous management service in 1985. Out of 2,336 facilities, 2,002 are estimated to produce organic emissions. Of these facilities, 1,098 facilities were storage-only facilities; the remaining 904 facilities provided all forms of hazardous waste management services. Nearly 70 of the 904 facilities were either government facilities or facilities listed under service industries. The economic analysis includes only the remaining 834 directly affected facilities. The excluded storage-only facilities (1,098) and government facilities (70) represented less than 5 percent of the total waste volume serviced by all the 2,002 facilities. In addition, the compliance costs of the excluded facilities comprised less than 1 percent of the total compliance costs in all options. The summary statistics by directly affected facilities, storage-only facilities, and government facilities are presented in Appendix I.

These directly affected facilities (834) were found in more than 100 different industries, as described by their 4-digit SIC code. To facilitate the economic analysis, the TSDF were grouped into 20 generating sectors and 1 commercial treatment sector. The 834 facilities were assigned to one of the 21 market sectors, based on their primary product or service as indicated by their SIC codes. In 20 of the 21 sectors, firms generated as well as treated, stored, or disposed of hazardous wastes. In the 21st sector, the commercial sector, facilities only supplied hazardous waste management services to firms in the other sectors. Table 8-3 lists the 20 generating sectors and the 1 commercial sector, along with the number of facilities in each sector and the volume managed by each sector.

The supply elasticities of hazardous waste management services, which measure the responsiveness of an industry's quantity supplied of hazardous waste management services to changes in the price of these services, are shown in Table 8-4. To compute these elasticities, unit cost estimates were first developed for each of the 12 processes using engineering relationships and costs. These cost functions are only valid for the range of output for which data are available; at very low outputs and very high outputs they give unreliable results. Therefore, the cost function was truncated using judgment and information about the costs of actual hazardous waste management firms. The cost curve is shaped like a backward L.

TABLE 8-3. VOLUME OF WASTE MANAGED BY SECTOR, 1986[a]

Sector	Number of facilities	Volume managed, 10^3 Mg/yr
Mining	12	92.8
Grain and textile mill products	4	130.0
Furniture, paper products, printing	35	38.3
Industrial chemicals, inorganic and organic	139	99,600.0
Plastics, fibers	39	53,900.0
Biological, pharmaceutical, medical chemicals	20	2,820.0
Assorted chemical products	54	20,800.0
Paint and allied products, petroleum and coal	99	6,740.0
Rubber, plastics	7	5.4
Cement companies	11	36.0
Primary metals	70	1,960.0
Metal fabrication	67	1,070.0
Nonelectrical machinery	15	42.3
Electrical machinery and supplies	45	514.0
Transportation equipment	29	764.0
Instruments	8	29.8
Miscellaneous manufacturing	5	260.0
Electric and gas utilities	24	340.0
Nondurable goods: wholesale sales	4	60.6
Research labs, hospitals, universities	11	0.2
Commercial hazardous waste handlers	136	5,720.0
Totals	834	195,000.0

[a]This table groups each of the 834 facilities included for the economic analysis into one of the 21 market sectors (20 generating sectors and 1 commercial sector). Facilities included in the generating sectors generate and manage (treat and/or store and/or dispose) hazardous wastes. Facilities included in the commercial sector only supply hazardous waste management services to the generating facilities. Data are taken from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

TABLE 8-4. SUPPLY ELASTICITIES FOR HAZARDOUS WASTE MANAGEMENT SERVICES BY SECTOR[a]

Sector	Supply elasticity
Mining	0.55
Grain and textile mill products	1.82
Furniture, paper products, printing	0.47
Industrial chemicals, inorganic and organic	0.10
Plastics, fibers	0.03
Biological, pharmaceutical, medical chemicals	0.03
Assorted chemical products	0.38
Paint and allied products, petroleum and coal	0.16
Rubber, plastics	0.05
Cement companies	0.46
Primary metals	0.13
Metal fabrication	0.08
Nonelectrical machinery	0.15
Electrical machinery and supplies	0.54
Transportation equipment	0.07
Instruments	1.26
Miscellaneous manufacturing	0.00
Electric and gas utilities	0.17
Nondurable goods: wholesale sales	0.01
Research labs, hospitals, universities	0.66
Commercial hazardous waste handlers	0.29

[a]The supply elasticities of hazardous waste management services in this table measure the responsiveness of a sector's quantity of hazardous waste management services to changes in the price of these services. Step supply functions for each of the 21 sectors reported in the table were constructed using the waste management cost functions reported in A Profile of the Market for Hazardous Waste Management Services, a 1986 draft report prepared by Research Triangle Institute for the U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. A log-linear regression was performed to estimate the elasticities. Data are taken from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

Up to the capacity volume of throughput, the marginal cost curve is horizontal (perfectly elastic); beyond that volume, vertical (perfectly inelastic).

Each facility's marginal cost (= average cost) of hazardous waste management service was calculated based on the volume of hazardous waste management service. Then, ranking facilities from the lowest unit cost to highest, the volumes of hazardous waste management services were accumulated across all the firms in the sector. This process results in a "stepped" supply function for each industry sector. After constructing these stepped supply functions for each sector, a log-linear regression was performed to find a constant elasticity of supply for each industry as reported in Table 8-4.

8.1.2 The Demand Side

As mentioned earlier, the demand for hazardous waste management services arises because, in the course of producing their final goods or services, firms may also generate hazardous wastes. The majority of the facilities generating hazardous wastes as a result of their production process are chemical manufacturers. In all, however, firms in more than 100 4-digit SIC codes demand hazardous waste management services.

Many facilities choose to recycle or incinerate their own hazardous waste on site, for a variety of reasons. Not all of these reasons are directly related to management costs. Under RCRA, generators retain some liability for the waste they generate after it leaves their facility. This undoubtedly induces some firms to reduce their risk by keeping the hazardous waste on site.

However, not all of the facilities generating hazardous wastes choose to manage them entirely on site. Rather, some use the services of commercial waste management firms. It is assumed in this analysis that all the demand for hazardous waste management services originates in the first 20 generating sectors listed in Table 8-3. Some of the demand is met by the generators themselves, while other firms in these same generating sectors use the services of commercial waste management facilities. The firms in the generating sectors that have RCRA permits are assumed here to manage all their own hazardous wastes on site. All other firms within these sectors are assumed to ship hazardous wastes off site to commercial waste management facilities.

To estimate total consumption of hazardous waste management services in each generating sector, it is necessary to sum the consumption that is met by onsite management with the sector's estimated share of commercially supplied management services. No information is available about commercial consumption arising in each of the generating sectors. It is assumed that all the demand for these services arises from the same 20 sectors that perform onsite captive management. The total commercially supplied hazardous waste management services are allocated across the 20 sectors based on the ratio of each sector's transported waste quantities to the total quantity transported by the 20 sectors. Table 8-5 shows the 20 demanding sectors, along with the total volume that each sector services commercially or on site, and the grand total of hazardous waste management demand originating in each generating sector.

To simplify the economic analysis, it is assumed that each firm uses only two inputs to produce its output: hazardous waste management services and one other composite input. Table 8-6 shows the estimated share of each industry's total production cost attributable to hazardous waste management services.

A measure of the price elasticity of demand for the products of each generating sector is needed for the economic analysis. Price elasticity of demand measures the percentage change in quantity demanded in response to a percentage change in product price. The elasticity of demand for intermediate products such as those produced by all the firms in the data base depends on several factors related to the final product. First, because an intermediate product is used to produce a final product, the demand for the intermediate product depends on the demand for the final product in which it is used. Thus, the demand for a chemical depends on the demand, for example, for the paint, pharmaceutical product, or plastic product it is used to produce. The degree of variation in quantity demanded of the intermediate product in response to a change in its price thus depends, in part, on the responsiveness of the final product's quantity demanded to changes in its price. It also depends on the cost share of the final

TABLE 8-5. CONSUMPTION OF HAZARDOUS WASTE MANAGEMENT SERVICES AND VALUE OF SHIPMENTS BY SECTOR, 1988[a]

Sector	Volume hazardous waste, 10^3 Mg/yr[b]			Value of shipments,[c] $\$10^6$/yr
	On site	Commercial	Total	
Mining	92.8	3.1	95.9	34,000.0
Grain and textile mill products	130.0	0.1	130.4	23,700.0
Furniture, paper products, printing	38.3	2.5	40.8	22,500.0
Industrial chemicals, inorganic and organic	99,600.0	4,560.0	104,000.0	198,000.0
Plastics, fibers	53,900.0	278.0	54,200.0	113,000.0
Biological, pharmaceutical, medical chemicals	2,820.0	165.0	2,980.0	23,600.0
Assorted chemical products	20,800.0	437.0	21,300.0	43,900.0
Paint and allied products, petroleum and coal	6,740.0	41.8	6,780.0	166,000.0
Rubber, plastics	5.4	0.3	5.7	61,800.0
Cement companies	36.0	1.9	40.0	5,050.0
Primary metals	1,960.0	97.3	2,061.0	113,000.0
Metal fabrication	1,070.0	44.8	1,120.0	71,200.0
Nonelectrical machinery	42.3	2.8	45.1	76,600.0
Electrical machinery and supplies	514.0	33.9	548.0	80,200.0
Transportation equipment	764.0	24.2	788.0	243,000.0
Instruments	29.8	1.0	30.7	31,400.0
Miscellaneous manufacturing	260.0	17.7	278.0	9,140.0
Electric and gas utilities	340.0	10.5	351.0	212,000.0
Nondurable goods: wholesale sales	60.6	0.1	60.7	86,000.0
Research labs, hospitals, universities	0.2	0.0	0.2	187,000.0
Commercial hazardous waste handlers	NA	5,720.0	5.7	7,300.0
Totals	189,000.0	5,720.0[d]	195,000.0	1,810,000.0

NA = Not applicable.

[a]This table shows the 20 demanding sectors, along with the total volume that each sector services commercially or on site, and the grand total of hazardous waste management demand originating in each generating sector. The volume of commercial services by the 20 demanding sectors was imputed by allocating the total commercially supplied quantities based on the ratio of each sector's transported waste quantities to the total quantity transported by the 20 sectors. This imputation was necessary because no information is available about commercial consumption arising in each of the 20 generating sectors.

[b]Data are taken from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

[c]1982 values. Data are taken from the Census of Service Industries, Washington, D.C., U.S. Department of Commerce, Bureau of the Census, 1982.

[d]Total consumption by captive facilities using commercial facilities.

TABLE 8-6. COST SHARES AND DEMAND ELASTICITIES BY SECTOR[a]

Sector	Cost share of HWM services, x 10^{-3}	Demand elasticity
Mining	0.5	-0.70
Grain and textile mill products	1.4	-0.70
Furniture, paper products, printing	0.4	-0.70
Industrial chemicals, inorganic and organic	84.6	-0.67
Plastics, fibers	180.0	-0.16
Biological, pharmaceutical, medical chemicals	14.1	-0.89
Assorted chemical products	43.1	-0.87
Paint and allied products, petroleum and coal	1.6	-0.23
Rubber, plastics	*	-0.13
Cement companies	1.5	-0.70
Primary metals	1.9	-0.70
Metal fabrication	1.8	-0.70
Nonelectrical machinery	0.1	-0.19
Electrical machinery and supplies	1.1	-1.05
Transportation equipment	1.1	-0.83
Instruments	0.2	-0.70
Miscellaneous manufacturing	2.6	-0.96
Electric and gas utilities	0.1	-1.90
Nondurable goods: wholesale sales	0.4	-0.70
Research labs, hospitals, universities	*	-2.92
Commercial hazardous waste handlers	NA	-2.41

* = Less than 0.05.
HWM = Hazardous waste management.
NA = Not applicable.

[a]The cost-shares and price elasticities reported in this table are the key parameters of the analytical model used to estimate the economic impacts of the air emission regulations. The cost-share of the hazardous waste management services of each of the generating sectors represents the ratio of the costs of hazardous waste management services to the value of shipments. The price elasticities of demand in the table are obtained from the literature.[8,9] Data on the value of shipments are taken from the Census of Service Industries, Washington, D.C., U.S. Department of Commerce, Bureau of the Census, 1982.

product this intermediate product represents. The elasticities of demand used in the model are found in the literature.[10,11] They are less than zero because an increase in the price of the commodity results, other things being equal, in a decrease in the quantity demanded of the commodity. For those sectors whose elasticity of demand is not available in the literature, -0.7 is assumed. This figure is consistent with the range of elasticities found in the literature for other sectors. These price elasticities of demand for hazardous waste management services are shown in Table 8-6.

8.1.3 Market Outcomes

The market forces represented above in the supply of and demand for hazardous waste management services result in a market solution for the quantity of each type of hazardous waste management service undertaken in each sector and the price of each type of management service. The baseline situation in these markets is the quantities for 1986 as shown in Table 8-5. In a competitive market, the market price for hazardous waste management services would equal the marginal cost of the highest cost supplier. Of course, most TSDF do not offer the service on the open market. Only the hazardous waste management services performed by the commercial sector actually pass through the market. The commercial TSDF were ordered by their marginal cost and the marginal cost of the highest-cost facility was selected as the market price. The price selected, $1,280/Mg, furnishes a baseline price against which the compliance costs of hazardous waste management resulting from the options may be compared.

8.2 ANALYTICAL APPROACH

This study estimates the economic impact of regulatory options on air emissions from hazardous waste TSDF, with special attention to the possible facility closure effects. The primary emphasis of the economic analysis is a multimarket partial equilibrium model of the hazardous waste management industry.

For the economic analysis, the 834 directly affected facilities in the 20 generator sectors and 1 commercial hazardous waste management sector were analyzed. The 1,098 storage-only facilities were excluded from detailed economic analysis because they represent less than 4 percent of the total compliance cost of all TSDF and less than 3 percent of the quantity of hazardous waste managed by all the TSDF. The costs of compliance for storage-only facilities are estimated and presented in Appendix I, Section I.2.

For each TSDF in the data base, the costs of implementing the emission controls were estimated. These costs are expressed as changes in capital and operating expenses incurred by the plants as a result of complying with the control options. Using this compliance cost information, the economic effects of the air emissions regulation on TSDF were then projected. The following impacts were projected:

- Price and quantity changes in affected markets
- Annual regulatory costs
- Employment effects
- Facility closures (if any)
- Small business effects.

The economic theory and operational model underlying this analysis are discussed in this section.

8.2.1 Model Overview

To estimate the impacts of the regulatory options, a comparative statics model, based in traditional microeconomic theory, was used. The term "comparative statics" means that a snapshot is presented of all of the affected markets in their baseline condition. It is then compared to another snapshot of the same markets after all of the adjustments have taken place in response to the controls. The market for the services of TSDF was assumed to be competitive. TSDF were assumed to operate in a profit-maximizing manner, and to have complete knowledge of all the markets in which they participated.

Decisions made by TSDF can be broken down into two broad categories:

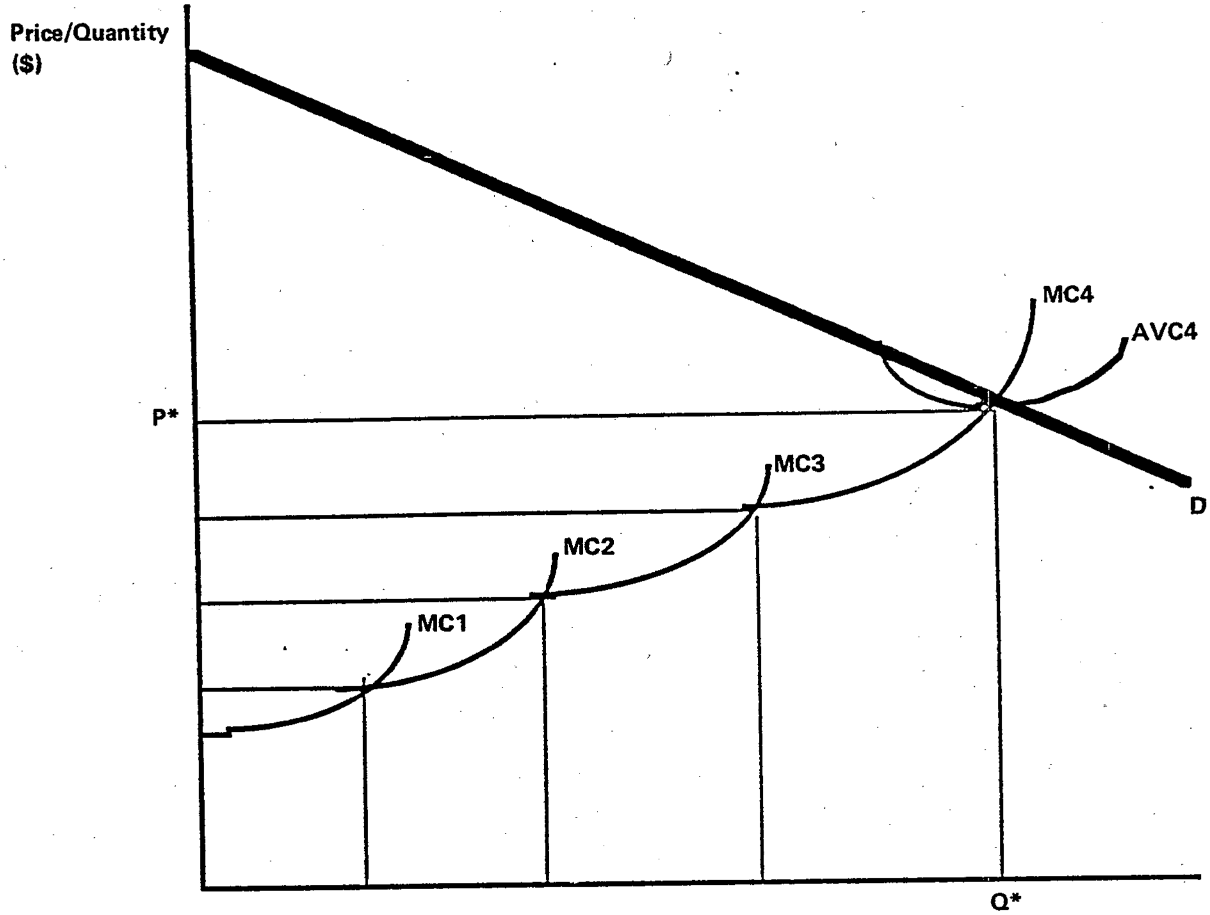
- Existing plant and equipment operating decisions, frequently referred to as short-run decisions
- Investment decisions for new plants and equipment, frequently referred to as long-run decisions.

Short-run or operating decisions concern the quantity of a good or services the firm produces to achieve the greatest profit, or the smallest loss. In general, a firm will continue to produce as long as the price received for its good or services is sufficient to cover the average variable, or operating, cost of producing it. As long as price exceeds average variable cost, the firm is covering the costs of all of its variable inputs and some of its capital costs as well.

Long-run or investment decisions require different reasoning. Because the investment in plant or equipment has not been made, that cost too is variable. For the firm to decide to invest in a new machine or plant, it must expect that the price it will receive for the goods or services produced by that machine or plant will be sufficiently high to cover all of the costs associated with producing it, including both the cost of purchasing the plant or equipment and a normal rate of return on the plant or equipment. In other words, the market price of the good or services must at least equal the plant's average total cost. The plant is not yet in place, so all inputs, and hence the scale of the plant, are variable.

At any given time, the firm's supply curve is its marginal cost curve above its average variable cost curve, and the market supply curve is the sum of the existing firms' supply curves (see Figure 8-1). The willingness of different plants--with different average variable costs of production--to produce at different market prices results in the familiar upward slope of the market supply curve. Firm 1 has the lowest operating costs, firm 4 the highest in Figure 8-1. The market price is determined by the intersection of the market demand and market supply curves. The marginal plant is that plant whose average operating costs just equal market price. If market price were to decrease, the marginal plant would close.

A regulation limiting air emissions from TSDF will increase both the capital and operating costs of these facilities. It is likely that the increase in costs will be greater per unit produced for existing plants, which must be retrofitted in order to comply with the regulation, than for new plants, which can design their equipment to comply. In addition, capital costs may be higher for small firms than for larger firms making the same change in equipment. This may be true because the interest rate



Note: In this market, firm 4, whose average operating costs exactly equal market price, is the marginal firm.

MC = Long-run marginal cost curve (for firms 1 through 4)
AVC = Average variable cost curve
P* = Market price
Q* = Quantity produced (output) at price P*
D = Market demand curve

Figure 8-1. A market supply curve constructed by summing four firms' supply curves.

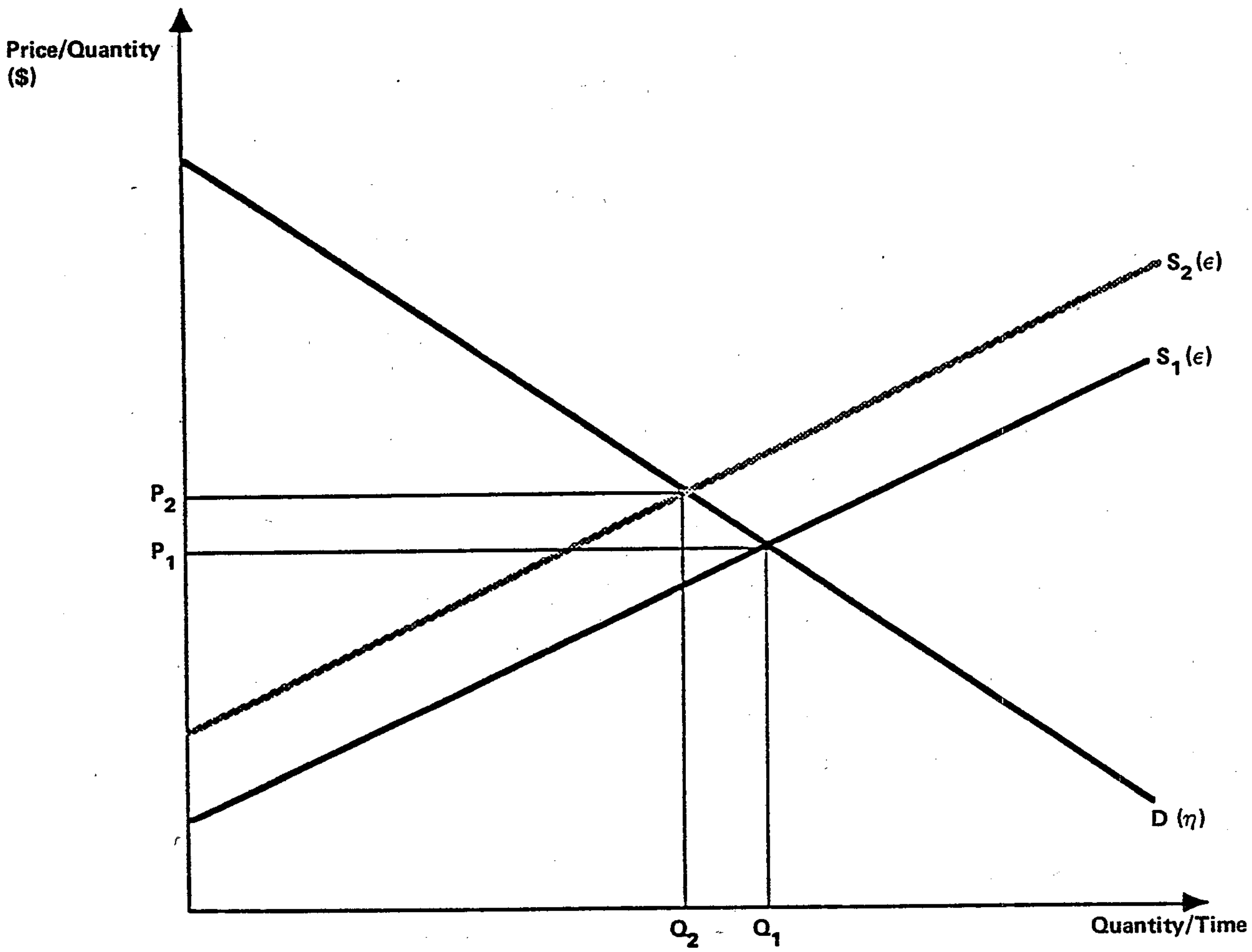
charged these smaller companies is higher than that charged larger companies. For example, while larger companies may be able to issue bonds (and have higher bond ratings and, hence lower financing costs than smaller companies), smaller companies more frequently must borrow funds from a bank. In fact, if their credit rating is sufficiently low, the smaller company may not be able to obtain a loan for pollution abatement equipment at any acceptable rate of interest. Finally, economies of scale in compliance are usually found, so small facilities may have higher unit compliance costs than large facilities.

The initial impact of the regulation will be in the directly affected market--the market for hazardous waste management services. The increased costs resulting from complying with the new air emission standard will cause each firm's supply curve, and therefore the market supply curve, of hazardous waste management services to shift upward. With a smaller supply, a higher market price is then required to justify producing any given level of output. The new equilibrium price will be higher and the new equilibrium quantity of services produced less than would have been the case in the absence of the regulation, all else being equal. Because the cost of onsite hazardous waste management services is higher than in the absence of the regulation, generators may reconsider their decision about whether to manage waste on site or off site. If the cost of their onsite management increases sufficiently, offsite hazardous waste management services may become more economical. They may also decide to alter their production process to reduce the quantity of hazardous waste management services they require.

In the market for the firms' primary products, the supply curve will also shift upward. This is because hazardous waste management is an input to their production process, and its cost has now risen. It will now cost more to produce a given output than without the regulation, resulting in higher prices and lower output rates. Figure 8-2 shows these changes.

8.2.2 Model Design

To assess the impact of the control options, a model of 82 simultaneous equations, designed to capture the major market interactions of firms in the affected industries identified earlier, was constructed. This model



P_1	=	Preregulation price
P_2	=	Postregulation price
Q_1	=	Preregulation quantity (output)
Q_2	=	Postregulation quantity (output)
S_1	=	Preregulation supply
S_2	=	Postregulation supply
D	=	Market demand
η	=	Demand elasticity (percent change in demand quantity for 1 percent change in price)
ϵ	=	Supply elasticity (percent change in supply quantity for 1 percent change in price)

Figure 8-2. Hypothetical price and output adjustments due to a market supply shift induced by air emission regulations.

is only for hazardous waste management facilities that, in addition to providing storage, treat or dispose of hazardous wastes. Storage-only facilities are addressed separately in Appendix I, Section I.2, by simply summing compliance costs.

When such a regulation is promulgated, its effects are felt throughout the economy. The major impact, however, will be felt in the active markets of firms directly affected by the regulation. Other markets both upstream and downstream from the directly affected markets will experience smaller impacts. It is beyond the scope of this analysis to detail every activity of every industry in these markets; rather, the most important trends and characteristics of each directly affected market are incorporated. The model is based on research by Muth,[12] Miedema,[13] and Gardner.[14] Specifically, it includes equations describing the industries' output markets and input markets for hazardous waste management services. Firms in these markets will bear the major impact of the regulation.

The model of TSDF is a comparative statics model. It portrays the impact of the control options on the markets most directly affected, assuming that all other conditions in the markets remain unchanged. For example, the prices of inputs other than hazardous waste management services are assumed constant, as is technology. The only thing that changes initially is the cost of hazardous waste management services, which increases as a result of the proposed regulation. It is assumed that all of the affected markets simultaneously arrive at new equilibrium positions.

The firms performing hazardous waste management services find that, as a result of the control options, their cost of doing business increases. This, in turn, may affect the price of hazardous waste management services, the quantities of hazardous waste management services performed on site and commercially, the quantity of other inputs used on site and commercially, and the quantity and price of final products produced.

The partial equilibrium multimarket model uses minimal data about the markets to project these market adjustments. The model uses percentage changes in production costs as a result of the regulation to generate the percentage changes in the following market variables:

- Price and quantity of goods produced in each generating sector

- Quantity of hazardous waste management services produced and consumed, on and off site, for each sector
- Price and quantity of commercial hazardous waste management services supplied.

These results are used to calculate economic impacts that result from the regulation. A detailed description of the model is presented in Appendix I, Section I.3.

To describe the relationships between the sectors in the affected markets, a set of parameters--including the demand elasticities in the final products markets, the supply elasticities in the hazardous waste management markets, and the share of total production costs represented by hazardous wastes--is used as presented in Section 8.1.

In addition to the parameters already developed, several other parameters--dealing largely with each sector's share of the hazardous wastes industries--are required to run the analytical model. These "share" parameters are shown in Table 8-7. The values shown in column 2 of Table 8-7 are each generating sector's share of commercial hazardous wastes. Similarly, columns 3 and 4 of Table 8-7 represent the other two parameters (the proportion of each sector's total demand for hazardous waste management services supplied onsite and commercially). The cost shift for the marginal facility is the shift parameter. Five shift parameters are used, one for each control option. These shift parameters, $\lambda 1$, $\lambda 2$, $\lambda 3$, $\lambda 4$, and $\lambda 5$, are shown in Table 8-8.

Another set of parameters describes the relationship between inputs in the production processes of each sector. These parameters are the elasticities of substitution between the various inputs used by the producers. It is assumed that the production of the goods produced by the generating sectors involves the use of two inputs. These inputs are (1) hazardous waste management services, and (2) a composite input. The elasticity of substitution between these inputs measures the ease with which the producer can substitute between them in his production process. It is difficult, *a priori*, to tell how much substitution is possible between hazardous waste management services and all other inputs--"waste minimization." It is assumed that some substitution is possible between hazardous waste

TABLE 8-7. MARKET SHARE PARAMETERS FOR HAZARDOUS WASTE MANAGEMENT SERVICES, BY SECTOR[a]

Sector	Share of all onsite HWM services, $\times 10^{-3}$	Distribution of HWM services: Onsite, $\times 10^{-3}$	Distribution of HWM services: Commercial, $\times 10^{-3}$
Mining	Ø.5	968.Ø	32.3
Grain and textile mill products	Ø.Ø	999.Ø	Ø.8
Furniture, paper products, printing	Ø.4	938.Ø	61.7
Industrial chemicals, inorganic and organic	797.Ø	956.Ø	43.7
Plastics, fibers	48.6	995.Ø	5.1
Biological, pharmaceutical, medical chemicals	28.8	945.Ø	55.2
Assorted chemical products	76.5	98Ø.Ø	2Ø.5
Paint and allied products, petroleum and coal	7.3	994.Ø	6.2
Rubber, plastics	Ø.1	946.Ø	54.2
Cement companies	Ø.3	949.Ø	51.1
Primary metals	17.Ø	953.Ø	47.2
Metal fabrication	7.8	96Ø.Ø	4Ø.1
Nonelectrical machinery	Ø.5	938.Ø	61.6
Electrical machinery and supplies	5.9	938.Ø	62.Ø
Transportation equipment	4.2	969.Ø	3Ø.7
Instruments	Ø.2	968.Ø	31.5
Miscellaneous manufacturing	3.1	936.Ø	63.5
Electric and gas utilities	1.8	97Ø.Ø	3Ø.Ø
Nondurable goods: wholesale sales	Ø.Ø	999.Ø	1.4
Research labs, hospitals, universities	Ø.Ø	97Ø.Ø	3Ø.4

HWM = Hazardous waste management.

[a]This table presents three additional "share" parameters required to run the analytical model. Column 2 of the table represents the generating sector's share of commercial hazardous waste management services (ratio of generating sector's consumption of commercial waste management services to the total commercial waste management services supplied by the commercial sector). Columns 3 and 4 of the table represent the proportion of each sector's total demand for hazardous waste management services supplied on site and commercially. Data are taken from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

TABLE 8-8. CONTROL OPTION SHIFT PARAMETERS BY SECTOR, PERCENT[a]

Sector	Control option,[b] $\times 10^{-3}$ 1	2	3	4	5
Mining	402.0	402.0	402.0	50.3	50.3
Grain and textile mill products	0.0	0.0	0.0	0.0	0.0
Furniture, paper products, printing	620.0	620.0	93.8	620.0	620.0
Industrial chemicals, inorganic and organic	487.0	381.0	108.0	7.9	7.9
Plastics, fibers	616.0	615.0	91.7	615.0	615.0
Biological, pharmaceutical, medical chemicals	624.0	93.0	75.0	93.0	14.3
Assorted chemical products	0.0	0.0	0.0	0.0	0.0
Paint and allied products, petroleum and coal	658.0	128.0	110.0	128.0	128.0
Rubber, plastics	616.0	616.0	85.3	616.0	616.0
Cement companies	581.0	581.0	50.3	581.0	581.0
Primary metals	402.0	402.0	402.0	402.0	402.0
Metal fabrication	402.0	118.0	95.6	118.0	118.0
Nonelectrical machinery	421.0	421.0	73.2	402.0	402.0
Electrical machinery and supplies	256.0	216.0	63.5	6.4	6.4
Transportation equipment	412.0	405.0	77.7	405.0	405.0
Instruments	0.0	0.0	0.0	0.0	0.0
Miscellaneous manufacturing	0.0	0.0	0.0	0.0	0.0
Electric and gas utilities	126.0	126.0	65.6	126.0	0.1
Nondurable goods: wholesale sales	3.6	0.0	0.0	0.0	0.0
Research labs, hospitals, universities	45.4	45.4	45.4	0.0	0.0
Commercial hazardous waste handlers	402.0	403.0	402.0	401.0	401.0

[a]The shift parameters, columns 2 through 6, characterize the effects of the regulatory control options 1 through 5, respectively, in the analytical model. For example, column 2 of the table represents the ratio of each sector's highest-cost facility's regulatory costs under control option 1 to the onsite hazardous waste management costs. Data for the analytical model are explained in Section 8.2.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

management services and all other inputs; specifically, all the elasticities of substitution are set equal to 1.

In summary, the impact model is a system of 82 linear equations representing the activities and relationships embodied in each of the affected markets in terms of the parameters described above and the dependent variables. These dependent variables are the percentage changes in prices and quantities in each of two sets of markets: the markets for goods and the market for hazardous waste management services. This system of linear equations is represented by

$$Zx = y \quad ,$$

where

Z = an 82 x 82 matrix of coefficients

x = an 82 x 1 vector of percentage changes in the dependent variables, and

y = an 82 x 1 vector of shifts in market relationships resulting from the control option.

To solve the system of equations, the Z matrix is inverted and multiplied by the vector of shift variables:

$$Z^{-1} y = x \quad .$$

For a more detailed description of the model, refer to Appendix I, Section I.3. This model is a simplification of a complex set of technical and behavioral relationships. It can provide only a general indication of the types of pressures and adjustments that may result due to the costs of complying with a control option.

8.3 ECONOMIC IMPACTS

The increased cost of performing hazardous waste management services due to the control options will affect plants with TSDF in several ways. Captive facilities use hazardous waste management as an input in the production of their products--for example, industrial chemicals. Managers of these plants may elect either to incur the higher costs of onsite hazardous waste management or to purchase these services from a commercial firm. Commercial firms will experience increased costs of hazardous waste management services. This will affect the prices they charge for hazardous waste management services. Next, the impact of the regulation may be felt in the markets for the goods and services produced by generators of hazardous waste. The partial equilibrium analytical model described above is used to estimate the direction and possible magnitude of changes in the following:

- Quantities of goods and services produced in the 20 generating sectors
- Prices of goods and services produced in the 20 generating sectors
- Quantities of hazardous waste management services supplied by captive and commercial facilities
- Quantity of commercial hazardous waste management demanded by each of the 20 generating sectors
- Price of hazardous waste management services
- Quantity of organic air emissions.

The number of facilities affected by the control options are identified in Table 8-9.

8.3.1 Price and Quantity Adjustments

Changes in the prices and quantities are projected for each control option for each of two markets:

- The market for goods and services produced by demanders of hazardous waste management services
- The market for hazardous waste management services.

Insignificant price increases and quantity decreases are projected for the products produced by the 20 generating sectors (see Tables 8-10 and 8-11). These adjustments are expected to be small due to the minor share of production costs represented by hazardous waste management services. Hazardous waste management costs represent less than one-tenth of one percent of production costs for all generator sectors except plastics.

Only slight reductions are projected in the quantity of hazardous waste generated under all control options. These reductions are due to two factors. First, the reduced output rate of the 20 generating sectors will

TABLE 8-9. NUMBER OF TREATMENT, STORAGE, AND DISPOSAL FACILITIES (TSDF) AFFECTED BY THE CONTROL OPTIONS[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	6	6	4	6	4
Grain and textile mill products	3	3	2	3	2
Furniture, paper products, printing	32	32	31	31	29
Industrial chemicals, inorganic and organic	113	105	97	103	103
Plastics, fibers	30	28	26	28	28
Biological, pharmaceutical, medical chemicals	16	16	15	16	16
Assorted chemical products	45	45	35	41	38
Paint and allied products, petroleum and coal	56	47	44	44	40
Rubber, plastics	6	6	5	5	5
Cement companies	10	10	10	3	3
Primary metals	62	61	52	49	43
Metal fabrication	61	49	40	45	41
Nonelectrical machinery	14	14	11	12	9
Electrical machinery and supplies	41	40	37	38	24
Transportation equipment	25	25	20	24	21
Instruments	6	6	4	5	4
Miscellaneous manufacturing	4	4	2	3	3
Electric and gas utilities	17	17	17	17	17
Nondurable goods: wholesale sales	4	3	1	3	2
Research labs, hospitals, universities	6	6	5	5	5
Commercial hazardous waste handlers	124	124	101	124	123
Totals	681	647	559	605	560

[a]The increased cost of performing hazardous waste management services as a result of the control options will affect TSDF in several ways. The number of facilities affected are obtained from the Source Assessment Model (SAM) Industry Profile data base (Appendix D, Section D.2.1) and are identified in this table.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-10. PRICE ADJUSTMENTS BY CONTROL OPTION FOR GOODS AND SERVICES PRODUCED BY HAZARDOUS WASTE GENERATORS, PERCENT[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	*	*	*	*	*
Grain and textile mill products	*	*	*	*	*
Furniture, paper products, printing	*	*	*	*	*
Industrial chemicals, inorganic and organic	0.037	0.031	0.008	0.016	0.016
Plastics, fibers	0.080	0.066	0.017	0.034	0.033
Biological, pharmaceutical, medical chemicals	0.006	0.005	0.001	0.003	0.003
Assorted chemical products	0.019	0.016	0.004	0.008	0.008
Paint and allied products, petroleum and coal	*	*	*	*	*
Rubber, plastics	*	*	*	*	*
Cement companies	*	*	*	*	*
Primary metals	*	*	*	*	*
Metal fabrication	*	*	*	*	*
Nonelectrical machinery	*	*	*	*	*
Electrical machinery and supplies	*	*	*	*	*
Transportation equipment	*	*	*	*	*
Instruments	*	*	*	*	*
Miscellaneous manufacturing	0.001	*	*	*	*
Electric and gas utilities	*	*	*	*	*
Nondurable goods: wholesale sales	*	*	*	*	*
Research labs, hospitals, universities	*	*	*	*	*

* = Less than 0.001.

[a]This table presents the changes in the prices estimated by the analytical model for the products produced by the 20 generating sectors. The price increases are insignificant because hazardous waste management services represent a minor share of production costs. Data for the analytical model are explained in Section 8.2.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-11. QUANTITY ADJUSTMENTS BY CONTROL OPTION FOR GOODS AND SERVICES PRODUCED BY HAZARDOUS WASTE GENERATORS, PERCENT[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	*	*	*	*	*
Grain and textile mill products	*	*	*	*	*
Furniture, paper products, printing	*	*	*	*	*
Industrial chemicals, inorganic and organic	-0.025	-0.021	-0.005	-0.011	-0.010
Plastics, fibers	-0.013	-0.011	-0.003	-0.005	-0.005
Biological, pharmaceutical, medical chemicals	-0.006	-0.005	-0.001	-0.002	-0.002
Assorted chemical products	-0.017	-0.014	-0.004	-0.007	-0.007
Paint and allied products, petroleum and coal	*	*	*	*	*
Rubber, plastics	*	*	*	*	*
Cement companies	*	*	*	*	*
Primary metals	*	*	*	*	*
Metal fabrication	*	*	*	*	*
Nonelectrical machinery	*	*	*	*	*
Electrical machinery and supplies	*	*	*	*	*
Transportation equipment	*	*	*	*	*
Instruments	*	*	*	*	*
Miscellaneous manufacturing	*	*	*	*	*
Electric and gas utilities	*	*	*	*	*
Nondurable goods: wholesale sales	*	*	*	*	*
Research labs, hospitals, universities	*	*	*	*	*

* = Less than -0.001.

[a]This table presents the changes in the quantities estimated by the analytical model for the products produced by the 20 generating sectors. The quantity decreases are insignificant because hazardous waste management services represent a minor share of production costs. Data for the analytical model are explained in Section 8.2.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

reduce the generation of hazardous waste. Also, it is assumed that some potential waste minimization will further contribute to the reduced level of hazardous waste generation. The sector-by-sector values for all options are shown in Tables 8-12 to 8-16. Overall, the projected reduction in hazardous waste generation is between approximately 200,000 and 800,000 Mg annually, depending on the control option.

The major adjustment projected is the shift to less offsite management. Although the price of offsite management services is projected to increase only minimally for all control options, these increases are more than the cost increase for relatively large captive hazardous waste management facilities. Thus, the quantity of offsite hazardous waste management is projected to decrease slightly, as shown in Table 8-17.

8.3.2 Regulatory Costs

A direct cost incurred by TSDF as a result of the regulation is the compliance cost. Compliance costs are the costs of meeting the air emissions control options. For each facility, these costs will vary depending on the configuration of the facility and the volume of throughput. Tables 8-18 and 8-19 present the compliance costs without quantity adjustments and with quantity adjustments presented above, respectively. The compliance costs are smaller with the quantity adjustments because less hazardous waste is projected to be generated due to reductions in production of the goods and services produced by each sector and due to increased waste minimization.

A large part of the compliance costs incurred by TSDF is the capital cost required to modify hazardous waste management units to comply with the control options. The capital costs are shown in Table 8-20. In Table 8-21, the percentage of the hazardous waste management costs are represented by compliance cost for all captive and commercial facilities. For most sectors this is below 5 percent.

8.3.3 Emissions and Cost Effectiveness

Organic air emissions will decrease for the affected facilities due to two factors: (1) the control efficiencies of each option, and (2) the reduction in hazardous waste generation.

Table 8-22 provides the baseline estimates of emissions and the percentage reduction from these values.

TABLE 8-12. QUANTITY ADJUSTMENTS IN WASTE GENERATION AND MANAGEMENT BY GENERATING SECTOR: CONTROL OPTION 1[a]

Sector	HWM services, 10^3 Mg/yr		
	Onsite	Commercial	Total
Mining	-0.14	-0.28	-0.42
Grain and textile mill products	1.05	-1.63	-0.58
Furniture, paper products, printing	-0.16	-0.02	-0.18
Industrial chemicals, inorganic and organic	-439.00	-9.78	-449.00
Plastics, fibers	-325.00	121.00	-204.00
Biological, pharmaceutical, medical chemicals	-17.20	4.03	-13.20
Assorted chemical products	35.60	-129.00	-93.80
Paint and allied products, petroleum and coal	-39.50	9.54	-30.00
Rubber, plastics	-0.03	*	-0.02
Cement companies	-0.14	-0.03	-0.17
Primary metals	-6.80	-2.33	-9.13
Metal fabrication	-3.92	-1.03	-4.95
Nonelectrical machinery	-0.15	-0.05	-0.20
Electrical machinery and supplies	-0.09	-2.34	-2.43
Transportation equipment	-2.91	-0.58	-3.49
Instruments	0.17	-0.30	-0.14
Miscellaneous manufacturing	*	-1.23	-1.23
Electric and gas utilities	-0.18	-1.38	-1.56
Nondurable goods: wholesale sales	*	-0.27	-0.27
Research labs, hospitals, universities	*	*	*
Commercial hazardous waste handlers	NA	-15.80	-15.80
Totals	-798.00	NA	-830.57[b]

* = Absolute value less than 0.01.
HWM = Hazardous waste management.
NA = Not applicable.

[a]Data for this table are obtained from the Source Assessment Model (SAM) Industry Profile data base, (Appendix D, Section D.2.1.), and from the analytical model (as explained in Section 8.2).

[b]The effects of control option 1 on the quantity of waste management services demanded by the 20 generating sectors estimated by the analytical model are presented in this table. Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-13. QUANTITY ADJUSTMENTS IN WASTE GENERATION AND MANAGEMENT BY GENERATING SECTOR: CONTROL OPTION 2[a]

Sector	HWM services, 10^3 Mg/yr Onsite	Commercial	Total
Mining	-0.18	-0.17	-0.35
Grain and textile mill products	0.87	-1.35	-0.48
Furniture, paper products, printing	-0.17	0.02	-0.15
Industrial chemicals, inorganic and organic	-341.00	-29.20	-370.00
Plastics, fibers	-326.00	157.00	-168.00
Biological, pharmaceutical, medical chemicals	-2.33	-8.57	-10.90
Assorted chemical products	29.40	-107.00	-77.50
Paint and allied products, petroleum and coal	-4.71	-20.10	-24.80
Rubber, plastics	-0.03	0.01	-0.02
Cement companies	-0.15	0.01	-0.14
Primary metals	-6.99	-0.55	-7.54
Metal fabrication	-0.94	-3.16	-4.09
Nonelectrical machinery	-0.15	-0.01	-0.16
Electrical machinery and supplies	-0.09	-1.91	-2.01
Transportation equipment	-2.90	0.01	-2.89
Instruments	0.14	-0.25	-0.11
Miscellaneous manufacturing	*	-1.02	-1.02
Electric and gas utilities	-0.22	-1.06	-1.28
Nondurable goods: wholesale sales	*	-0.22	-0.22
Research labs, hospitals, universities	*	*	*
Commercial hazardous waste handlers	NA	-17.00	-17.00
Totals	-656.00	NA	-690.00[b]

* = Absolute value less than 0.01.
HWM = Hazardous waste management.
NA = Not applicable.

[a]Data for this table are obtained from the Source Assessment Model (SAM) Industry Profile data base, (Appendix D, Section D.2.1.), and from the analytical model (as explained in Section 8.2).

[b]The effects of control option 2 on the quantity of waste management services demanded by the 20 generating sectors estimated by the analytical model are presented in this table. Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-14. QUANTITY ADJUSTMENTS IN WASTE GENERATION AND MANAGEMENT BY GENERATING SECTOR: CONTROL OPTION 3[a]

Sector	HWM services, 10^3 Mg/yr		
	Onsite	Commercial	Total
Mining	-0.32	0.23	-0.09
Grain and textile mill products	0.23	-0.36	-0.13
Furniture, paper products, printing	-0.02	-0.02	-0.04
Industrial chemicals, inorganic and organic	-97.60	0.05	-97.60
Plastics, fibers	-47.90	3.54	-44.40
Biological, pharmaceutical, medical chemicals	-2.04	-0.83	-2.87
Assorted chemical products	7.74	-28.10	-20.40
Paint and allied products, petroleum and coal	-6.41	-0.12	-6.53
Rubber, plastics	*	-0.00	*
Cement companies	*	-0.34	-0.04
Primary metals	-7.66	5.67	-1.99
Metal fabrication	-0.94	-0.14	-1.08
Nonelectrical machinery	-0.02	-0.02	-0.04
Electrical machinery and supplies	-0.06	-0.47	-0.53
Transportation equipment	-0.54	-0.22	-0.76
Instruments	0.04	-0.07	-0.03
Miscellaneous manufacturing	*	-0.27	-0.27
Electric and gas utilities	-0.168	-0.17	-0.34
Nondurable goods: wholesale sales	*	-0.06	-0.06
Research labs, hospitals, universities	*	*	*
Commercial hazardous waste handlers	NA	-21.40	-21.40
Totals	-156.00	NA	-199.00[b]

* = Absolute value less than 0.01.
HWM = Hazardous waste management.
NA = Not applicable.

[a]Data for this table are obtained from the Source Assessment Model (SAM) Industry Profile data base, (Appendix D, Section D.2.1.), and from the analytical model (as explained in Section 8.2).

[b]The effects of control option 3 on the quantity of waste management services demanded by the 20 generating sectors estimated by the analytical model are presented in this table. Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and I5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-15. QUANTITY ADJUSTMENTS IN WASTE GENERATION AND MANAGEMENT BY GENERATING SECTOR: CONTROL OPTION 4[a]

Sector	HWM services, 10^3 Mg/yr		
	Onsite	Commercial	Total
Mining	0.05	-0.23	-0.18
Grain and textile mill products	0.44	-0.69	-0.24
Furniture, paper products, printing	-0.20	0.13	-0.08
Industrial chemicals, inorganic and organic	11.40	-200.00	-189.00
Plastics, fibers	-328.00	243.00	-85.80
Biological, pharmaceutical, medical chemicals	-2.47	-3.08	-5.55
Assorted chemical products	15.00	-54.40	-39.40
Paint and allied products, petroleum and coal	-6.62	-6.00	-12.60
Rubber, plastics	-0.03	0.02	-0.01
Cement companies	-0.18	0.11	-0.07
Primary metals	-7.44	3.60	-3.84
Metal fabrication	-1.10	-0.99	-2.08
Nonelectrical machinery	-0.16	0.07	-0.08
Electrical machinery and supplies	0.48	-1.51	-1.02
Transportation equipment	-2.99	1.52	-1.47
Instruments	0.07	-0.13	-0.06
Miscellaneous manufacturing	*	-0.52	-0.52
Electric and gas utilities	-0.32	-0.33	-0.65
Nondurable goods: wholesale sales	*	-0.11	-0.11
Research labs, hospitals, universities	*	*	*
Commercial hazardous waste handlers	NA	-199.00	-19.90
Totals	-323.00	NA	-362.00[b]

* = Absolute value less than 0.01.
HWM = Hazardous waste management.
NA = Not applicable.

[a]Data for this table are obtained from the Source Assessment Model (SAM) Industry Profile data base, (Appendix D, Section D.2.1.), and from the analytical model (as explained in Section 8.2).

[b]The effects of control option 4 on the quantity of waste management services demanded by the 20 generating sectors estimated by the analytical model are presented in this table. Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and I5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-16. QUANTITY ADJUSTMENTS IN WASTE GENERATION AND MANAGEMENT BY GENERATING SECTOR: CONTROL OPTION 5[a]

Sector	HWM services, 10^3 Mg/yr		
	Onsite	Commercial	Total
Mining	0.05	-0.23	-0.18
Grain and textile mill products	0.44	-0.68	-0.24
Furniture, paper products, printing	-0.20	0.13	-0.08
Industrial chemicals, inorganic and organic	11.30	-190.00	-187.00
Plastics, fibers	-329.00	243.00	-85.20
Biological, pharmaceutical, medical chemicals	-0.26	-5.26	-5.51
Assorted chemical products	14.80	-54.00	-39.20
Paint and allied products, petroleum and coal	-6.63	-5.90	-12.50
Rubber, plastics	-0.03	0.02	-0.01
Cement companies	-0.18	0.11	-0.07
Primary metals	-7.44	3.62	-3.81
Metal fabrication	-1.10	-0.97	-2.07
Nonelectrical machinery	-0.16	0.08	-0.08
Electrical machinery and supplies	0.48	-1.50	-1.01
Transportation equipment	-2.99	1.53	-1.46
Instruments	0.07	-0.13	-0.06
Miscellaneous manufacturing	*	-0.52	-0.52
Electric and gas utilities	0.11	-0.76	-0.65
Nondurable goods: wholesale sales	*	-0.11	-0.11
Research labs, hospitals, universities	*	*	*
Commercial hazardous waste handlers	NA	-19.90	-19.90
Totals	-320.000	NA	-360.00[b]

* = Absolute value less than 0.01.
HWM = Hazardous waste management.
NA = Not applicable.

[b]The effects of control option 5 on the quantity of waste management services demanded by the 20 generating sectors estimated by the analytical model are presented in this table. Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and I5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-17. PRICE AND QUANTITY ADJUSTMENTS IN THE MARKET FOR COMMERCIAL HAZARDOUS WASTE MANAGEMENT SERVICES[a]

Control[b] option	Waste quantity, 10^3 Mg/yr	Price of HWM, $/Mg	Change from baseline, %	
			Quantity	Price
Baseline	5,718	1,276	--	--
Option 1	5,703	1,281	-0.28	0.44
Option 2	5,702	1,280	-0.30	0.37
Option 3	5,697	1,277	-0.37	0.10
Option 4	5,699	1,278	-0.35	0.19
Option 5	5,699	1,278	-0.35	0.19

HWM = Hazardous waste management.

[a]This table presents the changes in the prices and quantities estimated by the analytical model for the commercial hazardous waste management sector. The price increases and quantity decreases are small in comparison to the baseline price ($1,276/Mg) and baseline volume of hazardous waste services supplied (5.7 million Mg). Data for this table are obtained from the Source Assessment Model (SAM) Industry Profile data base, (Appendix D, Section D.2.1.), and from the analytical model (as explained in Section 8.2).

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-18. COMPLIANCE COSTS BY CONTROL OPTION WITHOUT QUANTITY ADJUSTMENTS, $\$10^6$/yr[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	0.19	0.10	0.04	0.10	0.07
Grain and textile mill products	0.97	0.97	0.10	0.97	0.97
Furniture, paper products, printing	0.17	0.17	0.04	0.17	0.12
Industrial chemicals, inorganic and organic	245.00	203.00	59.00	188.00	119.00
Plastics, fibers	445.00	420.00	255.00	21.30	21.26
Biological, pharmaceutical, medical chemicals	1.76	1.54	0.72	1.54	1.54
Assorted chemical products	155.00	38.40	22.50	34.20	32.63
Paint and allied products, petroleum and coal	12.00	4.20	0.98	3.21	3.17
Rubber, plastics	0.01	0.01	0.01	0.00	0.00
Cement companies	0.21	0.16	0.04	0.01	0.01
Primary metals	6.82	6.70	2.20	4.11	3.05
Metal fabrication	1.67	0.85	0.34	0.77	0.12
Nonelectrical machinery	0.18	0.11	0.03	0.11	0.09
Electrical machinery and supplies	2.41	2.38	0.32	2.25	2.23
Transportation equipment	0.37	0.22	0.08	0.08	0.07
Instruments	0.17	0.17	0.03	0.17	0.16
Miscellaneous manufacturing	0.13	0.13	0.00	0.13	0.06
Electric and gas utilities	0.22	0.21	0.12	0.21	0.00
Nondurable goods: wholesale sales	0.02	0.01	0.01	0.01	0.01
Research labs, hospitals, universities	0.00	0.00	0.00	0.00	0.00
Commercial hazardous waste handlers	19.10	15.10	13.40	13.00	12.90
Totals	892.00	695.00	355.00	271.00	197.00

[a]This table presents the compliance costs of each regulatory control option by the 21 market sectors (20 generating sectors and 1 commercial sector) by summing the compliance costs of facilities included in the sector. Data on compliance costs are obtained from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-19. COMPLIANCE COSTS BY CONTROL OPTION WITH QUANTITY ADJUSTMENTS, $\$10^6$/yr[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	0.19	0.10	0.04	0.10	0.07
Grain and textile mill products	0.97	0.97	0.10	0.97	0.97
Furniture, paper products, printing	0.17	0.17	0.04	0.17	0.12
Industrial chemicals, inorganic and organic	244.00	202.00	58.90	188.00	119.00
Plastics, fibers	443.00	418.00	255.00	21.13	21.13
Biological, pharmaceutical, medical chemicals	1.75	1.54	0.72	1.54	1.54
Assorted chemical products	155.00	38.40	22.50	32.20	32.60
Paint and allied products, petroleum and coal	12.00	4.19	0.98	3.20	3.17
Rubber, plastics	0.01	0.01	0.01	0.00	0.00
Cement companies	0.21	0.16	0.04	0.01	0.01
Primary metals	6.79	6.68	2.20	4.09	3.04
Metal fabrication	1.67	0.85	0.34	0.76	0.12
Nonelectrical machinery	0.18	0.11	0.03	0.11	0.09
Electrical machinery and supplies	2.41	2.38	0.32	2.25	2.23
Transportation equipment	0.37	0.22	0.08	0.08	0.07
Instruments	0.17	0.17	0.03	0.17	0.16
Miscellaneous manufacturing	0.13	0.13	0.00	0.13	0.06
Electric and gas utilities	0.22	0.21	0.12	0.21	0.00
Nondurable goods: wholesale sales	0.02	0.01	0.01	0.01	0.01
Research labs, hospitals, universities	0.00	0.00	0.00	0.00	0.00
Commercial hazardous waste handlers	19.00	15.00	13.40	13.00	12.90
Totals	888.00	691.00	354.00	271.00	197.00

[a]This table presents the compliance costs of each regulatory control option by the 21 market sectors (20 generating sectors and 1 commercial sector) by summing the compliance costs of facilities included in the sector. The compliance costs presented in this table account for the quantity changes estimated by the analytical model. Data on compliance costs are obtained from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-20. CAPITAL COSTS BY CONTROL OPTION, \$10⁶[a]

Sector	Control option[b] 1	2	3	4	5
Mining	0.44	0.29	0.17	0.29	0.20
Grain and textile mill products	1.98	1.98	0.50	1.98	1.98
Furniture, paper products, printing	0.38	0.38	0.11	0.38	0.28
Industrial chemicals, inorganic and organic	546.00	474.00	170.00	436.00	272.00
Plastics, fibers	1,040.00	1,000.00	631.00	48.00	48.00
Biological, pharmaceutical, medical chemicals	4.89	4.52	2.94	4.52	4.52
Assorted chemical products	318.00	122.00	90.00	112.00	107.00
Paint and allied products, petroleum and coal	24.70	10.80	3.98	8.26	8.13
Rubber, plastics	0.02	0.02	0.02	0.01	0.01
Cement companies	0.49	0.39	0.14	0.02	0.02
Primary metals	15.65	15.48	5.82	9.46	6.92
Metal fabrication	3.44	2.18	1.08	2.01	0.24
Nonelectrical machinery	0.38	0.27	0.11	0.26	0.23
Electrical machinery and supplies	4.78	4.72	1.42	4.50	4.46
Transportation equipment	0.72	0.45	0.24	0.18	0.16
Instruments	0.36	0.36	0.12	0.35	0.35
Miscellaneous manufacturing	0.22	0.22	0.00	0.21	0.10
Electric and gas utilities	0.53	0.51	0.30	0.50	0.00
Nondurable goods: wholesale sales	0.03	0.03	0.03	0.02	0.02
Research labs, hospitals, universities	0.00	0.00	0.00	0.00	0.00
Commercial hazardous waste handlers	42.40	36.00	32.40	30.70	30.00
Totals	2,000.00	1,680.00	941.00	660.00	486.00

[a]This table presents the capital costs of each regulatory control option by the 21 market sectors (20 generating sectors and 1 commercial sector) by summing the compliance capital costs of facilities included in the sector. Data on capital costs are obtained from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

TABLE 8-21. COMPLIANCE COSTS AS PERCENT OF HAZARDOUS WASTE MANAGEMENT COSTS, PERCENT[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	1.37	Ø.68	Ø.32	Ø.68	Ø.47
Grain and textile mill products	2.87	2.87	Ø.29	2.87	2.87
Furniture, paper products, printing	3.11	3.11	Ø.75	3.11	2.26
Industrial chemicals, inorganic and organic	2.24	1.85	Ø.54	1.72	1.Ø9
Plastics, fibers	2.23	2.1Ø	1.28	Ø.11	Ø.11
Biological, pharmaceutical, medical chemicals	1.43	1.25	Ø.59	1.25	1.25
Assorted chemical products	11.6Ø	2.88	1.68	2.57	2.45
Paint and allied products, petroleum and coal	5.68	1.98	Ø.46	1.51	1.49
Rubber, plastics	1.Ø8	1.Ø7	Ø.68	Ø.37	Ø.37
Cement companies	4.14	3.Ø8	Ø.84	Ø.2Ø	Ø.2Ø
Primary metals	7.23	7.12	2.34	4.36	3.23
Metal fabrication	2.27	1.16	Ø.46	1.Ø4	Ø.16
Nonelectrical machinery	8.51	5.33	1.23	5.28	4.3Ø
Electrical machinery and supplies	4.99	4.92	Ø.67	4.66	4.61
Transportation equipment	Ø.16	Ø.Ø9	Ø.Ø3	Ø.Ø4	Ø.Ø3
Instruments	2.66	2.65	Ø.46	2.65	2.6Ø
Miscellaneous manufacturing	8.95	8.95	Ø.Ø4	8.7Ø	4.35
Electric and gas utilities	2.26	2.18	1.24	2.14	Ø.ØØ
Nondurable goods: wholesale sales	Ø.Ø5	Ø.Ø4	Ø.Ø4	Ø.Ø2	Ø.Ø2
Research labs, hospitals, universities	Ø.29	Ø.27	Ø.Ø3	Ø.26	Ø.26
Commercial hazardous waste handlers	4.Ø5	3.2Ø	2.85	2.76	2.74

[a]This table presents the proportion (percent) of compliance costs (annualized capital plus operating costs) to the annual hazardous waste management costs of the onsite waste management for each control option and for each of the 21 market sectors (2Ø generating sectors and 1 commercial hazardous waste management sector). Data on compliance costs are obtained from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = Ø ppm organics; 2 and 3 = 5ØØ ppm; 4 = 1,5ØØ ppm; and 5 = 3,ØØØ ppm). The example control options are described in Chapter 5.Ø.

TABLE 8-22. EMISSIONS AND COST EFFECTIVENESS BY CONTROL OPTION

	Control option[a,b]				
	5	4	3	2	1
Emissions (10^3 Mg/yr)[c]	191	158	144	113	111
Emission reduction[d] (10^3 Mg/yr from baseline)	1,380	1,408	1,420	1,450	1,460
Compliance cost (10^6/yr)[e]	197	271	354	691	888
Cost effectiveness (average) (\$$10^3$/mg emission reduction)[e]	0.14	0.19	0.25	0.48	0.61
Cost effectiveness (marginal) (\$$10^3$/mg emission reduction)[e]	0.14	2.22	5.99	10.9	98.1

[a]This table presents the cost-effectiveness of the regulatory control options. The control options are listed in order of emissions reduction in columns 2 through 6. The rows of the table include the effectiveness of control options such as emissions, emission reduction, compliance cost, cost-effectiveness (average), and cost-effectiveness (marginal). For example, the average cost-effectiveness, 0.14 (row 4, column 1) is the ratio of compliance costs (197.14) and emission reduction (1,375). The marginal cost-effectiveness, 5.99 (row 5, column 3) is the ratio of the incremental compliance costs (354.51-270.64) and the incremental emission reduction (1,422-1,408).

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = 0 ppm organics; 2 and 3 = 500 ppm; 4 = 1,500 ppm; and 5 = 3,000 ppm). The example control options are described in Chapter 5.0.

[c]Baseline emissions were 1,566 from the affected facilities.

[d]Data on emission reduction are obtained from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

[e]With quantity adjustment. Data on compliance costs are obtained from Table 8-18.

8.3.4 Facility Closures

The costs of compliance will move each firm's average variable cost (marginal cost) upward. As a consequence of market adjustments of supply and demand, the economic model predicted that the new equilibrium price of hazardous waste services would be higher and the new market quantity lower. The reduced quantity of hazardous waste services implies reduced capacity utilization rates across the industry, and possibly facility closures.

The basic economic model of facility closures posits that if the price of the commodity does not cover average variable cost, then total costs exceed total revenue and the firm should close the facility. Porter[15] identifies a number of reasons why closures may not always accompany such situations:

- Existence of durable and specialized assets
- Presence of closure costs
- Absence of precise information on revenues and costs
- Existence of other managerial or emotional factors
- Absence of a mechanism for asset disposition.

However, the basic facility model is intuitively appealing and is capable of identifying possible closure candidates. For captive facilities, using the market price is especially problematic because the hazardous waste management services are the result of an internal transaction and do not take place in a market. However, the market price is the best surrogate available for the marginal benefit of the captive-provided hazardous waste management services. Also, simple hazardous waste management cost functions are used that represent the general relationship between hazardous waste management output and costs. Undoubtedly, many other important factors that affect production costs are ignored here. Thus, the results can only suggest the general magnitude of the facility closure pressures that the options may create.

Table 8-23 shows the possible facility closures given the assumptions employed in this analysis:

- Hazardous waste management services are competitively produced.

TABLE 8-23. POTENTIAL FACILITY CLOSURES BY CONTROL OPTION AND SECTOR[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	3	3	3	Ø	Ø
Grain and textile mill products	Ø	Ø	Ø	Ø	Ø
Furniture, paper products, printing	9	9	9	9	9
Industrial chemicals, inorganic and organic	11	11	11	Ø	Ø
Plastics, fibers	1Ø	1Ø	1Ø	1Ø	1Ø
Biological, pharmaceutical, medical chemicals	11	11	11	11	11
Assorted chemical products	Ø	Ø	Ø	Ø	Ø
Paint and allied products, petroleum and coal	9	9	9	9	9
Rubber, plastics	1	1	1	1	1
Cement companies	1	1	1	1	1
Primary metals	3	3	3	3	3
Metal fabrication	5	5	5	5	5
Nonelectrical machinery	5	5	5	5	5
Electrical machinery and supplies	2	2	2	Ø	Ø
Transportation equipment	5	5	5	5	5
Instruments	Ø	Ø	Ø	Ø	Ø
Miscellaneous manufacturing	Ø	Ø	Ø	Ø	Ø
Electric and gas utilities	1	1	1	1	Ø
Nondurable goods: wholesale sales	Ø	Ø	Ø	Ø	Ø
Research labs, hospitals, universities	Ø	Ø	Ø	Ø	Ø
Commercial hazardous waste handlers	7	7	7	7	7
Totals	83	83	83	67	66

[a]This table is estimated by the analytical model with the assumptions that (1) hazardous waste management services are produced competitively and (2) each facility has constant costs to the capacity utilization rate and infinite costs thereafter. Because hazardous waste generation is expected to decrease nominally, however, it is doubtful that few (if any) of the closures predicted by the model would actually take place.

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = Ø ppm organics; 2 and 3 = 5ØØ ppm; 4 = 1,5ØØ ppm; and 5 = 3,ØØØ ppm). The example control options are described in Chapter 5.Ø.

- Each hazardous waste management facility has constant costs to the capacity utilization rate, and infinite costs thereafter.

These assumptions lead to the conclusion that some very small facilities would be uneconomical and would experience pressures to close under the control options. However, given the nominal reduction in hazardous waste generation, it is doubtful that few, if any, of the closures predicted by the model would actually take place. There are several reasons for this interpretation of the results: (1) The reductions in hazardous waste generation are likely to be distributed across all generators. Thus, each generator will slightly reduce the operating rate of the hazardous waste management facility. (2) The permitting process for a hazardous waste management facility is long and costly. Facilities with transferrable permits are likely to become more valuable when market prices for waste management services are rising. Firms that run facilities with transferable permits* are likely to sell the permits to more efficient entrepreneurs. (3) Transportation costs will preclude some of the projected reallocations of waste management. (4) Closure costs can be very substantial.

8.3.5 Employment Effects

Increases in the cost of waste management services are projected to slightly reduce the quantity of these services. The possible changes in jobs due to these reductions is presented in Table 8-24.[16] These estimates are for the hazardous waste industry and are the direct consequences of the potential plant closures in Table 8-23. The number of jobs in the TSDF industry are estimated using a regression model. A representative sample of facilities was selected from the SAM Industry Profile data base and the number of production workers and amount of hazardous waste obtained.[17] A simple linear regression model was used to estimate the relationship between number of jobs and production quantity:

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*Transferable permits allow a business to sell the permit to a potential buyer of the facility.

TABLE 8-24. POTENTIAL EMPLOYMENT EFFECTS BY CONTROL OPTION AND SECTOR, NUMBER OF JOBS[a]

Sector	Control option[b]				
	1	2	3	4	5
Mining	-11	-11	-11	Ø	Ø
Grain and textile mill products	Ø	Ø	Ø	Ø	Ø
Furniture, paper products, printing	-Ø	-Ø	-Ø	-Ø	-Ø
Industrial chemicals, inorganic and organic	-135	-135	-135	Ø	Ø
Plastics, fibers	-98	-98	-98	-98	-98
Biological, pharmaceutical, medical chemical	-Ø	-Ø	-Ø	-Ø	-Ø
Assorted chemical products	Ø	Ø	Ø	Ø	Ø
Paint and allied products, petroleum and coal	-3	-3	-3	-3	-3
rubber, plastics	-Ø	-Ø	-Ø	-Ø	-Ø
Cement companies	-Ø	-Ø	-Ø	-Ø	-Ø
Primary metals	-4	-4	-4	-4	-4
Metal fabrication	-5	-5	-5	-5	-5
Nonelectrical machinery	-Ø	-Ø	-Ø	-Ø	-Ø
Electrical machinery and supplies	-Ø	-Ø	-Ø	Ø	Ø
Transportation equipment	-58	-58	-58	-58	-58
Instruments	Ø	Ø	Ø	Ø	Ø
Miscellaneous manufacturing	Ø	Ø	Ø	Ø	Ø
Electric and gas utilities	-Ø	-Ø	-Ø	-Ø	Ø
Nondurable goods: wholesale sales	Ø	Ø	Ø	Ø	Ø
Research labs, hospitals, universities	Ø	Ø	Ø	Ø	Ø
Commercial hazardous waste handlers	-4	-4	-4	-4	-4
Totals	-319	-319	-319	-172	-172

[a]This table is computed by summing the job losses (number of jobs per year) from the closed facilities projected in Table 8-23. The number of jobs in the closed facilities is estimated using the regression model:

$$L = A + B Q,$$

where L = number of production workers, Q = quantity of waste (Mg/yr), A = intercept of the regression, and B = slope of the regression. (See Reference 16 for source of data).

[b]Control options 1 through 5 are based predominantly on the use of add-on emission controls and reflect five levels of controls (1 = Ø ppm organics; 2 and 3 = 5ØØ ppm; 4 = 1,5ØØ ppm; and 5 = 3,ØØØ ppm). The example control options are described in Chapter 5.Ø.

$$L = A + BQ$$

where

L = number of production workers

Q = quantity of waste (Mg/yr)

A = intercept of the regression

B = slope of the regression.

The estimated regression equation was statistically significant (5 percent level of statistical significance).

Table 8-24 indicates that the number of hazardous waste management jobs is likely to decline overall. The number of jobs lost in the regulatory options 1 to 5 is less than 1.5 percent of the total number of jobs before the regulation. The number of jobs for the hazardous waste industry is presented in Appendix I, section I.A.

The regulatory costs identified and estimated above are annualized capital and operating costs of the options. There may also be one-time dislocation costs to workers due to the projected output changes. No attempt is made here to value the costs of these dislocations. Insignificant reductions in other jobs at captive facilities are projected due to the projected reduction in output. All generating sectors were projected to reduce the number of jobs in their hazardous waste management facilities in proportion to the reduction in their hazardous waste management activity.

Clearly, these projected reductions in jobs may not be translated one-for-one into worker dislocations. Firms may move workers between jobs, taking advantage of other demand shifts or attrition though resignations and retirements.

8.3.6 Small Business Effects

The Regulatory Flexibility Act requires Federal agencies to analyze the effects of their regulations on small entities and to involve these entities more actively in developing and reviewing regulations. "Small entities" here includes small businesses, small governmental jurisdictions, and small organizations. The purpose of the Regulatory Flexibility Act is to minimize the effects of the environmental regulations on small entities.

The regulation of TSDF affects the hazardous waste generators who supply onsite waste management services (captive facilities), and the suppliers of commercial hazardous waste management services (commercial facilities). The criteria for "smallness" applies to the firm, not to the facility. The Small Business Administration (SBA) defines "small businesses" by industry (by SIC code) in terms of annual sales or employment. (The SBA size criteria for each industry are shown in Table 8-25.) Determining the size of the business that owns a hazardous waste management captive facility (a facility generating and managing some or all waste on site) is complex because waste management is a secondary activity of the business. These captive facilities in the industrial sectors are owned by businesses that produce products such as petroleum products, solvents, chemicals, etc., besides supplying hazardous waste management services. The determination of the ownership of commercial facilities is less complex because the primary activity of such businesses is hazardous waste management services. Therefore, the formal analyses of small business effects were limited to the commercial facilities. However, some general conclusions are drawn for captive facilities at the end of this section.

A several-step process was initiated to investigate the potential small business effects for commercial facilities. Information on the U.S. Environmental Protection Agency (EPA) facility identification number, the SIC code, and the volume entering hazardous waste management processes was gathered from the Industry Profile Data Base. Using the baseline hazardous waste management service price of $1,280/Mg and volume from the data base, annual sales of waste management services were estimated (volume of hazardous waste management service multiplied by the baseline price) for each of the 136 commercial facilities. The SIC codes used to identify commercial facilities include SIC 4212 (local trucking and storage), SIC 4213 (trucking, without storage), SIC 4953 (refuse systems), and SIC 7399 (business services, not elsewhere classified). A uniform annual sales cutoff equal to $3.5 million is used to identify potential small businesses among the commercial facilities instead of the SBA annual sales cutoff (SIC 4953) equal to $6 million. The choice of $3.5 million is likely to overstate the small business effects from the regulation. Thus, the number of small businesses identified, 16, is likely to overstate the actual value.

TABLE 8-25. SMALL BUSINESS ADMINISTRATION SIZE CRITERIA BY SIC CODE[a]

SIC Code	SBA Cutoff
2800	Does not exist
2869	1,000 employees
2899	500 employees
3811	500 employees
4953	$6 million
4959	$3.5 million
5161	500 employees
5172	500 employees
7399	$3.5 million
8999	$3.5 million

[a]The Small Business Administration (SBA) uses annual sales and employment figures to determine the size of business entities, by Standard Industrial Classification (SIC) code. The SBA cutoff figures for "Small business" classification listed in this table were used to determine which of the 136 commercial hazardous waste management facilities could be designated as "small" (between 11 and 15). The next step was to assess the economic impact of the regulation on these small firms.

Of the 136 commercial facilities, 101 are estimated to have annual sales greater than or equal to $3.5 million and hence are not considered small businesses. The remaining 35 facilities have estimated annual sales of less than $3.5 million and are potential candidates for small business classification.

The survey forms for these 35 facilities from the National Survey of Hazardous Waste Treatment, Storage, Disposal, and Recycling Facilities[18] were examined to acquire more detailed information about the facilities and the firms that own them. From these forms, the following items of information were gathered:

- Facility name, contact person, and telephone number
- Name of the business owning the facility
- Names of other facilities also under the same ownership
- Types of hazardous waste management services performed
- Prices charged for hazardous waste management services
- Number of persons employed
- Current status of the facility (active or out of business).

Of the 35 facilities examined, 7 are owned by businesses with sales greater than $3.5 million and hence were determined to be large. Ten of these 35 facilities were verified to be small because they were owned by businesses with sales less than $3.5 million. Twelve of these facilities have gone out of business and are no longer active. The survey forms for the remaining five facilities were not readily available, but they are likely to be small. On the basis of this determination, between 10 and 16 facilities of the 136 total commercial facilities are likely to be potential small businesses.

Table 8-26 presents the baseline statistical data on the 16 potential small businesses. These facilities supplied hazardous waste management service (annual waste quantity) between 2 Mg and 2,300 Mg. Their annual management costs were between $400 and $1.7 million. The annual revenue from hazardous waste management services from these facilities was between $2,000 and $3 million.

TABLE 8-26. BASELINE STATISTICAL DATA FOR SMALL COMMERCIAL FACILITIES WITH ESTIMATED SALES REVENUE LESS THAN $3.5 MILLION (ANNUAL VALUES)[a]

Facility[b]	Waste quantity, Mg	Service cost,[c] $10^3	Service sales,[d] $10^3
1	2	0	2
2	2	2	2
3	7	1	9
4	19	24	24
5	62	62	79
6	70	59	90
7	94	104	119
8	175	22	223
9	438	78	559
10	744	265	949
11	951	226	1,213
12	981	420	1,252
13	1,111	62	1,417
14	1,965	1,686	2,507
15	2,201	91	2,808
16	2,346	94	2,993

[a]This table presents the baseline statistical data on the key variables such as hazardous waste management services supplied (Mg/yr), annual hazardous waste management costs ($/yr), annual revenue from hazardous waste management services ($/yr), and profits (dollar differences between annual revenue and annual costs) for the potential small businesses.

[b]Facility codes are not used so as to protect the anonymity of each facility.

[c]Service costs were estimated using cost functions.

[d]Service sales = Waste quantity times baseline price of $1,275.84.

The next issue is whether the regulation would have "a significant economic impact on a substantial number of small entities" was examined. A "substantial number" is generally thought to imply greater than 20 percent of the small entities, although this is not a fixed rule. A "significant economic impact" is said to occur whenever any of the following criteria are satisfied:

- Annual compliance costs (including annualized capital, operating, and reporting costs) increase as a percent of total costs of production for small entities for the relevant process or product by more than 5 percent.
- Compliance costs as a percent of sales for small entities are at least 10 percent higher than compliance costs as a percent of sales for large entities.
- Capital costs of compliance represent a significant portion of capital available to small entities, considering internal cash flow plus external financing capabilities.
- The requirements of the regulation are likely to result in closures of small entities.

To assess whether the economic impacts on small businesses are likely to be significant, the four criteria are examined. Table 8-27 summarizes the with-regulation implications of control option 1, the most stringent of the options. The first column presents the facility number. Column 2 provides the ratio of compliance costs to production cost. The ratio of compliance costs to annual sales for the small businesses is presented in column 3. Column 4 presents the ratio of capital costs to annual sales for each small businesses. Finally, column 5 identifies the small businesses that are potential closure candidates.

The compliance cost increases as a percent of total costs of production for small businesses are less than 3.5 percent for all small businesses.

The compliance costs as a percent of sales for small businesses are less than 2 percent. The estimated ratio of compliance costs to total sales for the 16 small businesses is 0.28 percent. For the larger businesses, the estimated ratio of total compliance costs to total sales is 0.26 percent. The compliance costs as a percent of sales for small

TABLE 8-27. EFFECTS OF THE MOST STRINGENT REGULATION (OPTION 1) ON SMALL COMMERCIAL FACILITIES WITH ESTIMATED SALES REVENUE LESS THAN $3.5 MILLION[a]

Facility[b]	Compliance cost/cost[c]	Compliance cost/sales[d]	Capital cost/sales[e]	Potential closure candidate
1	308	38	62	N
2	986	652	1,222	N
3	307	38	62	N
4	402	401	939	Y
5	824	647	1,213	N
6	98	65	113	N
7	70	61	168	N
8	203	20	33	N
9	337	47	63	N
10	2,669	743	1,548	N
11	3,607	602	1,303	N
12	1,200	401	939	N
13	878	38	62	N
14	942	631	1,427	N
15	735	24	29	N
16	771	24	28	N

N = Not likely to close.
Y = Potential for closure.

[a]The postregulatory financial implications of regulatory control option 1 are summarized in this table. Column 2 represents the ratio of annual compliance costs (annualized capital and operating costs) and annual hazardous waste management costs. Column 3 represents the ratio of compliance capital costs and annual profits. Column 4 represents the ratio of compliance costs and annual revenue, and column 5 represents the ratio of compliance capital costs and annual revenue. Data for this table are obtained from the Source Assessment Model (SAM) Industry Profile data base, Appendix D, Section D.2.1.

[b]Facility codes are not used so as to protect the anonymity of each facility.

[c]Compliance costs ($) per $100,000 of waste management costs.

[d]Compliance costs ($) per $100,000 of revenue received.

[e]Capital costs ($) per $100,000 of revenue received.

businesses are less than 10 percent higher than the compliance costs as a percent of sales for large businesses.

The capital costs as a percent of sales for small businesses are less than 2 percent. Because the compliance capital costs represent a small portion of the total amount of sales, it is reasonable to conclude that the capital costs of compliance represent an insignificant portion of the capital available to small businesses.

The economic impact model estimates that 6 of the larger businesses and 1 of the 16 small businesses are potential closure candidates if all the projected quantity adjustments are registered on the highest-cost facilities. However, given the nominal reduction in hazardous waste generation, it is likely that these adjustments will be spread over many facilities. Thus, it is doubtful that any of the closures predicted by the model would actually take place.

The analysis indicates that the economic impacts on small businesses are not "significant" using the criteria outlined above. The TSDF process is a component of the cost of production for captive facilities. As shown in Table 8-6, at the industry level, TSDF costs are estimated to represent a very small share of production costs. Thus, even large hazardous waste treatment costs would not typically be significant as a percent of the costs of the entire plant. Table 8-27 shows that the highest share of compliance to production costs for any small commercial businesses is less than 5 percent. Given these values, it seems reasonable to conclude also that it is unlikely that there would be any significant impact on small businesses in the captive sector.

8.4 REFERENCES

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APPENDIX A

EVOLUTION OF PROPOSED STANDARDS

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EVOLUTION OF PROPOSED STANDARDS

The EPA Office of Solid Waste and Emergency Response (OSWER) first initiated the development of air emission standards for hazardous waste treatment, storage, and disposal facilities (TSDF) in 1978. In December 1978, OSWER proposed air emission standards for treatment and disposal of hazardous waste based on an approach that included definition of volatile waste solely in terms of its vapor pressure and use of the U.S. Occupational Safety and Health Administration (OSHA) levels for determining acceptable emission levels (43 FR 59008, December 18, 1978). A supplemental notice of proposed rulemaking was published on October 8, 1980 (45 FR 66816).

The 1978 and 1980 actions were reproposed in 1981 (46 FR 11126, February 5, 1981); the proposed standards included requirements for systems to monitor ambient air quality and gaseous emissions, sampling and analysis plans, data evaluation by predictive models, and recordkeeping/reporting. General control requirements to prevent wind dispersion of particulate matter from land disposal sources also were proposed. The final standards adopted by EPA included the particulate control requirements, but they did not incorporate any other measures for air emission management (47 FR 32274, July 26, 1982).

In February 1984, EPA considered the need to further evaluate air emission standards and delegated authority to the Office of Air Quality Planning and Standards (OAQPS) to develop standards for air emissions from area sources at TSDF. At that time, OAQPS initiated the project that led to this draft background information document (BID). The program plan outlining the technical and regulatory approaches selected for the project was reviewed by the National Air Pollution Control Technique Advisory Committee (NAPCTAC) meeting held August 29-30, 1984. The NAPCTAC is composed of 16 persons from industry, State, and local air pollution agencies, environmental groups, and others with expertise in air pollution control. In November 1984, Congress passed the Hazardous and Solid Waste Amendments (HSWA) to the Resource Conservation and Recovery Act (RCRA) of

1976. Section 3004(n) of HSWA specifically directs the Administrator to establish standards for the monitoring and control of air emissions from hazardous waste TSDF as necessary to protect human health and the environment. It is under the authority of Section 3004(n) that these standards are being developed.

This OAQPS study to develop air standards for TSDF air emissions began with the collection of information on waste management processes, hazardous waste characteristics, and controls that could potentially be applied to reduce air emissions. This information was obtained through site visits and sampling surveys, industry surveys, various Agency data bases, and testing programs. Additional information was gathered through literature searches, meetings, and telephone contacts with experts within EPA, State and local regulatory authorities, and affected industries. Based on this information, preliminary draft BID chapters, which described the TSDF industry, emission sources, and potential controls were prepared and transmitted to representatives of industry, trade associations, and environmental groups for review and comment in February 1986. The comments received were analyzed and incorporated in the BID, as were additional data obtained through test programs, other data bases, and internal EPA review.

Public comments were also solicited on three specific aspects of the project. In February 1987, comments were solicited from TSDF operators, major trade associations, and environmental groups on potential test methods for determining the volatile organic content of hazardous wastes. In March 1987, a draft report on predictive models for estimating organic air emissions was mailed out for public review. This report was finalized and distributed in December 1987. (See "Hazardous Waste Treatment, Storage, and Disposal Facilities [TSDF] - Air Emission Models," EPA-450/3-87-026.) On June 9, 1987, OAQPS presented a status report on the project and test method development work at a public meeting of the NAPCTAC.

Under a separate project, the OAQPS proposed its initial set of TSDF air standards for organic emissions from process vents and equipment leaks (52 FR 3748, February 5, 1987). At that time, EPA requested comments from TSDF operators, trade associations, and environmental groups on the proposed air controls. A public hearing was held on March 23, 1987, in

Durham, North Carolina, to obtain external comments on the proposed standards. These standards were promulgated on June 21, 1990 (55 FR 25454). Additional information on this project can be found in Docket Number F-90-AESP-FFFFF.

On April 5, 1988, OAQPS distributed the draft BID for review to NAPCTAC members, industry representatives, and environmental groups prior to the NAPCTAC meeting held May 18, 1988. Also distributed for review were draft papers titled, "Preliminary Control Strategies for TSDF Air Emission Standards," and "Method for the Determination of Volatile Organic Content of Hazardous Waste." This meeting, open to the public, provided an additional opportunity for industry and environmental groups to comment on the draft rulemaking prior to proposal. This BID reflects revisions that have been made based on comments received since NAPCTAC review. Major events that have occurred in the development of background information for the proposed standards are present in Table A-1.

TABLE A-1. EVOLUTION OF PROPOSED TREATMENT, STORAGE, AND DISPOSAL FACILITY AIR STANDARD[a]

Date	Event
November 1983	Contractors begin site visits and source sampling at over 100 TSDF; testing under OAQPS/ORD/OSW program extending through 1986 also begins.
December 1983	Meeting with Chemical Manufacturers Association to review "Evaluation and Selection of Models for Estimating Air Emissions from Hazardous Waste Treatment, Storage, and Disposal Facilities," "Assessment of Air Emissions from Hazadous Waste Treatment, Storage, and Disposal Facilities: Hazardous Waste Rankings," and "Assessment of Air Emissions from Hazardous Waste Treatment, Storage, and Disposal Facilities: Preliminary National Emissions Estimates."
February 1984	OSWER delegates authority for development of air standards for TSDF area sources to OAQPS.
August 29-30, 1984	National Air Pollution Control Techniques Advisory Committee meeting held in Durham, North Carolina, to review TSDF program plan (49 FR 26808).
November 9, 1984	Congress passes Hazardous and Solid Waste Amendments to Resource Conservation and Recovery Act of 1976.
November 9, 1984	Meeting with Chemical Manufacturers Association Secondary Emissions Work Group to review and comment on draft technical note, "Basis for Design of Test Facility for Flux Chamber Emissions Measurement Validation."
April 24, 1985	Meeting with American Petroleum Institute to discuss status of standards development for land treatment.
January 8, 1985	Meeting with Chemicals Manufacturers Association to discuss current studies of air source emissions from TSDF.
October 1985	Research Triangle Institute begins work to develop air emissions for hazardous waste treatment, storage, and disposal facilities, under EPA Contract No. 68-02-4326.
February 6, 1986	Mailout of preliminary BID Chapters 3.0 to 6.0 to industry and environmental groups.
March 6-7, 1986	Meeting with Chevron Chemical Co. to discuss planned landfarm simulation study.

(continued)

TABLE A-1 (continued)

Date	Event
April 24, 1986	Meeting with American Petroleum Institute on status of TSDF standards development.
May 14, 1986	Meeting with Chemical Manufacturers Association to discuss project status and BID comments.
December 17, 1986	Meeting with American Petroleum Institute on land treatment air emission research.
February 5, 1987	Proposal of accelerated standards for selected sources at hazardous waste TSDF (52 FR 3748).
February 11, 1987	Mailout of draft test method approach document to industry and environmental groups.
March 23, 1987	Public hearing for accelerated rulemaking for selected sources at hazardous waste TSDF held in Durham, North Carolina.
April 10, 1987	Mailout of draft report on organic air emission models to industry and environmental groups.
June 9, 1987	Meeting of National Air Pollution Control Techniques Advisory Committee to review project status and test method development program (52 FR 15762).
September 30, 1987	Meeting with Chevron Chemical Corporation to discuss land treatment data.
December 10, 1987	Mailout of final report on organic air emission models to industry and environmental groups.
January 14, 1988	Meeting with Chemical Manufacturers Association to discuss project status.
April 5, 1988	Mailout of preliminary draft BID to National Air Pollution Control Techniques Advisory Committee, TSDF operators, trade associations, environmental groups, and other public groups.

(continued)

TABLE A-1 (continued)

Date	Event
May 18, 1988	Meeting of National Air Pollution Control Techniques Advisory Committee to review preliminary draft BID.
July 27, 1988	Meeting with Chemical Manufacturers Association to receive comments on preliminary draft BID.
August 16, 1988	Meeting with Chemical Manufacturers Association to receive comments on volatile organics test method.
June 21, 1990	Promulgation of accelerated standards for TSDF process vents and equipment leaks (55 FR 25454).

TSDF = Treatment, storage, and disposal facility.
OAQPS = Office of Air Quality Planning and Standards.
ORD = Office of Research and Development.
OSW = Office of Solid Waste.
BID = Background Information Document.

[a]This table presents those major events that have occurred to date in the development of background information for the TSDF air standard.

APPENDIX B

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

APPENDIX B

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

This appendix consists of a reference system that is cross-indexed with the October 21, 1974, Federal Register (39 FR 37419) containing EPA guidelines for the preparation of Environmental Impact Statements. This index can be used to identify sections of the document that contain data and information germane to any portion of the Federal Register guidelines.

APPENDIX B

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS

Agency guidelines for preparing regulatory action environmental impact statements (39 FR 37419)	Location within the Background Information Document (BID)
1. Background and description	
a. Summary of control options	A description of the control options is provided in Chapter 5.0 of BID Vol. I.
b. Industry affected by the control options	A discussion of the industry affected by the control options is presented in Chapter 3.0 of BID Vol. I.
c. Relationship to other regulatory Agency actions	The relationship to other regulatory Agency actions is discussed in Chapter 5.0 of BID Vol. I.
d. Specific processes affected by the control options	The specific processes affected by the control options are summarized in Chapter 3.0 of BID Vol. I.
2. Impacts of the alternatives	
a. Air pollution	The air pollution impacts are discussed in Chapter 6.0 of BID Vol. I. Supplementary information on the emission models and emission estimates is included in Appendix C of BID Vol. I. Appendix D of BID Vol. II describes the Source Assessment Model used to estimate nationwide emissions and their correlations to test methods. Test data are presented in Appendix F of BID Vol. II.
b. Water pollution	The water pollution impacts are described in Chapter 6.0 of BID Vol. I.
c. Solid waste disposal	The solid waste disposal impacts are discussed in Chapter 6.0 of BID Vol. I.
d. Energy impact	The energy impacts are discussed in Chapter 6.0 of BID Vol. I.

(continued)

INDEX TO ENVIRONMENTAL IMPACT CONSIDERATIONS (continued)

Agency guidelines for preparing regulatory action environmental impact statements (39 FR 37419)	Location within the Background Information Document (BID)
e. Cross-media impacts	Cross-media and secondary air environmental impacts are discussed in Chapter 6.0 of the BID Vol. I. Additional information is presented in Appendix K of BID Vol. III.
f. Economic impact	The cost and economic impacts of control options are presented in Chapters 7.0 and 8.0 of BID Vol. I. Supplementary information on control costs and on the economic impact analysis is included in Appendixes H and I of BID Vol. III.
g. Health impact	Incidence and risk impacts are presented in Chapter 6.0 of BID Vol. I. The health risk analyses are discussed further in Appendixes D and E of BID Vol. II and Appendix J of BID Vol. III.

APPENDIX C

EMISSION MODELS AND EMISSION ESTIMATES

APPENDIX C

EMISSION MODELS AND EMISSION ESTIMATES

The objective of Appendix C is to provide a link between

- Emission models used to estimate organic air emissions from treatment, storage, and disposal facility (TSDF) waste management units
- Model TSDF waste management unit analyses used to develop estimates of emission reductions and costs of applying emission control technologies
- The Source Assessment Model (SAM), which uses both the aforementioned to generate an estimate of nationwide TSDF organic air emissions and control costs.

This appendix provides a discussion of the mathematical models used to estimate nationwide air emissions from hazardous waste TSDF. These models represent most of the TSDF emission sources introduced in Chapter 3.0, Section 3.1. Some emission sources, such as drum crushing, are undergoing analysis at this time. The discussion of the emission models in Section C.1 includes a description of the models, a comparison of emission model estimates with results from specific field tests of TSDF waste management units, and a sensitivity analysis.

To estimate emissions with these emission models, inputs such as waste management unit surface area, waste retention time, and depth of unit are essential. Physical and chemical characteristics of the waste in the unit--such as the specific organic compounds present and their concentrations and knowledge of the presence or absence of multiple phases (e.g., separate aqueous and organic layers)--are also needed.

Use of these emission models to develop estimates of nationwide emissions requires some knowledge of the waste management unit characteristics that could affect emissions for each TSDF in the country. Given that only general information such as annual waste throughput is available for the thousands of TSDF, a model waste management unit approach was developed to facilitate emission estimates, as well as control emission reductions and control costs. Descriptions of the model units and the basis for developing the range of model units characteristics are given in Section C.2.1.

As explained above, knowledge of waste physical and chemical characteristics is essential to emission estimates. Emission reductions and control costs likewise are sensitive to waste properties, so a model unit analysis to derive emission reduction and control costs also requires a definition of wastes being managed in the model waste management units. Model wastes were defined for this purpose. Section C.2.2 provides a discussion of the selection of model wastes and defines those wastes.

Lastly, in Section C.2.3, control costs and control emission reductions for a selected set of model waste management units are given in tabular form. The data contained in the table demonstrate the variations in costs and emission reductions that occur along with variations in model waste compositions and degree of emission control provided by different control technologies. These model waste management unit control costs and control emission reductions are the bases for extrapolating costs and emission reductions to nationwide estimates. Appendix D contains a discussion of the procedure for relating costs to waste throughput in each model waste management unit and then extrapolating for nationwide cost estimates via the SAM. The emission reductions expressed as a percentage of uncontrolled emissions are discussed in Chapter 4.0 and Appendix D.

C.1 EMISSION MODELS

C.1.1 Description of Models

The emission models that are used to estimate air emissions from TSDF processes are drawn from several different sources. These models are presented in a TSDF air emission models report that provides the basis and description of each model, along with sample calculations and comparisons of modeled emissions to measured emissions using field test data.

The emission models discussed in Chapter 3.0 are those presented in the March 1987 draft of the TSDF air emission models report.[1] Certain TSDF emission models have been revised since that time, and a final version of the report has been released (December 1987).[2] The principal changes to the models involved refining the biodegradation component of the models to more accuractely reflect biologically active systems handling low organic concentration waste streams. With regard to emission model outputs, the changes, by and large, did not result in appreciable differences in the emission estimates. (Refer to Appendix D, Section D.2.4, for a more detailed discussion.)

In the emission models report, models are presented for the following TSDF management processes: surface impoundments and uncovered storage and treatment tanks; land treatment; landfills and wastepiles; and transfer, storage, and handling operations. In general, the report describes the chemical and physical pathways for organics released from hazardous wastes to the atmosphere, and it discusses their relevance to the different types of TSDF management processes and the sets of conditions that are important in emission estimation.

In the following paragraphs, the models are presented in simplified forms or in qualitative terms. For a full discussion, refer to the TSDF air emission models report.

C.1.1.1 Surface Impoundments and Uncovered Tanks.

This section presents emission models for quiescent and aerated/agitated surface impoundments and uncovered tanks. Quiescent surface impoundments where wastes flow through to other processes (i.e., storage and treatment) are addressed initially with uncovered tanks (C.1.1.1.1). Quiescent impoundments without waste flowthrough, such as disposal impoundments, are discussed in the next section (C.1.1.1.2). Aerated treatment impoundments and uncovered tanks are discussed in Section C.1.1.1.3.

C.1.1.1.1 Quiescent surface with flow. Emission characteristics from quiescent uncovered storage and treatment processes are similar; therefore, the same basic model was used to estimate emissions from all such processes. These waste management processes for flowthrough emission modeling include uncovered tank storage, storage surface impoundments, uncovered quiescent treatment tanks, and quiescent treatment impoundments. The modeling approach used to estimate emissions from these types of TSDF management units is based on the work of Springer et al.[3] and Mackay and

Yeun[4] for the liquid-phase mass transfer and MacKay and Matasugu[5] for the gas-phase mass transfer. The emission equation used is a form of the basic relationship describing the mass transfer of a volatile constituent from the opened liquid surface to the air. The model for flowthrough impoundments and tanks assumes that the system is well-mixed and that the bulk concentration is equal to the effluent concentration. A material balance for this yields:

$$QC_o = KAC_L + QC_L \tag{C-1}$$

where

Q = volumetric flow rate, m^3/s

C_o = influent concentration of organics in the waste, g/m^3

K = overall mass transfer coefficient, m/s

A = liquid surface area, m^2

C_L = bulk (effluent) concentration of organics, g/m^3.

The overall mass transfer coefficient is based on:

$$\frac{1}{K} = \frac{1}{K_L} + \frac{1}{K_G\, K_{eq}} \tag{C-2}$$

where

K = overall mass transfer coefficient, m/s

K_L = liquid-phase mass transfer coefficient, m/s

K_G = gas-phase mass transfer coefficient, m/s

K_{eq} = equilibrium constant or partition coefficient, unitless.

The air emissions from the liquid surface are calculated using the basic relationship describing mass transfer of a volatile constituent from the open liquid surface to the air:

$$E = KAC_L \tag{C-3}$$

where

E = air emissions from the liquid surface, g/s

K = overall mass transfer coefficient, m/s

A = liquid surface area, m^2

C_L = concentration of the constituent in the liquid phase, g/m^3.

C.1.1.1.2 Quiescent surface with no outlet flow. A disposal impoundment is defined as a unit that receives waste for ultimate disposal rather than for storage or treatment. This type of impoundment differs from the storage and treatment impoundments in that there is no liquid flow out of the impoundment. The calculation of the overall mass transfer coefficient is the same as that presented for quiescent surfaces with flow. However, the assumption that the bulk concentration is equal to the effluent concentration is not applicable here. The emission-estimating procedure differs in the calculation of the liquid-phase concentration that is the driving force for mass transfer to the air. The emission rate can be calculated as follows:

$$E = \frac{V\,Co}{t}\,[1 - \exp\,(-KAt/V)] \qquad \text{(C-4)}$$

where

E = Emission rate, g/s

V = Volume of the impoundment, m^3

t = Time after disposal, s

and with the other symbols as previously defined. Reference 2 gives a detailed derivation of the above equation.

C.1.1.1.3 Aerated systems. Aeration or agitation in an aqueous system transfers air (oxygen) to the liquid to improve mixing or to increase biodegradation. Aerated hazardous waste management processes include uncovered, aerated treatment tanks and aerated treatment impoundments. A turbulent liquid surface in uncovered tanks and impoundments enhances mass transfer to the air. Thus, there are two significant differences between the quiescent emission model and the aerated emission model: (1) the modified mass transfer coefficient and (2) the incorporation of a biodegradation term. The calculation of the overall mass transfer coefficient for mechanically aerated systems is based on the correlations of Thibodeaux and Reinhart for the liquid and gas phases, respectively.[6] The rate of biodegradation was assumed to be first order with respect to concentration based on experimental data in the form of a decay model; this is similar to the Monod model at low loadings.

A material balance around the well-mixed system yields:

$$QC_o = QC_L + K_b C_L V + KC_L A \qquad \text{(C-5)}$$

where

Q = volumetric flow rate, m^3/s

C_o = influent concentration of organics in the waste, g/m^3

C_L = bulk (effluent) concentration of organics in the waste, g/m^3

K_b = pseudo first-order rate constant for biodegradation, 1/s

V = system volume, m^3

K = overall mass transfer coefficient, m/s

A = surface area, m^2.

Air emissions can be estimated using Equation (C-3).

Additional research data have been obtained on biodegradation rates of specific constituents, and numerous comments were received on the emission and biodegradation models.[6.5] Based on the new information, an improved biodegradation model was developed that incorporates Monod kinetics. This model fits the available biodegradation rate data better than the model described above and generally provides a sounder technical basis for evaluating the extent of biodegradation. The comments also provided additional information on the concentration of organics in biologically active treatment processes and the aeration parameters used for the model units. Proposed revisions to the aerated units and the biodgradation model were evaluated in a sensitivity analysis to determine the effect on the nationwide impacts presented in this document.[7] The results of the analysis showed that the combined effects of the proposed changes had only a minor effect (less than 5 percent) on nationwide impacts.

C.1.1.2 Land Treatment. Emissions from land treatment operations may occur in three distinct ways: from application of waste to the soil surface, from the waste on the soil surface before tilling, and from the soil surface after the waste has been tilled into the soil or retilled after initial waste application.

Short-term emissions of organics from hazardous waste on the soil surface prior to tilling, a result of surface application land treatment, or immediately following tilling, are estimated by calculating an overall mass transfer coefficient similar to that for an oil film on a surface impoundment. The basic assumption is that mass transfer is controlled by the gas-phase resistance. The gas-phase mass transfer coefficient and the equilibrium constant are calculated from the correlation of MacKay and Matasugu[8] and from Raoult's law, respectively.

The RTI land treatment model is used to calculate emissions from waste that is mixed with the soil. This condition may exist when waste has been applied to the soil surface and has seeped into the soil, when waste has been injected beneath the soil surface, or when the waste has been tilled into the soil. In land treatment, soil tilling typically occurs regardless of the method of waste application. Air emissions from land treatment operations are at their highest when a waste containing volatile organics is applied onto or tilled into the soil or retilled after initial waste application. Within a few hours after application or tilling, the rate of air emissions will be substantially less than the maximum because the volatiles at the surface have been removed and the remaining volatiles must diffuse up through a layer of porous solids. The effect of tilling on emissions is reflected in the model by including a short-term maximum evaporation rate immediately after tilling occurs, then applying or resuming the long-term emission rate model.

The RTI land treatment emission model for long-term emissions from a land treatment unit incorporates terms that consider the major competing pathways for loss of organics from the soil; the model combines a diffusion equation for the waste vapors in the soil and a biological decay rate equation. The RTI model is based on Fick's second law of diffusion applied to a flat slab as described by Crank[9] and includes a term to estimate biological decay assuming a decay rate that is first order with respect to waste loading in the soil. No equations are presented here because they are not easily condensed. However, these equations are described in the TSDF air emission models report.

C.1.1.3 Waste Fixation, Wastepiles, and Landfills. Two major emission models are used in estimating emissions from landfills. Both assume that all wastes are fixed wastes and that no biological degradation takes place to reduce organic content.

One model estimates emissions from closed landfills.[10] The Closed Landfill Model is used to estimate emissions from waste placed in a closed (or capped) landfill that is vented to the atmosphere and, as a special case, emissions from active landfills receiving daily earth covers. This model accounts for the escape of organics resulting from diffusion through the cap and convective loss from landfill vents resulting from barometric pumping. The closed landfill model is based primarily on the work of Farmer et al.,[11] who applied Fick's first law for steady-state diffusion. Farmer's equation utilizes an effective diffusion coefficient for the soil cap based on the work of Millington and Quirk.[12] The model also includes a step to estimate convective losses from the landfill. The TSDF air emission models report describes the model in detail.

The RTI land treatment model is used to estimate the air emissions from active landfills (landfills still receiving wastes) and wastepiles.[13] As previously stated, this model is based on Fick's second law of diffusion applied to a flat slab as described by Crank, and it includes a term to estimate biological decay assuming a decay rate that is first order with respect to waste loading in the soil. A land-treatment-type model was selected for estimating emissions from open landfills and wastepiles because (1) there are a number of similarities in physical characteristics of open landfills, wastepiles, and land treatment operations, and (2) the input parameters required for the land treatment model are generally available for open landfills and wastepiles, which is not the case for some of the more theoretical models for these sources.

The emission model developed to characterize organic air emissions from uncovered wastes described in the air emissions model report was not considered appropriate for estimating emissions from waste fixation processes. However, a number of field tests have been conducted,[14] and these data were used to develop an emission factor for this process.

C.1.1.4 Transfer, Storage, and Handling. This subsection discusses organic emission models for container loading and spills, fixed-roof tank loading and storage, dumpster storage, and equipment leaks.

C.1.1.4.1 Container loading and spills. Containers can include drums, tank trucks, railroad tank cars, and dumpsters. To calculate organic emissions from loading liquid wastes into all of these containers except dumpsters, the AP-42 equation for loading petroleum liquids is applied.[15] This equation was derived for tank cars and marine vessels. It is also applied to tank trucks and 0.21-m^3 (55-gal) drums in this case because the loading principles are similar. (No equation has been developed exclusively for small containers such as drums.) Covered container loading emissions are based on the AP-42 equation:

$$L_L = \frac{12.46}{T} SMP \quad \text{(C-6)}$$

where

L_L = loading loss, lb/1,000 gal of liquid loaded

T = bulk temperature of liquid, K

S = saturation factor, dimensionless

M = molecular weight of vapor, lb/lb mol

P = true vapor pressure of liquid, psia.

Spillage is the only other significant emission source from covered containers. An EPA study of truck transport to and from TSDF and truck emissions at TSDF terminals provided the background information necessary to estimate spillage losses during TSDF trucking, handling, and storage operations. The emission estimate for losses at a storage facility applies the same spill fraction used for drum handling, 1 x 10^{-4}, developed by EPA.[16] The following equation estimates drum handling and storage emissions:

$$L_s = 10^{-4} \times T \times W_i \times V_i \quad \text{(C-7)}$$

where

L_s = emissions from drum storage, Mg/yr

T = throughput, Mg/yr

W_i = organic weight fraction

V_i = volatilization fraction.

Spillage emissions from tank trucks and railroad tank cars are estimated using the same equation except that the spill fraction of 10^{-5} for other types of waste movement is applied instead of the 10^{-4} spill fraction for drum handling.[17] (See the TSDF air emission models report, Section 7.7.)

C.1.1.4.2 Dumpster storage. Emissions from open dumpster storage are estimated using a model based originally upon the work of Arnold, which was subsequently modified by Shen[18] and EPA/GCA[19] Corporation to characterize organic air emissions from uncovered wastes. The equation in its final form is thus presented as:

$$E_i = \frac{2\ P_o\ MW_i\ y_i^*\ w}{RT} \sqrt{\frac{D_i l U}{\pi\ F_v}} \qquad \text{(C-8)}$$

where:

E_i = emission rate of constituent of interest from the emitting surface, g/s

P_o = total system pressure (ambient pressure), mmHg

MW_i = molecular weight of constituent i, g/g mol

y_i^* = equilibrium mole fraction of the i-th constitutent in the gas phase

w = width of the volatilizing surface perpendicular to the wind direction, cm

R = ideal gas constant, 62,300 mmHg•cm^3/g mol•K

T = ambient temperature, K

D_i = diffusivity of volatilizing constituent in air, cm^2/s

l = length of volatilizing surface parallel to the wind direction, cm

U = windspeed, cm/s

F_v = correction factor for Fick's law

π = 3.1416.

C.1.1.4.3 Tank storage. Stationary, fixed-roof tank working losses are those created by loading and unloading wastes and are estimated using AP-42, "Storage of Organic Liquids":[20]

$$L_w = 1.09 \times 10^{-8} \times M_v \times P \times V \times K_n \times K_c \qquad \text{(C-9)}$$

where

L_w = working losses, Mg/yr (the AP-42 constant of 2.4×10^{-2} is converted to 1.09×10^{-8} to convert lb/gal throughput to Mg/yr)

M_v = molecular weight of vapor in tank, lb/lb mol

P = true vapor pressure at bulk liquid conditions, psia

V = throughput, gal/yr

K_n = turnover factor, dimensionless

K_c = product factor, dimensionless.

There are also "breathing" losses for a fixed-roof tank caused by temperature and pressure changes. An existing AP-42[21] equation is used to estimate these emissions:

$$L_b = 1.02 \times 10^{-5} M_v \left[\frac{P}{14.7-P} \right]^{0.68} \times D^{1.73} \times H^{0.51} \times \Delta T^{0.5} \times F_p \times C \times K_c \qquad \text{(C-10)}$$

where

L_b = fixed-roof breathing loss, Mg/yr (the AP-42 constant of 2.26×10^{-2} is converted to 1.02×10^{-5} to convert lb/gal thoughput to Mg/yr)

M_v = molecular weight, lb/lb mol

P = true vapor pressure, psia

D = tank diameter, ft

H = average vapor space height, ft

ΔT = average ambient diurnal temperature change, °F

F_p = paint factor, dimensionless

C = adjustment factor for small diameter tanks, dimensionless

K_c = product factor, dimensionless.

These equations originally were developed for handling organic liquids in industries producing or consuming organic liquids, but are used here for TSDF tank storage.

C.1.1.4.4 Equipment leaks. Emissions from equipment leaks are those resulting from leaks in equipment that is used to control pressure, provide samples, or transfer pumpable organic hazardous waste. The emissions from equipment leaks in hazardous waste management are dependent on the number of pump seals, valves, pressure relief devices, sampling connections, open-ended lines, and the volatility of the wastes handled. The emission-estimating model used for TSDF equipment leaks is independent of the throughput, type, or size of the process unit. The TSDF equipment leak emission model is based on the Synthetic Organic Chemical Manufacturing Industries (SOCMI) emission factors developed to support standard SOCMI equipment leak emission standards.[22] The input parameters required for the equipment leak emission model begin with the emission factor for the equipment pieces such as pump seals, the number of sources, and the residence time of the waste in the equipment. It was assumed that with no purge of waste from the equipment when the equipment is not in use, organics are continuously being leaked to the atmosphere. Section C.2, "Model Unit Description," explains the selection process for the number of emission sources used to develop the equipment model units.

C.1.2 Comparison of Emission Estimates with Test Results

Predictions from TSDF emission models have been compared with field test data. The following sections summarize qualitatively the comparative results that are discussed in detail in Chapter 8.0 of the TSDF air emission models report. Actual field test data are presented in Appendix F. This comparison was made with the knowledge that some uncertainty in field test precision and accuracy and the empirical nature of emission models must be considered.

C.1.2.1 Surface Impoundments and Uncovered Tanks Comparison. Emission test data were available for five quiescent surface impoundments. The overall mass transfer coefficients determined in these tests agreed within an order of magnitude with the overall coefficient predicted by the mass transfer correlations. Predicted emissions for these impoundments using the March 1987 version of the air emission models were higher than the measured emissions in some cases and lower in others.

When predicted emission estimates were compared to uncovered tank measured emissions, the results were mixed. For quiescent tanks, the predicted emissions were generally lower than measured emissions but agreed within an order of magnitude. For the aerated systems, the model predictions agreed well with material balance and ambient air measurements for an open aerated system.

C.1.2.2 Land Treatment. Field test data from four sites and one laboratory simulation were used as a basis of comparison with estimates from the land treatment emission model (see Section C.1.1.2). Estimated and measured emissions were within an order of magnitude. Estimates of both emission flux rates and cumulative emissions show results above and below measured values. Considering the potential for error in measuring or estimating values for input parameters, differences in the range of an order of magnitude are not unexpected. The emission test reports did not provide complete sets of model input data; therefore, field data averages, averages from the TSDF data base, or values identified elsewhere as representative were used as model inputs.

C.1.2.3 Landfills and Wastepiles. Comparisons between predicted and measured emissions from a landfill are of limited value because of lack of detailed, site-specific soil, waste, and landfill operating parameters. Typically, the composition of the landfilled waste and other required inputs to the emission models, such as the porosity of the landfill cap and the barometric pumping rate, were not included in the field test data. Comparisons of model emissions were made to measured emissions from two active landfills. The modeled emissions were found to be higher than field test measurements, in general, by factors ranging from 1 to 2 orders of magnitude. No test data were available for wastepiles.

C.1.2.4 Transfer, Storage, and Handling Comparison. Emission models for transfer, storage, and handling operations are based on extensive testing that led to AP-42[23] emission models and to models developed for the petroleum industry and SOCMI. The following models were developed in the petroleum industry and are applied to TSDF:

- Container loading (AP-42, Section 4.4)
- Stationary covered tank loading (AP-42, Section 4.3)
- Stationary covered tank storage (AP-42, Section 4.3).

Equipment leak emission factors are drawn from the study of organics leak control at SOCMI facilities. Test data supporting the SOCMI equipment leak emission standard[24] were collected to develop these factors. An EPA study[25] of truck transport to and from TSDF and truck emissions at TSDF terminals provided information for spillage loss estimates. No test data were available for comparison in this TSDF effort.

C.1.3 Sensitivity Analysis

The emission models have been evaluated to determine which parameters have the greatest impacts on emissions. A brief discussion follows on the important model parameters for the four major types of TSDF processes: (1) surface impoundments and uncovered tanks, (2) land treatment, (3) landfills and wastepiles, and (4) transfer, storage, and handling operations. Input parameters were varied individually over the entire range of reasonable values in order to generate emission estimates. A full discussion of the emission model sensitivity analysis is presented in the TSDF air emission models report.

C.1.3.1 Surface Impoundments and Uncovered Tanks. Parameters to which emission estimates are most sensitive include waste concentration, retention time, windspeed for quiescent systems, fetch to depth, and biodegradation.

The emission estimates for highly volatile constituents (as defined in Appendix D, Section D.2.3.3.1) are sensitive to short retention times. For retention times on the order of several days, essentially all high volatiles are emitted. In impoundments, significant emissions of medium volatiles (as defined in Appendix D, Section D.2.3.3.1) may occur over long retention times. Henry's law constant has a direct effect on emissions of medium volatiles and a greater effect on relatively low volatile organics for which mass transfer is controlled by the gas-phase resistance.

Temperature did not affect emission estimates of the highly volatile constituents, although mass transfer for low volatile constituents was affected because of the temperature dependence of Henry's law constant. Diffusivity in air and water did not affect emission estimates.

Physical parameters of aerated systems, such as kilowatts (horsepower) and turbulent area, did affect emission estimates of medium volatiles, although highly volatile constituents were unaffected. High volatiles are stripped out almost completely under any aerated condition.

C.1.3.2 Land Treatment. Air emissions from land treatment units are dependent on the chemical/physical properties of the organic constituents, such as vapor pressure, diffusivity, and biodegradation rate.

Operating and field parameters affect the emission rate, although their impact is not as great as that of constituent properties. Tilling depth, for example, plays a role; the deeper the tilling depth, the greater the time required for diffusion to the surface and therefore the greater is the potential for organics to be biodegraded. Waste concentration and waste loading (the amount of material applied to the soil per unit area) affect the emission rate on a unit area basis (emissions per unit area), but not in terms of the mass of organics disposed of (emissions per unit mass of waste).

C.1.3.3 Landfills and Wastepiles. Emissions from active (open) landfills, those still receiving wastes, are estimated by applying the RTI land treatment model. The sensitivity of the land treatment model to some parameters differs in its application to open landfills and wastepiles from that in land treatment operations. For application to open landfills and wastepiles, the model is sensitive to the air porosity of the solid waste, the liquid loading in the solid waste, the waste depth, the concentration of the constituent in the waste, and the volatility of the constituent under consideration. In contrast, the model is less sensitive to the diffusion coefficient of the constituent in air.

Emissions from closed landfills, those filled to design capacity and with a cap (final cover) installed, are estimated using the closed landfill model. The model is highly sensitive to the air porosity of the clay cap, which largely determines the diffusion rate through the cap. The model is also sensitive to the properties of the constituent of interest, particularly vapor pressure, Henry's law constant, and concentration. In contrast, the model exhibits relatively low sensitivity to the diffusiveness of the constituent in air, the cap thickness, and the total mass of constituent in the landfill.

C.1.3.4 Transfer, Storage, and Handling Operations. Equipment leak emission estimates are a function of the number of pump seals, valves, pressure-relief valves, open-ended lines, and sampling connections selected for given process rather than throughput rate. However, equipment leak frequencies and leak rates have been shown to vary with stream volatility; emissions for high-volatility streams are greater than those for streams of low volatility.

Loading emission estimates are also sensitive to the volatility of the constituents. Both loading and spill emissions are directly proportional to throughput. The loading emission estimates for open aqueous systems, such as impoundments and uncovered tanks, are highly sensitive to the type of loading, which is either submerged or splash loading.

The fraction of waste spilled and waste throughput are used to estimate emissions resulting from spills.

C.2 MODEL TSDF WASTE MANAGEMENT UNIT ANALYSES

To evaluate the effectiveness (emission reductions) and costs of applying various types of control technologies (discussed in Chapter 4.0) to reduce emissions from waste management process units, a model unit analysis was performed. Hazardous waste management model units and model waste compositions were input to the emission models discussed above to generate uncontrolled emissions estimates from which emission reductions were computed. The model units and model waste compositions also served as the bases for estimating add-on and suppression-type control costs for each applicable control technology. Appendix H presents a discussion of the costing of add-on and suppression-type controls.

The development of model units, selection of model waste compositions and the results of the analyses of emission reductions and control costs are discussed in the following sections.

C.2.1 Model Unit Descriptions

Sets of model units were developed to represent the range of sizes and throughputs of hazardous waste management processes. For each model unit, parameters needed as input to the emission models were specified. The following paragraphs provide the sources of information and rationale used in developing the model units. Discussions are presented as four categories, each containing waste management processes with similar emission characteristics.

Multiple model units were developed for each waste management process to describe the nationwide range of characteristics (surface area, waste throughputs, retention time, etc.). This was determined using the frequency distributions of quantity processed, unit size, or unit area of each waste management process that were results of the Westat Survey. The distributions (expressed as weighting factors for the SAM) are presented with the tabular listing of model units in this section. The distributions were used to develop a "national average model unit" to represent each waste management process when using the Source Assessment Model. Each frequency serves as a weighting factor to approximate a national distribution of the model units defined for a particular TSDF waste management process. Appendix D, Section D.2.4.3, describes these weights and the approach to estimating nationwide organic air emissions in greater detail.

C.2.1.1 Surface Impoundments and Uncovered Tanks. Hazardous waste surface impoundment storage, treatment, and disposal model units are displayed in Table C-1. The ranges of surface areas and depths were based on results of the National Survey of Hazardous Waste Generators and Treatment, Storage, and Disposal Facilities Regulated Under RCRA in 1981 (Westat Survey).[26] The median surface area for storage and treatment impoundments in the Westat Survey was 1,500 m^2 and the median depth was 1.8 m. Three model unit surface areas and depths were chosen for storage and treatment impoundments, representing the medians and spanning the representative ranges of sizes for each parameter. The Westat Survey data summary for impoundments indicated that disposal impoundments generally have higher surface areas and shallower depths than storage and treatment impoundments. The model disposal impoundment was designed with the Westat Survey median surface area of 9,000 m^2 and the median depth of approximately 1.8 m.

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a]

Model unit (weights,[b] %)	Parameters[c]
Surface impoundment storage	
S04A Quiescent impoundment	Throughput - 99,000 Mg/yr Surface area - 300 m^2 Depth - 0.9 m Volume - 270 m^3 Retention time - 1 d Flow rate - 3.1 L/s Temperature - 25 °C Windspeed - 4.5 m/s
S04B Quiescent impoundment	Throughput - 9,800 Mg/yr Surface area - 300 m^2 Depth - 0.9 m Volume - 270 m^3 Retention time - 10 d Flow rate - 0.31 L/s Temperature - 25 °C Windspeed - 4.5 m/s
(S04A and B = 38.3)	
S04C Quiescent impoundment	Throughput - 49,000 Mg/yr Surface area - 1,500 m^2 Depth - 1.8 m Volume - 2,700 m^3 Retention time - 20 d Flow rate - 1.6 L/s Temperature - 25 °C Windspeed - 4.5 m/s
S04D Quiescent impoundment	Throughput - 25,000 Mg/yr Surface area - 1,500 m^2 Depth - 1.8 m Volume - 2,700 m^3 Retention time - 40 d Flow rate - 0.78 L/s Temperature - 25 °C Windspeed - 4.5 m/s
(S04C and D = 35.9)	

See notes at end of table. (continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Surface impoundment storage (con.)		
S04E	Quiescent impoundment	Throughput - 120,000 Mg/yr Surface area - 9,000 m^2 Depth - 3.7 m Volume 33,000 m^3 Retention time - 100 d Flow rate - 3.8 L/s Temperature - 25 °C Windspeed - 4.5 m/s
S04F	Quiescent impoundment	Throughput - 67,000 Mg/yr Surface area - 9,000 m^2 Depth - 3.7 m Volume - 33,000 m^3 Retention time - 180 d Flow rate - 2.1 L/s Temperature - 25 °C Windspeed - 4.5 m/s
(S04E and F = 25.9)		
Surface impoundment treatment		
T02A	Quiescent impoundment with no biodegradation	Throughput - 200,000 Mg/yr Surface area - 300 m^2 Depth - 0.9 m Volume - 270 m^3 Retention time - 0.5 d Flow rate - 6.3 L/s Temperature - 25 °C Windspeed - 4.5 m/s
T02B	Quiescent impoundment with no biodegradation	Throughput - 20,000 Mg/yr Surface area - 300 m^2 Depth - 0.9 m Volume - 270 m^3 Retention time - 5 d Flow rate - 0.63 L/s Temperature - 25 °C Windspeed - 4.5 m/s
(T02A and B = 31.2)		

See notes at end of table. (continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Surface impoundment treatment (con.)		
T02C	Quiescent impoundment with no biodegradation	Throughput - 990,000 Mg/yr Surface area - 1,500 m^2 Depth - 1.8 m Volume - 2,700 m^3 Retention time - 1 d Flow rate - 31 L/s Temperature - 25 °C Windspeed - 4.5 m/s
T02D	Quiescent impoundment with no biodegradation	Throughput - 99,000 Mg/yr Surface area - 1,500 m^2 Depth - 1.8 m Volume - 2,700 m^3 Retention time - 10 d Flow rate - 3.1 L/s Temperature - 25 °C Windspeed - 4.5 m/s
(T02C and D = 35.6)		
T02E	Quiescent impoundment with no biodegradation	Throughput - 608,000 Mg/yr Surface area - 9,000 m^2 Depth - 3.7 m Volume - 33,000 m^3 Retention time - 20 d Flow rate - 19 L/s Temperature - 25 °C Windspeed - 4.5 m/s
T02F	Quiescent impoundment with no biodegradation	Throughput - 302,000 Mg/yr Surface area - 9,000 m^2 Depth - 3.7 m Volume - 33,000 m^3 Retention time - 40 d Flow rate - 9.6 L/s Temperature - 25 °C Windspeed - 4.5 m/s
(T02E and F = 33.3)		

See notes at end of table.

(continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Surface impoundment treatment (con.)		
T02G	Aerated/agitated impoundment with biodegradation	Throughput - 200,000 Mg/yr Surface area - 300 m^2 Depth - 0.9 m Volume - 270 m^3 Retention time - 0.5 d Flow rate - 6.3 L/s Turbulent area - 63 m^2 Total power - 5.6 kW (7.5 hp) Impeller power - 4.8 kW (6.4 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 0.5 g/L Temperature - 25 °C Windspeed - 4.5 m/s
T02H	Aerated/agitated impoundment with biodegradation	Throughput - 20,000 Mg/yr Surface area - 300 m^2 Depth - 0.9 m Volume - 270 m^3 Retention time - 5 d Flow rate - 0.63 L/s Turbulent area - 63 m^2 Total power - 5.6 kW (7.5 hp) Impeller power - 4.8 kW (6.4 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 0.5 g/L Temperature - 25 °C Windspeed - 4.5 m/s
(T02G and H = 31.2)		

See notes at end of table.

(continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Surface impoundment treatment (con.)		
T02I	Aerated/agitated impoundment with biodegradation	Throughput - 990,000 Mg/yr Surface area - 1,500 m^2 Depth - 1.8 m Volume - 2,700 m^3 Retention time - 1 d Flow rate - 31 L/s Turbulent area - 370 m^2 Total power - 56 kW (75 hp) Impeller power - 48 kW (64 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 0.5 g/L Temperature - 25 °C Windspeed - 4.5 m/s
T02J	Aerated/agitated impoundment with biodegradation	Throughput - 99,000 Mg/yr Surface area - 1,500 m^2 Depth - 1.8 m Volume - 2,700 m^3 Retention time - 10 d Flow rate - 3.1 L/s Turbulent area - 370 m^2 Total power - 56 kW (75 hp) Impeller power - 48 kW (64 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 0.5 g/L Temperature - 25 °C Windspeed - 4.5 m/s
(T02I and J = 35.6)		

See notes at end of table. (continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Surface impoundment treatment (con.)		
T02K	Aerated/agitated impoundment with biodegradation	Throughput - 608,000 Mg/yr Surface area - 9,000 m^2 Depth - 3.7 m Volume - 33,000 m^3 Retention time - 20 d Flow rate - 19 L/s Turbulent area - 2,700 m^2 Total power - 671 kW (900 hp) Impeller power - 574 kW (85 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 0.5 g/L Temperature - 25 °C Windspeed - 4.5 m/s
T02L	Aerated/agitated impoundment with biodegradation	Throughput - 302,000 Mg/yr Surface area - 9,000 m^2 Depth - 3.7 m Volume - 33,000 m^3 Retention time - 40 d Flow rate - 9.6 L/s Turbulent area - 2,700 m^2 Total power - 671 kW (900 hp) Impeller power - 574 kW (85 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 0.5 g/L Temperature - 25 °C Windspeed - 4.5 m/s
(T02K and L = 33.3)		
Surface impoundment disposal		
D83A	Quiescent impoundment with no biodegradation (100)	Throughput - 32,000 Mg/yr Surface area - 9,000 m^2 Depth - 1.8 m Volume - 16,000 m^3

See notes at end of table. (continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Surface impoundment disposal (con.)		
		Retention time - 183 d Temperature - 25 °C Windspeed - 4.5 m/s
Storage tanks		
S02F	Uncovered tank (37.7)	Throughput - 110 m^3/yr Surface area - 2.3 m^2 Depth - 2.4 m Volume - 5.3 m^3 Retention time - 18.3 d Temperature - 25 °C Windspeed - 4.5 m/s
S02G	Uncovered tank (0[d])	Throughput - 60 m^3/yr Surface area - 13 m^2 Depth - 2.4 m Volume - 30 m^3 Retention time - 183 d Temperature - 25 °C Windspeed - 4.5 m/s
S02H	Uncovered tank (32.3)	Throughput - 1,100 m^3/yr Surface area - 13 m^2 Depth - 2.4 m Volume - 30 m^3 Retention time - 9.9 d Temperature - 25 °C Windspeed - 4.5 m/s
S02I	Uncovered tank (17.8)	Throughput - 3,300 m^3/yr Surface area - 26 m^2 Depth - 2.7 m Volume - 76 m^3 Retention time - 8.3 d Temperature - 25 °C Windspeed - 4.5 m/s
S02J	Uncovered tank (12.2)	Throughput - 17,000 m^3/yr Surface area - 65 m^2 Depth - 12 m Volume - 800 m^3 Retention time - 17.4 d Temperature - 25 °C Windspeed - 4.5 m/s

See notes at end of table.

(continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Treatment tanks		
T01A	Uncovered quiescent tank (28.3)	Throughput - 11,000 Mg/yr Surface area - 13 m^2 Depth - 2.4 m Volume - 30 m^3 Retention time - 24 h Flow rate - 0.35 L/s Temperature - 25 °C Windspeed - 4.5 m/s
T01B	Uncovered quiescent tank (21.8)	Throughput - 28,000 Mg/yr Surface area - 26 m^2 Depth - 2.7 m Volume - 76 m^3 Retention time - 24 h Flow rate - 0.88 L/s Temperature - 25 °C Windspeed - 4.5 m/s
T01C	Uncovered quiescent tank (50.0)	Throughput - 290,000 Mg/yr Surface area - 65 m^2 Depth - 12 m Volume - 800 m^3 Retention time - 24 h Flow rate - 9.2 L/s Temperature - 25 °C Windspeed - 4.5 m/s
T01G	Uncovered aerated/agitated tank (78.3)	Throughput - 240,000 Mg/yr Surface area - 27 m^2 Depth - 4 m Volume - 108 m^3 Retention time - 4 h Flow rate - 7.5 L/s Turbulent area - 14 m^2 Total power - 5.6 kW (7.5 hp) Impeller power - 4.8 kW (6.4 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 4.0 g/L Temperature - 25 °C Windspeed - 4.5 m/s

(continued)

TABLE C-1. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE SURFACE IMPOUNDMENT AND UNCOVERED TANK MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters[c]
Treatment tanks (con.)		
T01H	Uncovered aerated/agitated tank (21.8)	Throughput - 2,800,000 Mg/yr Surface area - 430 m^2 Depth - 3.7 m Volume - 1,600 m^3 Retention time - 5 h Flow rate - 88 L/s Turbulent area - 250 m^2 Total power - 89.5 kW (120 hp) Impeller power - 38 kW (51 hp) Impeller speed - 130 rad/s Impeller diameter - 61 cm O_2 transfer - 1.83 kg/kW/h (3 lb/hp/h) O_2 correction factor - 0.83 Biomass concentration - 4.0 g/L Temperature - 25 °C Windspeed - 4.5 m/s

[a]Hazardous waste surface impoundment and uncovered tank model units represent the ranges of uncovered, quiescent, and aerated surface storage, treatment, and disposal surface impoundments and storage and treatment tanks in the hazardous waste management industry.

[b]Because design characteristics and operating parameters (surface area, waste throughputs, detention times, and so on) were generally not available for all treatment, storage, and disposal facilities (TSDF), weighting factors were developed to approximate the nationwide distribution of model units defined for a particular TSDF waste management process. The weighting factors are based on the considerable statistical data available in the 1981 EPA survey of hazardous waste generators and TSDF conducted by Westat, Inc. (Westat Survey). For example, results of this survey were used to determine the national distribution of sizes of storage tanks (storage volume), surface impoundments (surface area), and landfills (surface area and depth). For further information on weighting factors, refer to Appendix D, Sections D.2.4.3 and D.2.5.

[c]Model unit parameters may not be equal (e.g., Throughput ≠ Volume x Turnovers) because of rounding.

[d]This model unit was weighted 0% because S02H also has the same surface area. This avoids double weighting of a unit size.

Retention times in the Westat Survey ranged from 1 to 550 days, with over half of the values at 46 days or less. The storage impoundment model unit retention times, ranging from 1 to 180 days, were chosen to span the reasonable range of values, based on knowledge of the operation of impoundments that are representative of the industry. Retention times greater than 180 days were not used to estimate emissions because organics are emitted from a surface impoundment within 180 days. The retention time in treatment impoundments was expected to be less than the retention times in storage impoundments. Two design manuals listed typical retention times for aerated impoundments as 7 to 20 days[27] and 3 to 10 days.[28] Retention times bounding these ranges were chosen for the quiescent and aerated/agitated impoundments. No data were available concerning disposal surface impoundment retention times; therefore, the disposal surface impoundment was selected with a 6-month retention time or the time within which the organics would be emitted. Volume for each surface impoundment model unit was calculated from area and depth; the retention time yielded the flow rate.

Two meteorological parameters required for the emission models were temperature and windspeed. The parameters chosen were a standard temperature of 25 °C and a windspeed of 4.5 m/s. These standard values were evaluated by estimating emissions from surface impoundments for windspeed/temperature combinations at actual sites based on their frequency of occurrence. Over a 1-yr period, the results from site-specific data on windspeed and temperature were not significantly different from the results using the standard values. Consequently, the standard values were judged adequate for the model units.

With regard to the aerated/agitated treatment impoundments, one source, Metcalf and Eddy,[29] suggests a range of 0.37 to 0.75 kW/28.3 m^3 (0.5 to 1.0 hp/1,000 ft^3) for mixing. However, more power may be needed to supply additional oxygen or to mix certain treatment solutions. Information obtained through site visits to impoundments indicates power usage as high as 2.6 kW/28.3 m^3 (3.5 hp/1,000 ft^3) at a specific TSDF impoundment.[30] For this analysis, a midrange value of 0.56 kW/28.3 m^3 (0.75 hp/1,000 ft^3) from Metcalf and Eddy was used to generate estimates of the power required for mixing in each model unit.

Data from Reference 31 indicate that an aerator with a 56-kW (75-hp) motor and a 61-cm-diameter propeller turning at 126 rad/s would agitate a volume of 660 m^3. Agitated volumes were estimated by holding propeller diameter and rotation constant and treating agitated volume as being proportional to power. The agitated volume divided by depth yielded the agitated surface area, which was modeled as turbulent area. Typical values were chosen for the oxygen transfer rating of the aerator and the oxygen transfer correction factor. A value of 1.83 kg O_2/kW/h (3.0 lb O_2/hp/h) was chosen for the oxygen transfer rating from a range of 1.76 to 1.83 (2.9 to 3.0).[32] A value of 0.83 was used for the correction factor from a typical range of 0.80 to 0.85.[33] For estimating the impeller power, an 85-percent efficient transfer of power to the impeller was used.[34] A midrange biomass concentration for continuous stirred tank reactors was chosen from Reference 35. A biomass concentration of 0.5 g/L was chosen as an estimate, representing an upper bound on the design guidelines in References 36 and 37.

Table C-1 also presents uncovered, quiescent and aerated/agitated hazardous waste treatment tank model units. According to responses to the 1981 EPA survey of hazardous waste generators and TSDF conducted by Westat, Inc. (Westat Survey),[38] there are four sizes of tanks that best represent the waste management industry: 5.3 m^3, 30 m^3, 76 m^3, and 800 m^3. The quiescent storage and treatment tank model units were sized accordingly.

Retention times were chosen to span the retention times commonly used by wastewater treatment tank units.[39] The retention times and tank capacities were used to arrive at flow rates for the model units. These flow rates are comparable to those found in the EPA survey conducted by Westat for medium and large wastewater treatment tanks. The remaining physical parameters for quiescent treatment tanks were chosen on the basis of engineering judgment. Meteorological conditions cited for quiescent and aerated tanks represent standard annual (temperature and windspeed) and daily (temperature change) values.

For aerated/agitated treatment tanks, the agitation parameters for the aerated, biologically active tanks were derived as described previously for aerated/agitated surface impoundments.

C.2.1.2 Land Treatment. Table C-2 displays hazardous waste land treatment model units. Model unit parameters were based primarily on a data base developed by EPA[40] from site visits and contacts with State, regional, and industry sources and supplemented by information from recent literature. These values were chosen as reasonably representative of average or typical practices currently used at land treatment operations. The data base showed annual throughput varying from about 2 Mg/yr to about 400,000 Mg/yr with a median value of 1,800 Mg/yr. The area of land treatment sites ranged from less than 1 ha to about 250 ha with a median value of 5 ha. These two median values were selected to develop the model units. The data base showed tilling depth varying from 15 cm to one case of 65 cm, with most being in the range of 15 to 30 cm. The single most frequently reported tilling depth was 20 cm, which was selected as a typical value. This value is in line with values of 15 to 30 cm reported in another study.[41] The data base showed oil content of the waste streams varying from about 2 to 50 percent, with a median value of about 12 percent and model value of 10 percent. The 10-percent figure was selected as typical.

Very little soil porosity information has been identified. One study reported measured values of soil porosity in a land treatment plot as ranging from 43.3 to 65.1 percent[42] with an average value of about 50 percent. The literature did not specify whether this soil porosity represented total soil porosity or soil air porosity. Therefore, these literature values were chosen to represent soil air porosity. Total soil porosity included the air porosity and the space occupied by oil and water within soil. One field study reported measured values of both total porosity and air-filled porosity.[43] Measured values of total soil porosity ranged from 54.7 to 64.8 percent, with an average value of 60.7 percent. Measured values of air-filled porosity ranged from 27.4 to 46.9 percent, with an average of 37.2 percent. Thus, the value of 61 percent for total soil porosity was chosen to be a representative value based on the median measured total soil porosity of 60.7 percent. A value of 50 percent was used as a default for air porosity.

C.2.1.3 Waste Fixation, Wastepiles, and Landfills. As part of the landfill operation, fixation model units were developed. Table C-3 shows hazardous waste fixation pit model units. The fixation pit has a length of

TABLE C-2. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE LAND TREATMENT MODEL UNITS[a]

Model unit (weights,[b] %)	Parameters
D81A (NA)	Throughput - 360 Mg/yr Land area[c] - 1 ha Oil content of waste - 10% Soil air porosity - 0.5 Soil total porosity - 0.61 Tilling depth - 20 cm Temperature - 25 °C
D81B (NA)	Throughput - 1,800 Mg/yr Land area[c] - 5 ha Oil content of waste - 10% Soil air porosity - 0.5 Soil total porosity - 0.61 Tilling depth - 20 cm Temperature - 25 °C
D81C (NA)	Throughput - 5,400 Mg/yr Land area[c] - 15 ha Oil content of waste - 10% Soil air porosity - 0.5 Soil total porosity - 0.61 Tilling depth - 20 cm Temperature - 25 °C
D81D (NA)	Throughput - 27,000 Mg/yr Land area[c] - 75 ha Oil content of waste - 10% Soil air porosity - 0.5 Soil total porosity - 0.61 Tilling depth - 20 cm Temperature - 25 °C

NA = Not applicable.

[a]Hazardous waste land treatment model units represent the range of land treatment processes in the hazardous waste management industry.

[b]Weighting factors were developed for each unit to represent each waste management process when estimating nationwide emissions. These factors are based on frequency distributions of quantity processed, unit size, or unit area that were results of the Westat Survey, approximately a national distribution of model units.

[c]Waste is applied only to one-half of the land area based on knowledge of industry practice, allowing the undisturbed area to stabilize.

TABLE C-3. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE FIXATION PIT, WASTEPILE STORAGE, AND LANDFILL DISPOSAL MODEL UNITS[a]

Model unit (weights,[b] %)	Parameters
<u>Fixation pit</u>	
Fixation pit A (46.0)	Throughput - 17,000 Mg/yr fixed waste Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Fixed waste density - 1.8 g/cm^3 Number of pits - 1 Pit surface dimensions - 3x6 m Pit depth - 3 m Number of batches - 160/yr Windspeed - 4.5 m/s Wind direction - along length of pit Temperature = 25 °C Duration of fixation - 2 h
Fixation pit B (14.9)	Throughput - 120,000 Mg/yr fixed waste Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Fixed waste density - 1.8 g/cm^3 Number of pits - 2 Pit surface dimensions - 3x6 m Pit depth - 3 m Number of batches - 1,200/yr Windspeed - 4.5 m/s Wind direction - along length of pit Temperature - 25 °C Duration of fixation - 2 h

See notes at end of table. (continued)

TABLE C-3. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE FIXATION PIT, WASTEPILE STORAGE, AND LANDFILL DISPOSAL MODEL UNITS[a] (continued)

Model unit (weights,[b] %)	Parameters
Fixation pit (con.)	
Fixation pit C (39.2)	Throughput - 170,000 Mg/yr fixed waste Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Fixed waste density - 1.8 g/cm^3 Number of pits - 4 Pit surface dimensions - 3x6 m Pit depth - 3 m Number of batches - 1,600/yr Windspeed - 4.5 m/s Wind direction - along length of pit Temperature - 25 °C Duration of fixation - 2 h
Wastepile	
S03D Wastepile (41.5)	Throughput - 17,000 Mg/yr Surface area - 46 m^2 Average height - 0.77 m Volume - 35 m^3 Waste density - 1.8 g/cm^3 Turnovers - 300/yr Retention time - 1.2 days Temperature - 25 °C Windspeed - 4.5 m/s Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Total porosity fixed waste - 0.50 Air porosity fixed waste - 0.25 Biomass concentration - 0 g/cm^3

See notes at end of table.

(continued)

TABLE C-3. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE FIXATION PIT, WASTEPILE STORAGE, AND LANDFILL DISPOSAL MODEL UNITS[a] (continued)

Model unit (weights,[b] %)	Parameters
Wastepile (con.)	
S03E Wastepile (36.0)	Throughput - 120,000 Mg/yr Surface area - 470 m^2 Average height - 1 m Volume - 470 m^3 Waste density - 1.8 g/cm^3 Turnovers - 140/yr Retention time - 2.6 days Temperature - 25 °C Windspeed - 4.5 m/s Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Total porosity fixed waste - 0.50 Air porosity fixed waste - 0.25 Biomass concentration - 0 g/cm^3
S03F Wastepile (22.5)	Throughput - 170,000 Mg/yr Surface area - 14,000 m^2 Average height - 4 m Volume - 56,000 m^3 Waste density - 1.8 g/cm^3 Turnovers - 1.6/yr Retention time - 220 days Windspeed - 4.5 m/s Temperature - 25 °C Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Total porosity fixed waste - 0.50 Air porosity fixed waste - 0.25 Biomass concentration - 0 g/cm^3

See notes at end of table. (continued)

TABLE C-3. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE FIXATION PIT, WASTEPILE STORAGE, AND LANDFILL DISPOSAL MODEL UNITS[a] (continued)

Model unit (weights,[b] %)	Parameters
Landfill disposal	
D80D Active landfill (46.0)	Surface area - 0.4 ha Depth of waste - 1.1 m Degree of filling - half full Ambient temperature - 25 °C Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Total porosity of fixed waste - 0.50 Air porosity of fixed waste - 0.25 Biomass conc. - 0 g/cm^3
D80E Active landfill (14.9)	Surface area - 1.4 ha Depth of waste - 2.3 m Degree of filling - half full Ambient temperature - 25 °C Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Total porosity of fixed waste - 0.50 Air porosity of fixed waste - 0.25 Biomass conc. - 0 g/cm^3
D80F Active landfill (39.2)	Surface area - 2 ha Depth of waste - 2.3 m Degree of filling - half full Ambient temperature - 25 °C Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Total porosity of fixed waste - 0.50 Air porosity of fixed waste - 0.25 Biomass conc. - 0 g/cm^3

See notes at end of table.

(continued)

TABLE C-3. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE FIXATION PIT, WASTEPILE STORAGE, AND LANDFILL DISPOSAL MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters
Landfill disposal (con.)		
D80G	Closed landfill (46.0)	Surface area - 0.4 ha Waste bed thickness - 2.3 m Cap thickness - 110 cm Total porosity of cap - 0.41 Air porosity of cap - 0.08 Temperature beneath cap - 15 °C Typical barometric pressure - 1.01×10^{-5} Pa (1,013 mbar) Daily barometric pressure drop - 4.0×10^{-8} Pa (4 mbar) Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Air porosity of fixed waste - 0.25 Biomass conc. - 0 g/cm^3
D80H	Closed landfill (14.9)	Surface area - 1.4 ha Waste bed thickness - 4.6 m Cap thickness - 110 cm Total porosity of cap - 0.41 Air porosity of cap - 0.08 Temperature beneath cap - 15 °C Typical barometric pressure - 1.01×10^{-5} Pa (1,013 mbar) Daily barometric pressure drop - 4.0×10^{-8} Pa (4 mbar) Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Air porosity of fixed waste - 0.25 Biomass conc. - 0 g/cm^3

See notes at end of table.

(continued)

TABLE C-3. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE FIXATION PIT, WASTEPILE STORAGE, AND LANDFILL DISPOSAL MODEL UNITS[a] (continued)

Model unit (weights,[b] %)	Parameters
Landfill disposal (con.)	
D80I Closed landfill (39.2)	Surface area - 2 ha Waste bed thickness - 4.6 m Cap thickness - 110 cm Total porosity of cap - 0.41 Air porosity of cap - 0.08 Temperature beneath cap - 15 °C Typical barometric pressure - 1.01×10^{-5} Pa (1,013 mbar) Daily barometric pressure drop - 4.0×10^{-8} Pa (4 mbar) Liquid/fixative - 1 cm^3 liquid + fixative = 1 cm^3 fixed waste Air porosity of fixed waste - 0.25 Biomass conc. - 0 g/cm^3

[a]Hazardous waste fixation pit, wastepile storage, and landfill disposal model units represent the ranges of these processes in the hazardous waste management industry.

[b]Because design characteristics and operating parameters (surface area, waste throughputs, detention times, and so on) were generally not available for all treatment, storage, and disposal facilities (TSDF), weighting factors were developed to approximate the nationwide distribution of model units defined for a particular TSDF waste management process. The weighting factors are based on the considerable statistical data available in the 1981 EPA survey of hazardous waste generators and TSDF conducted by Westat, Inc. (Westat Survey). For example, results of this survey were used to determine the national distribution of sizes of storage tanks (storage volume), surface impoundments (surface area), and landfills (surface area and depth). For further information on weighting factors, refer to Appendix D, Sections D.2.4.3 and D.2.5.

6 m, with a width of 3 m and a depth of 3 m. These dimensions represent reasonable estimates of industry practice based on observations at actual sites. The duration of the fixation operation was taken to be a maximum of 2 h, based on operating practice at one site.[44] The wind direction was assumed to be along the length of the pit, and a standard temperature of 25 °C and windspeed of 4.5 m/s were used.

Hazardous waste wastepile storage model units are presented in Table C-3 as part of landfill operations. The wastepile surface areas were designed to represent the range of basal areas reported in the Westat Survey, with 470 m^2 being an approximately midrange value. For modeling purposes, the pile was assumed to be flat. The heights were based on Westat information and engineering judgment. The wastepile retention times were derived from the landfill volumes, the wastepile volumes, and the landfill filling time (to capacity) of 1 yr. With regard to the waste characteristics, the waste density represents a fixed two-phase aqueous/organic waste. The fixation industry indicated that waste liquid, when combined with fixative, may increase in volume by up to 50 percent,[45,46,47] depending on the specific combination of waste fixative. However, because of the inherent variability in the fixation process and the lack of real data on volume changes, this analysis did not incorporate a waste volume change during fixation. Measurements[48] performed on various types of fixed waste yielded a broad range of total porosities; therefore, 50 percent was chosen as a reasonable estimate of total porosity. A 25-percent air porosity value was inferred from measurements of total porosity and moisture content.[49] The toxic property of the waste can inhibit the biological processes and prevent biogas generation.[50] Therefore, the waste biomass concentration is 0 g/cm^3.

Table C-3 also provides hazardous waste landfill disposal model units. The active landfill surface areas represent the range of surface areas reported in the Westat Survey. A standard temperature of 25 °C was chosen for the model.

As with active landfills, the closed landfill surface areas and depths were based on Westat Survey data. The landfill cap was considered to be composed of compacted clay. The cap thickness of 110 cm represents the average of extremes in thickness of clay caps (61 cm to 180 cm) reported in site studies.[51] The value used for air porosity of the clay cap is 8 percent, while the total porosity is 41 percent. These values were computed based on reasonable physical properties and level of compaction for compacted clay.[52] The temperature beneath the landfill cap was estimated at 15 °C, which represents the temperature of shallow ground water at a mid-latitude U.S. location.[53] A constant temperature was used. The landfill is exposed to a nominal barometric pressure of 1.01 x 10^{-5} Pa (1,013 mbar), which represents an estimate of the annual average atmospheric pressure in the United States.[54] Barometric pumping was estimated for the landfill using a daily pressure drop from the nominal value of 4.0 x 10^{-8} Pa (4 mbar). The 4.0 x 10^{-8} Pa (4 mbar) value represents an estimate of the annual average diurnal pressure drop.[55] The closed landfill model units were designed to contain fixed or solid wastes. As explained previously for hazardous waste wastepile model units, biomass concentration was taken to be 0 g/cm^3 for active and closed landfills.

C.2.1.4 Transfer, Storage, and Handling. Table C-4 presents model units for loading and storing hazardous waste in containers and covered tanks and for sources of equipment leaks during waste transfer. The EPA's Hazardous Waste Data Management System was reviewed[56] to select the most representative volumetric capacities of container storage (drums and dumpsters) facilities. Based on this review, two model drum storage facilities were developed: an onsite or private TSDF with a 21-m^3 capacity processing 42 m^3 annually, and a commercial TSDF with a 40-m^3 capacity processing 460 m^3 annually. The Westat Survey indicated that waste containers are typically in the form of 0.21-m^3 (55-gal) drums.[57] Therefore, these model capacities would hold 100 and 180 drums, respectively, at any one time. A telephone conversation with a dumpster vendor[58] identified two basic capacities of small roll-off containers: 3.1 m^3 and 4.6 m^3. The 3.1-m^3 roll-off, which turns over 6.1 m^3 annually, was selected as a model. It has a length of 1.9 m, width of 1.5 m, and height of 1.2 m. In addition, an average annual ambient temperature of 25 °C and an average windspeed of 4.5 m/s were used.

Containers (drums, tank trucks, and rail tank cars) were considered to be splash-loaded for emission-estimating purposes because data were not

TABLE C-4. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE TRANSFER, STORAGE, AND HANDLING OPERATION MODEL UNITS[a]

Model unit (weights,[b] %)	Parameters
Container storage	
S01A Drum storage (66.1)	Throughput - 42 m^3/yr Volume - 0.21 m^3/drum Capacity - 100 drums Turnovers - 2/yr Spill fraction - 10^{-4} Volatilization fraction - 0.5
S01B Drum storage (33.9)	Throughput - 450 m^3/yr Volume - 0.21 m^3/drum Capacity - 180 drums Turnovers - 12/yr Spill fraction - 10^{-4} Volatilization fraction - 0.5
S01C Dumpster storage (0)	Throughput - 6.8 m^3/yr Windspeed - 4.5 m/s Temperature - 25 °C Length - 1.9 m Width - 1.5 m Height - 1.2 m Turnovers - 2/yr
Container loading	
Drum loading (NA)	Throughput - 42 m^3/yr Volume - 0.21 m^3/drum Bulk temperature - 25 °C Saturation factor (dimensionless) - 1.45 Number of loadings - 200/yr
Drum loading (NA)	Throughput - 460 m^3/yr Volume - 0.21 m^3/drum Bulk temperature - 25 °C Saturation factor (dimensionless) - 1.45 Number of loadings - 2,200/yr
Tank truck loading (NA)	Throughput - 110 m^3/yr Volume - 27 m^3 Bulk temperature - 25 °C Saturation factor (dimensionless) - 1.45 Number of loadings - 4/yr

See notes at end of table. (continued)

TABLE C-4. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE TRANSFER, STORAGE, AND HANDLING OPERATION MODEL UNITS[a] (continued)

Model unit (weights,[b] %)	Parameters
Container loading (con.)	
Tank truck loading (NA)	Throughput - 430 m^3/yr Volume - 27 m^3 Bulk temperature - 25 °C Saturation factor (dimensionless) - 1.45 Number of loadings - 16/yr
Rail tank car loading (NA)	Throughput - 440 m^3/yr Volume - 110 m^3 Bulk temperature - 25 °C Saturation factor (dimensionless) - 1.45 Number of loadings - 4/yr
Rail tank car loading (NA)	Throughput - 1,800 m^3/yr Volume - 110 m^3 Bulk temperature - 25 °C Saturation factor (dimensionless) - 1.45 Number of loadings - 16/yr
Storage tanks	
S02A Covered tank (37.7)	Throughput - 110 m^3/yr (30,000 gal/yr) Volume - 5.7 m^3 (1,500 gal) Diameter - 1.7 m (5.6 ft) Adjustment for small diameter (dimensionless) - 0.26 Height - 2.4 m (8 ft) Average vapor space height - 1.2 m (4 ft) Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Turnovers - 20/yr

See notes at end of table.

(continued)

TABLE C-4. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE TRANSFER, STORAGE, AND HANDLING OPERATION MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters
Storage tanks (con.)		
S02B	Covered tank (0[c])	Throughput - 60 m^3/yr (16,000 gal/yr) Volume - 30 m^3 (8,000 gal) Diameter - 4 m (13 ft) Adjustment for small diameter (dimensionless) - 0.65 Height - 2.4 m (8 ft) Average vapor space height - 1.2 m (4 ft) Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Turnovers - 2/yr
S02C	Covered tank (32.3)	Throughput - 1,100 m^3/yr (290,000 gal/yr) Volume - 30 m^3 (8,000 gal) Diameter - 4 m (13 ft) Adjustment for small diameter (dimensionless) - 0.65 Height - 2.4 m (8 ft) Average vapor space height - 1.2 m (4 ft) Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Turnovers - 37/yr
S02D	Covered tank (17.8)	Throughput - 3,300 m^3/yr (870,000 gal/yr) Volume - 76 m^3 (20,000 gal) Diameter - 5.8 m (19 ft) Adjustment for small diameter (dimensionless) - 0.86 Height - 2.7 m (9 ft) Average vapor space height - 1.4 m (4.6 ft) Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Turnovers - 44/yr

See notes at end of table. (continued)

TABLE C-4. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE TRANSFER, STORAGE, AND HANDLING OPERATION MODEL UNITS[a] (continued)

Model unit (weights,[b] %)		Parameters
Storage tanks (con.)		
S02E	Covered tank (12.2)	Throughput - 17,000 m^3/yr (4,500,000 gal/yr) Volume - 800 m^3 (210,000 gal) Diameter - 9.1 m (30 ft) Adjustment for small diameter (dimensionless) - 1 Height - 12 m (39 ft) Average vapor space height - 6 m (20 ft) Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Turnovers - 21/yr
Treatment tanks[d]		
T01D	Covered quiescent tank (28.3)	Throughput - 11,000 Mg/yr Volume - 30 m^3 Diameter - 4 m Adjustment for small diameter (dimensionless) - 0.65 Height - 2.4 m Average vapor space height - 1.2 m Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Retention time - 24 h Turnovers - 365/yr
T01E	Covered quiescent tank (21.8)	Throughput - 28,000 Mg/yr Volume - 76 m^3 Diameter - 5.8 m Adjustment for small diameter (dimensionless) - 0.86 Height - 2.7 m Average vapor space height - 1.4 m Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Turnovers - 365/yr

See notes at end of table.

(continued)

TABLE C-4. DESIGN AND OPERATING PARAMETERS OF HAZARDOUS WASTE TRANSFER, STORAGE, AND HANDLING OPERATION MODEL UNITS[a] (continued)

Model unit (weights,[b] %)	Parameters
<u>Treatment tanks</u> (con.)	
T01F Covered quiescent tank (50.0)	Throughput - 290,000 Mg/yr Volume - 800 m^3 Diameter - 9.1 m Adjustment for small diameter (dimensionless) - 1 Height - 12 m Average vapor space height - 6 m Average diurnal temperature change - 11 °C Paint factor (dimensionless) - 1 Turnovers - 365/yr
<u>Equipment leaks</u>	
Equipment leak model unit A[e] (NA)	Pump seals - 5 Valves - 165 Sampling connections - 9 Open-ended lines - 44 Pressure relief valves - 3

NA = Not applicable.

[a]Hazardous waste transfer, storage, and handling operation model units represent the ranges of these operations in the hazardous waste management industry.

[b]Because design characteristics and operating parameters (surface area, waste throughputs, detention times, and so on) were generally not available for all treatment, storage, and disposal facilities (TSDF), weighting factors were developed to approximate the nationwide distribution of model units defined for a particular TSDF waste management process. The weighting factors are based on the considerable statistical data available in the 1981 EPA survey of hazardous waste generators and TSDF conducted by Westat, Inc. (Westat Survey). For example, results of this survey were used to determine the national distribution of sizes of storage tanks (storage volume), surface impoundments (surface area), and landfills (surface area and depth). For further information on weighting factors, refer to Appendix D, Sections D.2.4.3 and D.2.5.

[c]The model unit was weighted 0% because S02C also has the same volumetric capacity. This avoids double-weighting of a unit size.

[d]Loading emissions from covered quiescent treatment tanks are estimated in the same manner as loading emissions from covered storage tanks.

[e]Equipment leak model units B and C were not specified in terms of equipment counts. Emission estimates and control costs were calculated on the basis of model unit A equipment counts, and emission and control costs for model units B and C were factored from these estimates.

available to determine whether one loading method predominates. This loading method creates larger quantities of organic vapors and increases the saturation factor of each volatile compound within the container. A saturation factor is a dimensionless quantity that represents the expelled vapors fractional approach to saturation and accounts for the variations observed in emission rates from the different unloading and loading methods.[59] A saturation factor of 1.45 was selected for the emission estimates, based on previous documentation of splash-loading petroleum liquids.[60,61] Typical capacities for containers were selected, and 25 °C was considered the annual average ambient operating temperature.

Table C-4 presents covered, hazardous waste tank storage and quiescent treatment model units. The tank sizes were based on Westat Survey information, as has been explained previously for open hazardous waste quiescent treatment tank model units in Section C.2.1.1. (The Westat Survey did not distinguish between storage and treatment tanks.) Turnovers per year were selected based on volumes of waste processed as reported in Westat[62] and the Hazardous Waste Data Management System.[63] The remaining parameters were chosen, based on documented information and engineering judgment, to represent hazardous waste tank storage processes. Meteorological conditions used represent standard temperature (25 °C) and daily average temperature change (11 °C).

Table C-4 also provides hazardous waste transfer, handling, and loading (THL) operation model units to estimate emissions from equipment leaks. The equipment leak model unit A was obtained from the benzene fugitives emissions promulgation background information document[64] and was used as the baseline to develop equipment leak model units B and C. Equipment leak model units B and C were not specified in terms of equipment counts and, therefore, are not presented in Table C-4. Emission estimates and control costs were calculated on the basis of model unit A equipment counts, and emissions and control costs for model units B and C were factored from these estimates. Although the emission estimating model for equipment leaks (essentially the emission factor) is independent of throughput, it was necessary to account for throughput when applying the model units to a TSDF to estimate emissions. TSDF may treat, store, or dispose of large volumes of waste by one management process. Rather than assume that only one very large process unit (and, in turn, one fugitive model unit) is operated, the throughput of the process is divided by the throughput of its average model process unit, thus simulating the presence of multiple process units. This estimates the number of average model process units operating at the TSDF, and one equipment leak model unit is then applied to each average model process unit to estimate emissions from equipment leaks.

C.2.2 Model Wastes

A set of model waste compositions was developed to provide a uniform basis for emission control, emission reductions, and cost estimation for the model waste management units. Table C-5 lists the model waste compositions. These model wastes were used to develop control costs and control efficiencies by waste form for add-on and suppression-type controls. It should be noted that the model waste compositions defined here are not used to estimate uncontrolled emissions from the industry facilities. The compositions and quantities of actual waste streams processed at the existing facilities were used to estimate nationwide TSDF emissions and the emission reductions resulting from the control options.

The waste stream compositions in Table C-5 were selected to be representative of the major hazardous waste types containing organics.[66] One EPA study using the Waste Environmental Treatment (WET) data base[67] categorized organic-containing waste streams into major classes and evaluated pretreatment options for these wastes. That study categorized organic-containing wastes according to the following waste classes:[68]

- Organic liquids
- Aqueous organics (up to 20 percent organics)
- Dilute aqueous wastes (less than 2 percent organics)
- Organic sludges
- Aqueous/organic sludges.

Other data bases are available for specific industries,[69] but comprehensive waste stream listings for all domestic wastes are not available. Based on the known physical and chemical forms of organic-containing wastes, the following six generic waste stream types were selected for evaluation of add-on and suppression-type controls:

TABLE C-5. MODEL WASTE COMPOSITIONS[a]

Waste form	Organic content	Water content, wt %	Solid content, wt %	Composite molecular weight g/g mole (lb/lb mole)	Composite vapor pressure psia	Composite vapor pressure kPa	Composite density g/cm^3	Composite density lb/gal
Dilute aqueous	0.25% ethyl chloride 0.15% benzene	99.6	0	19.67	0.476	3.27	1	8.34
Two-phase aqueous/organic	20% chloroform 20% 1.2 dichlorobenzene	59	1	49.5	0.609	4.10	1.17	9.75
Organic liquid	30% benzene 30% naphthalene 39% phenol	0	1	78.2	0.689	4.73	1.05	8.72
Organic sludge/slurry	25% benzene 25% dichlorobenzene 25% naphthalene 25% hexachlorobenzene	0	0	78.7	0.770	5.29	1.35	11.22
Aqueous sludge/slurry	10% dibutylphthalate 2.5% 1-hexanol 2.5% chloroform	65	20 (Inorganic)	22.9	0.472	3.24	1.23	10.30
Organic-containing solid	1% acetonitrile	15	84 (Inorganic)	20.3	0.495	3.40	1.75	14.63

[a]The waste compositions were defined to provide bases for estimating the effectiveness and associated costs of controlling organic emissions from hazardous waste management units. These waste compositions are defined as models only and do not necessarily represent real waste streams. Specific chemical properties were used in the cost exercise. These properties are listed for the majority of chemicals in Appendix D, Table D-10. Properties of the remaining chemicals are provided in Reference 65.

- Dilute aqueous wastes
- Organic liquids
- Organic sludge/slurry
- Aqueous sludge/slurry
- Two-phase aqueous/organic
- Organic-containing solids.

For each generic waste type, specific chemical compositions were next defined so that material/energy balances and costs could be calculated. Chemical compositions were chosen that represent the properties of hazardous waste, but they may not represent specific constituents. In general, compositions were specified that are:

- Representative of the generic waste stream type, i.e., that include the major organic chemical classes of environmental importance (e.g., chlorinated organics, aromatics)
- Composed of chemicals representing a range of physical and chemical properties, based on Henry's law, biodegradability, and vapor pressure
- Physically and chemically realistic (e.g., a two-phase aqueous/organic waste that in fact forms two phases at the proposed composition)
- Readily characterized by available physical and chemical property data required for the treatment or control system process designs (e.g., vapor-liquid equilibrium compositions).

To validate the criterion of being physically and chemically realistic, small samples of most of the selected generic waste streams were prepared. However, the physical and chemical properties (e.g., vapor-liquid equilibrium compositions) needed for the material and energy balances have not been verified experimentally. Many organic-containing wastes are complex multicomponent mixtures. Trace levels of certain compounds (not examined in this study) could significantly affect the properties of a particular waste stream. However, the chosen waste compositions are generally suitable for developing design and cost information for treatment and control processes.

C.2.3 Summary of Model Unit Analysis of Emission Reductions and Control Costs

The model unit analysis was conducted to provide a basis for estimating the effectiveness (achievable emission reductions) and associated costs of controlling organic air emissions from TSDF hazardous waste management units. In the model unit analysis, control costs (both capital and annualized) and achievable emission reductions were determined for a matrix of (1) TSDF model units (e.g., covered storage tanks, quiescent uncovered treatment tanks, waste fixation operations, and open landfills), (2) waste forms (e.g., aqueous sludges, organic liquids, and dilute aqueous wastes), and (3) control technologies (e.g., suppression controls such as tank covers, add-on controls such as carbon adsorbers). The cost and emission reduction data generated in the analysis were then used to develop the control technology and cost file used for estimating nationwide impacts for alternative TSDF control options. This file provides control device efficiencies, emission reductions, and control costs according to waste form for each emission control technology that is applicable to a waste management process.

Table C-6 presents a summary of the results of the model unit analysis in terms of uncontrolled emission estimates, emission reductions, and control costs for the various model hazardous waste management units. This model unit analysis includes only compatible combinations of model waste forms and model unit. Incompatible combinations of waste form and model unit were not analyzed; e.g., an organic-containing solid waste would not be treated in a tank.

In Table C-6, the emission control refers to the control technologies described in Chapter 4.0. Model units and their annual throughputs are those described in Section C.2.1. Model wastes are as defined in Section C.2.2. Uncontrolled emissions are estimates generated by the applicable emission model described in Section C.1.1. The emission reduction is calculated on the basis of efficiencies presented in Chapter 4.0 for each control technology. The costs of add-on and suppression-type controls are calculated as described in Appendix H.

The emission estimates in Table C-6 show the wide range of emission levels possible from a given model waste management model unit when wastes

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
			CONTAINER STORAGE			
--- DRUM STORAGE (S01A) - 200 Drums/yr ---						
Fixed Bed Carbon Adsorber	Aqueous Sludge	50	0.00033	0.00031	$43,460	$18,300
	Dilute Aqueous-1	40	0.0000083	0.0000079	$43,460	$18,300
	Organic Liquid	40	0.0022	0.0021	$43,460	$18,300
	Organic Sludge/Slurry	60	0.0027	0.0026	$43,460	$18,300
	Two-Phase Aqueous/Organic	40	0.000017	0.000016	$43,460	$18,300
--- DRUM STORAGE (S01B) - 2200 Drums/yr ---						
Fixed Bed Carbon Adsorber	Aqueous Sludge	560	0.0036	0.0034	$43,460	$18,300
	Dilute Aqueous-1	450	0.000091	0.000086	$43,460	$18,300
	Organic Liquid	440	0.024	0.022	$43,460	$18,300
	Organic Sludge/Slurry	610	0.030	0.028	$43,460	$18,300
	Two-Phase Aqueous/Organic	440	0.00018	0.00017	$43,460	$18,300
--- DUMPSTER STORAGE (S01C) - 3.4 m^3 (120 ft^3) Dumpster volume ---						
Dumpster Cover	Aqueous Sludge	16	0.72	0.71	$150	$64
	Organic Solid	24	0.049	0.0485	$150	$72

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
TANK STORAGE						
COVERED STORAGE TANK (S02A) - 1,500 gal tank						
Internal Floating Roof	Aqueous Sludge	140	0.0045	0.004	$4,820	$1,520
	Dilute Aqueous-1	110	0.083	0.061	$4,820	$1,520
	Organic Liquid	110	0.017	0.014	$4,820	$1,520
	Organic Sludge/Slurry	130	0.043	0.035	$4,820	$1,520
	Two-Phase Aqueous/Organic	131	0.035	0.027	$4,820	$1,520
Vent to Existing Control Device	Aqueous Sludge	140	0.0045	0.004	$1,600	$320
	Dilute Aqueous-1	110	0.083	0.079	$1,600	$320
	Organic Liquid	110	0.017	0.016	$1,600	$320
	Organic Sludge/Slurry	130	0.043	0.041	$1,600	$320
	Two-Phase Aqueous/Organic	131	0.035	0.033	$1,600	$320
Vent to Carbon Canisters	Aqueous Sludge	140	0.0045	0.004	$1,050	$2,220
	Dilute Aqueous-1	110	0.083	0.079	$1,050	$5,330
	Organic Liquid	110	0.017	0.016	$1,050	$2,800
	Organic Sludge/Slurry	130	0.043	0.041	$1,050	$3,520
	Two-Phase Aqueous/Organic	131	0.035	0.033	$1,050	$3,500

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
		TANK STORAGE				
COVERED STORAGE TANK (S02B) - 8,000 gal tank						
Internal Floating Roof	Aqueous Sludge	70	0.013	0.011	$8,400	$2,600
	Dilute Aqueous-1	60	0.180	0.133	$8,400	$2,600
	Organic Liquid	60	0.0465	0.038	$8,400	$2,600
	Organic Sludge/Slurry	70	0.114	0.093	$8,400	$2,600
	Two-Phase Aqueous/Organic	70	0.075	0.058	$8,400	$2,600
Vent to Existing Control Device	Aqueous Sludge	70	0.013	0.012	$1,600	$320
	Dilute Aqueous-1	60	0.180	0.171	$1,600	$320
	Organic Liquid	60	0.0465	0.044	$1,600	$320
	Organic Sludge/Slurry	70	0.114	0.108	$1,600	$320
	Two-Phase Aqueous/Organic	70	0.075	0.071	$1,600	$320
Vent to Carbon Canisters	Aqueous Sludge	70	0.013	0.012	$1,050	$2,220
	Dilute Aqueous-1	60	0.180	0.171	$1,050	$8,720
	Organic Liquid	60	0.0465	0.044	$1,050	$3,520
	Organic Sludge/Slurry	70	0.114	0.108	$1,050	$6,100
	Two-Phase Aqueous/Organic	70	0.075	0.071	$1,050	$4,810

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
— TANK STORAGE —						
— COVERED STORAGE TANK (S02C) - 8,000 gal tank—						
Internal Floating Roof	Aqueous Sludge	1,380	0.045	0.037	$8,400	$2,600
	Dilute Aqueous-1	1,120	0.813	0.602	$8,400	$2,600
	Organic Liquid	1,090	0.167	0.137	$8,400	$2,600
	Organic Sludge/Slurry	1,320	0.424	0.348	$8,400	$2,600
	Two-Phase Aqueous/Organic	1,300	0.342	0.267	$8,400	$2,600
Vent to Existing Control Device	Aqueous Sludge	1,380	0.045	0.043	$1,600	$320
	Dilute Aqueous-1	1,120	0.813	0.772	$1,600	$320
	Organic Liquid	1,090	0.167	0.159	$1,600	$320
	Organic Sludge/Slurry	1,320	0.424	0.403	$1,600	$320
	Two-Phase Aqueous/Organic	1,300	0.342	0.325	$1,600	$320
Vent to Carbon Canisters	Aqueous Sludge	1,380	0.045	0.043	$1,050	$3,530
	Dilute Aqueous-1	1,120	0.813	0.772	$1,050	$34,130
	Organic Liquid	1,090	0.167	0.159	$1,050	$8,730
	Organic Sludge/Slurry	1,320	0.424	0.403	$1,050	$18,500
	Two-Phase Aqueous/Organic	1,300	0.342	0.325	$1,050	$15,220

See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
			TANK STORAGE			
— COVERED STORAGE TANK (S02D) - 20,000 gal tank —						
Internal Floating Roof	Aqueous Sludge	4,100	0.117	0.096	$11,380	$3,500
	Dilute Aqueous-1	3,300	2.12	1.569	$11,380	$3,500
	Organic Liquid	3,200	0.437	0.358	$11,380	$3,500
	Organic Sludge/Slurry	3,900	1.11	0.910	$11,380	$3,500
	Two-Phase Aqueous/Organic	3,900	0.891	0.695	$11,380	$3,500
Vent to Existing Control Device	Aqueous Sludge	4,100	0.117	0.111	$1,600	$320
	Dilute Aqueous-1	3,300	2.12	2.014	$1,600	$320
	Organic Liquid	3,200	0.437	0.415	$1,600	$320
	Organic Sludge/Slurry	3,900	1.11	1.055	$1,600	$320
	Two-Phase Aqueous/Organic	3,900	0.891	0.846	$1,600	$320
Vent to Carbon Canisters	Aqueous Sludge	4,100	0.117	0.111	$1,050	$8,110
	Dilute Aqueous-1	3,300	2.12	2.014	$1,050	$87,600
	Organic Liquid	3,200	0.437	0.415	$1,050	$20,480
	Organic Sludge/Slurry	3,900	1.11	1.055	$1,050	$47,240
	Two-Phase Aqueous/Organic	3,900	0.891	0.846	$1,050	$38,750

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
		— TANK STORAGE —				
— COVERED STORAGE TANK (S02E) - 210,000 gal tank —						
Internal Floating Roof	Aqueous Sludge	20,520	0.678	0.556	$19,660	$6,100
	Dilute Aqueous-1	16,660	12.35	9.139	$19,660	$6,100
	Organic Liquid	16,260	2.53	2.075	$19,660	$6,100
	Organic Sludge/Slurry	19,640	6.43	5.273	$19,660	$6,100
	Two-Phase Aqueous/Organic	19,300	5.19	4.048	$19,660	$6,100
Vent to Existing Control Device	Aqueous Sludge	20,520	0.678	0.644	$1,600	$11,080
	Dilute Aqueous-1	16,660	12.35	11.733	$1,600	$15,660
	Organic Liquid	16,260	2.53	2.403	$1,600	$13,170
	Organic Sludge/Slurry	19,640	6.43	6.108	$1,600	$13,160
	Two-Phase Aqueous/Organic	19,300	5.19	4.931	$1,600	$13,700
Vent to Fixed Bed Carbon Adsorber	Aqueous Sludge	20,520	0.678	0.644	$72,300	$40,000
	Dilute Aqueous-1	16,660	12.35	11.733	$72,300	$50,480
	Organic Liquid	16,260	2.53	2.403	$72,300	$40,000
	Organic Sludge/Slurry	19,640	6.43	6.108	$72,300	$40,260
	Two-Phase Aqueous/Organic	19,300	5.19	4.931	$72,300	$40,140

[a]See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
TANK STORAGE						
QUIESCENT UNCOVERED STORAGE TANK (S02F) - 1,500 gal tank						
Fixed Roof	Aqueous Sludge	140	1.5	1.496	$3,790	$760
	Dilute Aqueous-1	110	0.36	0.28	$3,790	$760
	Organic Liquid	110	26	25.98	$3,790	$760
	Organic Sludge/Slurry	130	31	30.96	$3,790	$760
	Two-Phase Aqueous/Organic	130	0.39	0.36	$3,790	$760
Internal Floating Roof (+ fixed roof)	Aqueous Sludge	140	1.5	1.499	$7,330	$1,870
	Dilute Aqueous-1	110	0.36	0.34	$7,330	$1,870
	Organic Liquid	110	26	25.996	$7,330	$1,870
	Organic Sludge/Slurry	130	31	30.99	$7,330	$1,870
	Two-Phase Aqueous/Organic	130	0.39	0.383	$7,330	$1,870
Vent to Existing Control Device (+ fixed roof)	Aqueous Sludge	140	1.5	1.4998	$5,370	$1,080
	Dilute Aqueous-1	110	0.36	0.356	$5,370	$1,080
	Organic Liquid	110	26	25.999	$5,370	$1,080
	Organic Sludge/Slurry	130	31	30.998	$5,370	$1,080
	Two-Phase Aqueous/Organic	130	0.39	0.389	$5,370	$1,080
Vent to Carbon Canister (+ fixed roof)	Aqueous Sludge	140	1.5	1.4998	$4,840	$2,980
	Dilute Aqueous-1	110	0.36	0.356	$4,840	$6,090
	Organic Liquid	110	26	25.939	$4,840	$3,560
	Organic Sludge/Slurry	130	31	30.998	$4,840	$4,280
	Two-Phase Aqueous/Organic	130	0.39	0.389	$4,840	$4,260

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
TANK STORAGE						
QUIESCENT UNCOVERED STORAGE TANK (S02G) - 8,000 gal tank						
Fixed Roof	Aqueous Sludge	70	1.4	1.39	$9,500	$1,880
	Dilute Aqueous-1	60	0.24	0.06	$9,500	$1,880
	Organic Liquid	60	24	23.95	$9,500	$1,880
	Organic Sludge/Slurry	70	29	28.89	$9,500	$1,880
	Two-Phase Aqueous/Organic	70	0.23	0.16	$9,500	$1,880
Internal Floating Roof (+ fixed roof)	Aqueous Sludge	70	1.4	1.398	$16,450	$4,000
	Dilute Aqueous-1	60	0.24	0.19	$16,450	$4,000
	Organic Liquid	60	24	23.99	$16,450	$4,000
	Organic Sludge/Slurry	70	29	28.98	$16,450	$4,000
	Two-Phase Aqueous/Organic	70	0.23	0.21	$16,450	$4,000
Vent to Existing Control Device (+ fixed roof)	Aqueous Sludge	70	1.4	1.3995	$11,080	$2,200
	Dilute Aqueous-1	60	0.24	0.23	$11,080	$2,200
	Organic Liquid	60	24	23.998	$11,080	$2,200
	Organic Sludge/Slurry	70	29	28.99	$11,080	$2,200
	Two-Phase Aqueous/Organic	70	0.23	0.227	$11,080	$2,200
Vent to Carbon Canister (+ fixed roof)	Aqueous Sludge	70	1.4	1.3995	$10,550	$4,100
	Dilute Aqueous-1	60	0.24	0.23	$10,550	$10,600
	Organic Liquid	60	24	23.998	$10,550	$5,460
	Organic Sludge/Slurry	70	29	28.99	$10,550	$7,980
	Two-Phase Aqueous/Organic	70	0.23	0.227	$10,550	$6,690

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
TANK STORAGE						
QUIESCENT UNCOVERED STORAGE TANK (S02H) - 8,000 gal tank						
Fixed Roof	Aqueous Sludge	1,380	11	10.96	$9,500	$1,880
	Dilute Aqueous-1	1,120	3.2	2.4	$9,500	$1,880
	Organic Liquid	1,090	217	216.8	$9,500	$1,880
	Organic Sludge/Slurry	1,320	243	242.6	$9,500	$1,880
	Two-Phase Aqueous/Organic	1,300	3.6	3.3	$9,500	$1,880
Internal Floating Roof (+ fixed roof)	Aqueous Sludge	1,380	11	10.99	$16,450	$4,000
	Dilute Aqueous-1	1,120	3.2	3.0	$16,450	$4,000
	Organic Liquid	1,090	217	216.96	$16,450	$4,000
	Organic Sludge/Slurry	1,320	243	242.9	$16,450	$4,000
	Two-Phase Aqueous/Organic	1,300	3.6	3.53	$16,450	$4,000
Vent to Existing Control Device (+ fixed roof)	Aqueous Sludge	1,380	11	10.998	$11,080	$2,200
	Dilute Aqueous-1	1,120	3.2	3.16	$11,080	$2,200
	Organic Liquid	1,090	217	216.99	$11,080	$2,200
	Organic Sludge/Slurry	1,320	243	242.98	$11,080	$2,200
	Two-Phase Aqueous/Organic	1,300	3.6	3.59	$11,080	$2,200
Vent to Carbon Canister (+ fixed roof)	Aqueous Sludge	1,380	11	10.998	$10,550	$5,410
	Dilute Aqueous-1	1,120	3.2	3.16	$10,550	$36,010
	Organic Liquid	1,090	217	216.99	$10,550	$10,610
	Organic Sludge/Slurry	1,320	243	242.98	$10,550	$20,380
	Two-Phase Aqueous/Organic	1,300	3.6	3.59	$10,550	$17,100

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
— TANK STORAGE —						
— QUIESCENT UNCOVERED STORAGE TANK (S02I) - 20,000 gal —						
Fixed Roof	Aqueous Sludge	4,100	24	23.9	$14,800	$2,930
	Dilute Aqueous-1	3,300	8.1	6.0	$14,800	$2,930
	Organic Liquid	3,200	514	513.6	$14,800	$2,930
	Organic Sludge/Slurry	3,900	586	584.9	$14,800	$2,930
	Two-Phase Aqueous/Organic	3,900	9.7	8.8	$14,800	$2,930
Internal Floating Roof (+ fixed roof)	Aqueous Sludge	4,100	24	23.98	$24,420	$5,860
	Dilute Aqueous-1	3,300	8.1	7.6	$24,420	$5,860
	Organic Liquid	3,200	514	513.9	$24,420	$5,860
	Organic Sludge/Slurry	3,900	586	585.8	$24,420	$5,860
	Two-Phase Aqueous/Organic	3,900	9.7	9.5	$24,420	$5,860
Vent to Existing Control Device (+ fixed roof)	Aqueous Sludge	4,100	24	23.995	$16,380	$3,250
	Dilute Aqueous-1	3,300	8.1	8.0	$16,380	$3,250
	Organic Liquid	3,200	514	513.98	$16,380	$3,250
	Organic Sludge/Slurry	3,900	586	585.9	$16,380	$3,250
	Two-Phase Aqueous/Organic	3,900	9.7	9.66	$16,380	$3,250
Vent to Carbon Canister (+ fixed roof)	Aqueous Sludge	4,100	24	23.995	$15,850	$11,040
	Dilute Aqueous-1	3,300	8.1	8.0	$15,850	$90,530
	Organic Liquid	3,200	514	513.98	$15,850	$23,410
	Organic Sludge/Slurry	3,900	586	585.9	$15,850	$50,170
	Two-Phase Aqueous/Organic	3,900	9.7	9.66	$15,850	$41,680

See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS[c] (Mg/yr)	EMISSION REDUCTION[d] (Mg/yr)	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
		— TANK STORAGE —				
— QUIESCENT UNCOVERED STORAGE TANK (S02J) - 210,000 gal tank —						
Fixed Roof	Aqueous Sludge	20,520	70	69.3	$26,040	$5,200
	Dilute Aqueous-1	16,660	30	17.7	$26,040	$5,200
	Organic Liquid	16,260	1,730	1,727	$26,040	$5,200
	Organic Sludge/Slurry	19,640	1,960	1,954	$26,040	$5,200
	Two-Phase Aqueous/Organic	19,300	41	35.8	$26,040	$5,200
Internal Floating Roof (+ fixed roof)	Aqueous Sludge	20,520	70	69.9	$40,560	$9,500
	Dilute Aqueous-1	16,660	30	26.8	$40,560	$9,500
	Organic Liquid	16,260	1,730	1,729.5	$40,560	$9,500
	Organic Sludge/Slurry	19,640	1,960	1958.9	$40,560	$9,500
	Two-Phase Aqueous/Organic	19,300	41	39.9	$40,560	$9,500
Vent to Existing Control Device (+ fixed roof)	Aqueous Sludge	20,520	70	69.97	$27,620	$5,600
	Dilute Aqueous-1	16,660	30	29.4	$27,620	$5,600
	Organic Liquid	16,260	1,730	1,729.9	$27,620	$5,600
	Organic Sludge/Slurry	19,640	1,960	1959.7	$27,620	$5,600
	Two-Phase Aqueous/Organic	19,300	41	40.7	$27,620	$5,600
Vent to Fixed Bed Carbon Adsorber (+ fixed roof)	Aqueous Sludge	20,520	70	69.97	$98,340	$45,200
	Dilute Aqueous-1	16,660	30	29.4	$98,340	$55,680
	Organic Liquid	16,260	1,730	1,729.9	$98,340	$45,200
	Organic Sludge/Slurry	19,640	1,960	1959.7	$98,340	$45,460
	Two-Phase Aqueous/Organic	19,300	41	40.7	$98,340	$45,340

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
			WASTEPILE STORAGE			
— WASTEPILE COVER (S03D) - 1300 ft^3 waste volume —						
Wastepile Cover-30 mil HDPE	Aqueous Sludge	17,000	16.0	15.95	$650	$2,500
	Two-Phase Aqueous/Organic	17,000	10.0	4.9	$650	$2,500
— WASTEPILE COVER (S03E) - 16,000 ft^3 waste volume —						
Wastepile Cover-30 mil HDPE	Aqueous Sludge	120,000	139.7	139.3	$6,480	$4,700
	Two-Phase Aqueous/Organic	120,000	100.0	49.3	$6,480	$4,700
— WASTEPILE COVER (S03F) - 2,010,000 ft^3 waste volume —						
Wastepile Cover-30 mil HDPE	Aqueous Sludge	170,000	457.0	455.6	$197,300	$62,000
	Two-Phase Aqueous/Organic	170,000	390.0	192.3	$197,300	$62,000

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
			SURFACE IMPOUNDMENT STORAGE			
QUIESCENT STORAGE IMPOUNDMENT (S04A) - 71,300 gal Impoundment						
ASP+FBCA	Aqueous Sludge	99,000	278	264	$181,000	$84,000
	Dilute Aqueous-1	99,000	114	108	$177,000	$78,000
	Two-Phase Aqueous/Organic	99,000	191	181	$177,000	$78,000
MEMBRANE	Aqueous Sludge	99,000	278	236	$15,000	$8,000
	Dilute Aqueous-1	99,000	114	97	$15,000	$8,000
	Two-Phase Aqueous/Organic	99,000	191	162	$15,000	$8,000
QUIESCENT STORAGE IMPOUNDMENT (S04B) - 71,300 gal Impoundment						
ASP+FBCA	Aqueous Sludge	9,800	140	133	$180,000	$78,000
	Dilute Aqueous-1	9,800	32	30	$179,000	$74,000
	Two-Phase Aqueous/Organic	9,800	36	34	$179,000	$74,000
MEMBRANE	Aqueous Sludge	9,800	140	119	$15,000	$8,000
	Dilute Aqueous-1	9,800	32	27	$15,000	$8,000
	Two-Phase Aqueous/Organic	9,800	36	31	$15,000	$8,000

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
			SURFACE IMPOUNDMENT STORAGE			
QUIESCENT STORAGE IMPOUNDMENT (S04C) - 713,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	49,000	686	652	$311,000	$42,000
	Dilute Aqueous-1	49,000	159	151	$249,000	$42,000
	Two-Phase Aqueous/Organic	49,000	183	174	$249,000	$42,000
MEMBRANE	Aqueous Sludge	49,000	686	583	$57,000	$16,200
	Dilute Aqueous-1	49,000	159	135	$57,000	$16,200
	Two-Phase Aqueous/Organic	49,000	183	156	$57,000	$16,200
QUIESCENT STORAGE IMPOUNDMENT (S04D) - 713,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	25,000	442	420	$310,000	$127,000
	Dilute Aqueous-1	25,000	157	149	$310,000	$114,000
	Two-Phase Aqueous/Organic	25,000	93	88	$310,000	$114,000
MEMBRANE	Aqueous Sludge	25,000	442	376	$57,000	$17,000
	Dilute Aqueous-1	25,000	157	133	$57,000	$17,000
	Two-Phase Aqueous/Organic	25,000	93	79	$57,000	$17,000

See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
——— SURFACE IMPOUNDMENT STORAGE ———						
—— QUIESCENT STORAGE IMPOUNDMENT (S04E) - 8,720,000 gal impoundment ——						
ASP+FBCA	Aqueous Sludge	120,000	2,200	2,090	$1,160,000	$488,000
	Dilute Aqueous-1	120,000	446	424	$804,000	$284,000
	Two-Phase Aqueous/Organic	120,000	464	441	$804,000	$284,000
MEMBRANE	Aqueous Sludge	120,000	2,200	1,870	$300,000	$65,000
	Dilute Aqueous-1	120,000	446	379	$300,000	$65,000
	Two-Phase Aqueous/Organic	120,000	464	394	$300,000	$65,000
—— QUIESCENT STORAGE IMPOUNDMENT (S04F) - 8,720,000 gal impoundment ——						
ASP+FBCA	Aqueous Sludge	67,000	1,420	1,349	$1,170,000	$450,000
	Dilute Aqueous-1	67,000	253	240	$806,000	$276,000
	Two-Phase Aqueous/Organic	67,000	262	249	$806,000	$276,000
MEMBRANE	Aqueous Sludge	67,000	1,420	1,207	$300,000	$65,000
	Dilute Aqueous-1	67,000	253	215	$300,000	$65,000
	Two-Phase Aqueous/Organic	67,000	262	223	$300,000	$65,000

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS[c] (Mg/yr)	EMISSION REDUCTION[d] (Mg/yr)	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
TANK TREATMENT						
QUIESCENT UNCOVERED TREATMENT TANK (T01A) - 8,000 gal tank						
Fixed Roof	Aq Sludge	11,000	16	15.9	$9,500	$1,880
	Dilute Aq	11,000	8.6	6.8	$9,500	$1,880
	Org Liquid	11,000	467	466.5	$9,500	$1,880
	Org Sludge/Slurry	11,000	523	522.4	$9,500	$1,880
	Two-Phase Aq/Org	11,000	14	13.2	$9,500	$1,880
Internal Floating Roof (+ fixed roof)	Aq Sludge	11,000	16	15.98	$16,450	$4,090
	Dilute Aq	11,000	8.6	8.12	$16,450	$4,090
	Org Liquid	11,000	467	466.91	$16,450	$4,090
	Org Sludge/Slurry	11,000	523	522.90	$16,450	$4,090
	Two-Phase Aq/Org	11,000	14	13.83	$16,450	$4,090
Vent to Existing Control Device (+ fixed roof)	Aq Sludge	11,000	16	15.995	$11,080	$2,210
	Dilute Aq	11,000	8.6	8.51	$11,080	$2,210
	Org Liquid	11,000	467	466.98	$11,080	$2,210
	Org Sludge/Slurry	11,000	523	522.97	$11,080	$2,210
	Two-Phase Aq/Org	11,000	14	13.96	$11,080	$2,210
Vent to Carbon Canister (+ fixed roof)	Aq Sludge	11,000	16	15.995	$10,550	$7,300
	Dilute Aq	11,000	8.6	8.5	$10,550	$76,380
	Org Liquid	11,000	467	466.98	$10,550	$22,360
	Org Sludge/Slurry	11,000	523	522.97	$10,550	$25,570
	Two-Phase Aq/Org	11,000	14	13.96	$10,550	$34,090

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS[c] (Mg/yr)	EMISSION REDUCTION[d] (Mg/yr)	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
——— TANK TREATMENT ———						
— QUIESCENT UNCOVERED TREATMENT TANK (T01B) - 20,000 gal tank —						
Fixed Roof	Aq Sludge	28,000	34	33.8	$14,800	$3,050
	Dilute Aq	28,000	19	14.4	$14,800	$3,050
	Org Liquid	28,000	954	952.8	$14,800	$3,050
	Org Sludge/Slurry	28,000	1,026	1,024.6	$14,800	$3,050
	Two-Phase Aq/Org	28,000	31	29.1	$14,800	$3,050
Internal Floating Roof (+ fixed roof)	Aq Sludge	28,000	34	33.96	$24,420	$6,100
	Dilute Aq	28,000	19	17.80	$24,420	$6,100
	Org Liquid	28,000	954	953.79	$24,420	$6,100
	Org Sludge/Slurry	28,000	1,026	1025.75	$24,420	$6,100
	Two-Phase Aq/Org	28,000	31	30.57	$24,420	$6,100
Vent to Existing Control Device (+ fixed roof)	Aq Sludge	28,000	34	33.99	$16,380	$3,350
	Dilute Aq	28,000	19	18.8	$16,380	$3,350
	Org Liquid	28,000	954	953.9	$16,380	$3,350
	Org Sludge/Slurry	28,000	1,026	1025.9	$16,380	$3,350
	Two-Phase Aq/Org	28,000	31	30.9	$16,380	$3,350
Vent to Carbon Canister (+ fixed roof)	Aq Sludge	28,000	34	33.99	$15,850	$15,790
	Dilute Aq	28,000	19	18.8	$15,850	$188,920
	Org Liquid	28,000	954	953.9	$15,850	$53,460
	Org Sludge/Slurry	28,000	1,026	1025.9	$15,850	$20,220
	Two-Phase Aq/Org	28,000	31	30.9	$15,850	$82,830

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
——— TANK TREATMENT ———						
—— QUIESCENT UNCOVERED TREATMENT TANK (T01C) - 210,000 gal tank ——						
Fixed Roof	Aq Sludge	290,000	83	80.6	$26,040	$5,810
	Dilute Aq	290,000	53	5.8	$26,040	$5,810
	Org Liquid	290,000	4,770	4,759	$26,040	$5,810
	Org Sludge/Slurry	290,000	5,320	5,306	$26,040	$5,810
	Two-Phase Aq/Org	290,000	98	78.1	$26,040	$5,810
Internal Floating Roof (+ fixed roof)	Aq Sludge	290,000	83	68.06	$40,560	$11,620
	Dilute Aq	290,000	53	60.16	$40,560	$11,620
	Org Liquid	290,000	4,770	3912.44	$40,560	$11,620
	Org Sludge/Slurry	290,000	5,320	5219.01	$40,560	$11,620
	Two-Phase Aq/Org	290,000	98	1243.69	$40,560	$11,620
Vent to Existing Control Device (+ fixed roof)	Aq Sludge	290,000	83	82.88	$42,460	$8,720
	Dilute Aq	290,000	53	50.64	$42,460	$8,720
	Org Liquid	290,000	4,770	4769.45	$42,460	$8,720
	Org Sludge/Slurry	290,000	5,320	5319.28	$42,460	$8,720
	Two-Phase Aq/Org	290,000	98	97.01	$42,460	$8,720
Vent to Fixed Bed Carbon Adsorber (+ fixed roof)	Aq Sludge	290,000	83	82.88	$100,220	$58,120
	Dilute Aq	290,000	53	50.64	$100,220	$58,120
	Org Liquid	290,000	4,770	4769.45	$100,220	$58,120
	Org Sludge/Slurry	290,000	5,320	5319.28	$100,220	$58,120
	Two-Phase Aq/Org	290,000	98	97.01	$100,220	$58,120

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS[c] (Mg/yr)	EMISSION REDUCTION[d] (Mg/yr)	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
— TANK TREATMENT —						
— COVERED QUIESCENT TREATMENT TANK (T01D) - 8,000 gal tank —						
Internal Floating Roof	Aq Sludge	11,000	0.0953	0.08	$8,400	$2,660
	Dilute Aq	11,000	1.83	1.35	$8,400	$2,660
	Org Liquid	11,000	0.473	0.39	$8,400	$2,660
	Org Sludge/Slurry	11,000	0.56	0.46	$8,400	$2,660
	Two-Phase Aq/Org	11,000	0.769	0.60	$8,400	$2,660
Vent to Existing Control Device	Aq Sludge	11,000	0.0953	0.09	$1,600	$330
	Dilute Aq	11,000	1.83	1.74	$1,600	$330
	Org Liquid	11,000	0.473	0.45	$1,600	$330
	Org Sludge/Slurry	11,000	0.56	0.53	$1,600	$330
	Two-Phase Aq/Org	11,000	0.769	0.73	$1,600	$330
Vent to Carbon Canister	Aq Sludge	11,000	0.0953	0.09	$1,050	$5,420
	Dilute Aq	11,000	1.83	1.74	$1,050	$74,500
	Org Liquid	11,000	0.473	0.45	$1,050	$20,480
	Org Sludge/Slurry	11,000	0.56	0.53	$1,050	$23,690
	Two-Phase Aq/Org	11,000	0.769	0.73	$4,900	$32,210

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
——— TANK TREATMENT ———						
— COVERED QUIESCENT TREATMENT TANK (T01E) - 20,000 gal tank —						
Internal Floating Roof	Aq Sludge	28,000	0.24	0.20	$11,380	$3,600
	Dilute Aq	28,000	4.60	3.40	$11,380	$3,600
	Org Liquid	28,000	1.19	0.98	$11,380	$3,600
	Org Sludge/Slurry	28,000	1.40	1.15	$11,380	$3,600
	Two-Phase Aq/Org	28,000	1.94	1.51	$11,380	$3,600
Vent to Existing Control Device	Aq Sludge	28,000	0.24	0.23	$1,600	$300
	Dilute Aq	28,000	4.60	4.37	$1,600	$300
	Org Liquid	28,000	1.19	1.13	$1,600	$300
	Org Sludge/Slurry	28,000	1.40	1.33	$1,600	$300
	Two-Phase Aq/Org	28,000	1.94	1.84	$1,600	$300
Vent to Carbon Canister	Aq Sludge	28,000	0.24	0.23	$1,050	$12,740
	Dilute Aq	28,000	4.60	4.37	$1,050	$185,870
	Org Liquid	28,000	1.19	1.13	$1,050	$50,410
	Org Sludge/Slurry	28,000	1.40	1.33	$1,050	$5,900
	Two-Phase Aq/Org Two-Phase	28,000	1.94	1.84	$1,050	$79,780

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS[c] (Mg/yr)	EMISSION REDUCTION[d] (Mg/yr)	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
			TANK TREATMENT			
	— COVERED QUIESCENT TREATMENT TANK (T01F) - 210,000 gal tank —					
Internal Floating Roof	Aq Sludge	290,000	2.45	2.01	$19,660	$5,810
	Dilute Aq	290,000	47.23	34.95	$19,660	$5,810
	Org Liquid	290,000	11.05	9.06	$19,660	$5,810
	Org Sludge/Slurry	290,000	14.32	11.74	$19,660	$5,810
	Two-Phase Aq/Org	290,000	19.89	15.52	$19,660	$5,810
Vent to Existing Control Device	Aq Sludge	290,000	2.45	2.32	$1,600	$300
	Dilute Aq	290,000	47.23	44.87	$1,600	$300
	Org Liquid	290,000	11.05	10.49	$1,600	$300
	Org Sludge/Slurry	290,000	14.32	13.60	$1,600	$300
	Two-Phase Aq/Org	290,000	19.89	18.90	$1,600	$300
Vent to Fixed Bed Carbon Adsorber	Aq Sludge	290,000	2.45	2.32	$74,180	$52,310
	Dilute Aq	290,000	47.23	44.87	$74,180	$52,310
	Org Liquid	290,000	11.05	10.49	$74,180	$52,310
	Org Sludge/Slurry	290,000	14.32	13.60	$74,180	$52,310
	Two-Phase Aq/Org	290,000	19.89	18.90	$74,180	$52,310

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
—— TANK TREATMENT ——						
— UNCOVERED AERATED/AGITATED TREATMENT TANK (T01G) - 28,500 gal tank —						
ASP+FBCA	Aqueous Sludge	240,000	870	827	$124,000	$66,600
	Dilute Aqueous-1	240,000	130	124	$125,000	$94,800
— UNCOVERED AERATED/AGITATED TREATMENT TANK (T01H) - 423,000 gal tank —						
ASP+FBCA	Aqueous Sludge	2,800,000	10,600	10,070	$732,000	$607,000
	Dilute Aqueous-1	2,800,000	4,600	4,370	$732,000	$607,000

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
SURFACE IMPOUNDMENT TREATMENT						
QUIESCENT TREATMENT IMPOUNDMENT (T02A) - 71,300 gal impoundment						
ASP+FBCA	Aqueous Sludge	200,000	301	286	$181,200	$85,300
	Dilute Aqueous-1	200,000	135	128	$179,800	$83,300
	Two-Phase Aqueous/Organic	200,000	265	252	$179,800	$83,300
MEMBRANE	Aqueous Sludge	200,000	301	256	$14,760	$8,000
	Dilute Aqueous-1	200,000	135	115	$14,760	$8,000
	Two-Phase Aqueous/Organic	200,000	265	225	$14,760	$8,000
QUIESCENT TREATMENT IMPOUNDMENT (T02B) - 71,300 gal impoundment						
ASP+FBCA	Aqueous Sludge	20,000	191	181	$176,900	$79,200
	Dilute Aqueous-1	20,000	53	50	$171,800	$72,600
	Two-Phase Aqueous/Organic	20,000	65	62	$171,800	$72,600
MEMBRANE	Aqueous Sludge	20,000	191	162	$14,760	$8,000
	Dilute Aqueous-1	20,000	53	45	$14,760	$8,000
	Two-Phase Aqueous/Organic	20,000	65	55	$14,760	$8,000

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
SURFACE IMPOUNDMENT TREATMENT						
QUIESCENT TREATMENT IMPOUNDMENT (T02C) - 713,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	990,000	1,400	1,330	$280,600	$147,900
	Dilute Aqueous-1	990,000	700	665	$277,500	$147,900
	Two-Phase Aqueous/Organic	990,000	1,320	1,254	$277,500	$147,900
MEMBRANE	Aqueous Sludge	990,000	1,400	1190	$57,000	$19,700
	Dilute Aqueous-1	990,000	700	595	$57,000	$19,700
	Two-Phase Aqueous/Organic	990,000	1,320	1122	$57,000	$19,700
QUIESCENT TREATMENT IMPOUNDMENT (T02D) - 713,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	99,000	946	899	$262,800	$128,200
	Dilute Aqueous-1	99,000	269	256	$237,500	$97,600
	Two-Phase Aqueous/Organic	99,000	326	310	$237,500	$97,600
MEMBRANE	Aqueous Sludge	99,000	946	804	$57,000	$15,800
	Dilute Aqueous-1	99,000	269	229	$57,000	$15,800
	Two-Phase Aqueous/Organic	99,000	326	277	$57,000	$15,800

See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS[c] (Mg/yr)	EMISSION REDUCTION[d] (Mg/yr)	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
—— SURFACE IMPOUNDMENT TREATMENT ——						
— QUIESCENT TREATMENT IMPOUNDMENT (T02E) - 8,720,000 gal impoundment —						
ASP+FBCA	Aqueous Sludge	608,000	5,530	5,254	$636,600	$395,200
	Dilute Aqueous-1	608,000	1,710	1,625	$500,000	$224,900
	Two-Phase Aqueous/Organic	608,000	2,040	1,938	$500,000	$224,900
MEMBRANE	Aqueous Sludge	608,000	5,530	4,701	$300,070	$10,800
	Dilute Aqueous-1	608,000	1,710	1,454	$300,070	$10,800
	Two-Phase Aqueous/Organic	608,000	2,040	1,734	$300,070	$10,800
— QUIESCENT TREATMENT IMPOUNDMENT (T02F) - 8,720,000 gal impoundment —						
ASP+FBCA	Aqueous Sludge	302,000	4,030	3,829	$577,900	$321,000
	Dilute Aqueous-1	302,000	990	941	$461,500	$169,300
	Two-Phase Aqueous/Organic	302,000	1,120	1,064	$461,500	$169,300
MEMBRANE	Aqueous Sludge	302,000	4,030	3,426	$300,070	$66,500
	Dilute Aqueous-1	302,000	990	842	$300,070	$66,500
	Two-Phase Aqueous/Organic	302,000	1,120	952	$300,070	$66,500

See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
SURFACE IMPOUNDMENT TREATMENT						
AERATED/AGITATED TREATMENT IMPOUNDMENT (T02G) - 71,300 gal impoundment						
ASP+FBCA	Aqueous Sludge	200,000	683	649	$196,200	$103,000
	Dilute Aqueous-1	200,000	760	722	$199,200	$107,000
	Two-Phase Aqueous/Organic	200,000	763	725	$199,200	$107,000
AERATED/AGITATED TREATMENT IMPOUNDMENT (T02H) - 71,300 gal impoundment						
ASP+FBCA	Aqueous Sludge	20,000	302	287	$181,300	$9,000
	Dilute Aqueous-1	20,000	78	74	$179,000	$8,000
	Two-Phase Aqueous/Organic	20,000	77	73	$179,000	$8,000
AERATED/AGITATED TREATMENT IMPOUNDMENT (T02I) - 713,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	990,000	6,530	6,204	$481,000	$404,000
	Dilute Aqueous-1	990,000	3,800	3,610	$376,000	$266,000
	Two-Phase Aqueous/Organic	990,000	3,860	3,667	$376,000	$266,000
AERATED/AGITATED TREATMENT IMPOUNDMENT (T02J) - 713,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	99,000	1,920	1,824	$305,000	$177,000
	Dilute Aqueous-1	99,000	390	371	$298,000	$122,000
	Two-Phase Aqueous/Organic	99,000	380	361	$298,000	$122,000

See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
SURFACE IMPOUNDMENT TREATMENT						
AERATED/AGITATED TREATMENT IMPOUNDMENT (T02K) - 8,720,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	608,000	12,160	11,552	$777,000	$693,000
	Dilute Aqueous-1	608,000	2,300	2,185	$512,000	$237,000
	Two-Phase Aqueous/Organic	608,000	2,400	2,280	$512,000	$237,000
AERATED/AGITATED TREATMENT IMPOUNDMENT (T02L) - 8,720,000 gal impoundment						
ASP+FBCA	Aqueous Sludge	302,000	6,520	6,194	$675,000	$445,000
	Dilute Aqueous-1	302,000	810	770	$460,000	$169,000
	Two-Phase Aqueous/Organic	302,000	1,200	1,140	$460,000	$169,000

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
			— WASTE FIXATION —			
— WASTE FIXATION (Fixation Pit A) —						
Mixer Baghouse, & FBCA	Aqueous Sludge	17,000	51.0	48.0	$464,000	$228,000
	Two-Phase Aqueous/Organic	17,000	51.0	50.0	$464,000	$228,000
— WASTE FIXATION (Fixation Pit B) —						
Mixer Baghouse, & FBCA	Aqueous Sludge	117,000	351.0	330	$572,000	$213,000
	Two-Phase Aqueous/Organic	117,000	351.0	300	$572,000	$213,000
— WASTE FIXATION (Fixation Pit C) —						
Mixer Baghouse, & FBCA	Aqueous Sludge	167,000	501.0	480	$616,000	$277,000
	Two-Phase Aqueous/Organic	167,000	501.0	500	$616,000	$277,000

See notes at end of table.

(continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
——— LANDFILL DISPOSAL ———						
— ACTIVE LANDFILL (D80D) - 1 acre —						
Daily Earth Cover	Aqueous Sludge	16,650	100.6	11.1	$0	$44,800
	Two-Phase Aqueous/Organic	16,650	86.1	9.5	$0	$44,800
— ACTIVE LANDFILL (D80E) - 3.5 acres —						
Daily Earth Cover	Aqueous Sludge	116,500	358.1	39.4	$0	$313,400
	Two-Phase Aqueous/Organic	116,500	299	32.9	$0	$313,400
— ACTIVE LANDFILL (D80F) - 5 acres —						
Daily Earth Cover	Aqueous Sludge	166,500	510.9	56.2	$0	$447,900
	Two-Phase Aqueous/Organic	166,500	427	47	$0	$447,900

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
		LANDFILL DISPOSAL				
— CLOSING LANDFILL (D80G) - 1 acre —						
C.Landfill 30 mil-HDPE	Aqueous Sludge	16,650	0.020	0.019	$17,260	$2,000
	Two-Phase Aqueous/Organic	16,650	0.6	0.29	$17,260	$2,000
C.Landfill 100 mil-HDPE	Aqueous Sludge	16,650	0.020	0.019	$44,490	$6,000
	Two-Phase Aqueous/Organic	16,650	0.6	0.51	$44,490	$6,000
— CLOSING LANDFILL (D80H) - 3.5 acres —						
C.Landfill 30 mil-HDPE	Aqueous Sludge	116,500	0.068	0.0678	$60,370	$9,000
	Two-Phase Aqueous/Organic	116,500	2.09	1.03	$60,370	$9,000
C.Landfill 100 mil-HDPE	Aqueous Sludge	116,500	0.068	0.0679	$155,720	$23,000
	Two-Phase Aqueous/Organic	116,500	2.09	1.77	$155,720	$23,000
— CLOSING LANDFILL (D80I) - 5 acres —						
C.Landfill 30 mil-HDPE	Aqueous Sludge	166,500	0.0973	0.0970	$86,250	$13,000
	Two-Phase Aqueous/Organic	166,500	2.89	1.42	$86,250	$13,000
C.Landfill 100 mil-HDPE	Aqueous Sludge	166,500	0.0973	0.0972	$222,450	$33,000
	Two-Phase Aqueous/Organic	166,500	2.89	2.45	$222,450	$33,000

See notes at end of table. (continued)

TABLE C-6. SUMMARY OF TSDF MODEL UNIT ANALYSIS RESULTS[a]

EMISSION CONTROL[b]	MODEL WASTE TYPE	ANNUAL THROUGHPUT (Mg/yr)	UNCONTROLLED EMISSIONS (Mg/yr)[c]	EMISSION REDUCTION (Mg/yr)[d]	TOTAL CAPITAL INVESTMENT	TOTAL ANNUAL COSTS
CONTAINER LOADING[e]						
DRUM LOADING - 200 drums/yr						
Submerged Fill Pipe	Aqueous Sludge	50	0.0018	0.0012	$390	$70
	Dilute Aqueous-1	40	0.0357	0.0232	$390	$70
	Organic Liquid	40	0.0068	0.0044	$390	$70
	Organic Sludge/Slurry	60	0.0175	0.0114	$390	$70
	Two-Phase Aqueous/Organic	40	0.0150	0.0098	$390	$70
DRUM LOADING - 2,200 drums/yr						
Submerged Fill Pipe	Aqueous Sludge	560	0.0195	0.0127	$390	$70
	Dilute Aqueous-1	450	0.3900	0.2535	$390	$70
	Organic Liquid	440	0.0743	0.0483	$390	$70
	Organic Sludge/Slurry	610	0.1910	0.1242	$390	$70
	Two-Phase Aqueous/Organic	440	0.1640	0.1066	$390	$70
TANK TRUCK LOADING						
Submerged Fill Pipe	Aqueous Sludge	521	0.0045	0.003	$390	$70
	Dilute Aqueous-1	423	0.0908	0.059	$390	$70
	Organic Liquid	413	0.0169	0.011	$390	$70
	Organic Sludge/Slurry	499	0.0446	0.029	$390	$70
	Two-Phase Aqueous/Organic	490	0.0385	0.025	$390	$70

See notes at end of table. (continued)

[a]This table summarizes the control costs and emission reductions by process unit for controlling organic air emissions from hazardous waste treatment, storage, and disposal facilities (TSDF). The control costs and achievable emission reductions were estimated through a model unit analysis utilizing a variety of diverse yet representative TSDF process model units, model waste compositions or forms, and applicable control technologies. The costs (in terms of $/Mg of waste throughput) were then used to develop the control technology and cost file (Appendix D, Section D.2.5) that is used in combination with the TSDF Industry Profile (Appendix D, Section D.1.3) and the waste characterization data base (Appendix D, Section D.1.4) to estimate nationwide cost impacts for alternative control strategies.

The model wastes used in the determination of control costs and emission reduction in the model unit analysis may not necessarily be representative of all actual waste streams processed at existing facilities. However, to the extent possible, the composition and quantities of the actual waste streams processed at existing facilities were used in estimating nationwide emissions and emission reductions resulting from the alternative control strategies.

Please note that all costs presented in this table are in January 1986 dollars.

[b]1. Carbon Adsorption--Two different carbon adsorption systems were examined for application as control devices. One system involves the use of fixed-bed, regenerable carbon adsorption units (FBCA); the other involves use of disposable carbon canisters. Both carbon canisters and fixed bed regenerable carbon systems were costed for each of the model unit/waste form cases; the less expensive system was selected for application. The fixed-bed carbon system's operating costs include the regeneration and eventual replacement and disposal of spent carbon; carbon canister's operating costs include carbon canister replacement and disposal. Carbon adsorption can reasonably be expected to achieve a 95-percent control efficiency for most organics under a wide variety of stream conditions provided (1) the adsorber is supplied with an adequate quantity of high quality activated carbon, (2) the gas stream receives appropriate conditioning (e.g., cooling, filtering) before entering the carbon bed, and (3) the carbon beds are regenerated or replaced before breakthrough.

2. Internal Floating Roofs--Emission reductions for internal floating roofs relative to a fixed-roof tank were estimated by using the emission models described in Appendix C, Section C.1.1.4.3 (fixed roof tank emissions) and EPA's Compilation of Air Pollutant Emission Factors (AP-42). Estimated emission reductions ranged from 74 to 82 percent. The variation in emission reductions is attributable to differences in composition and concentrations of model wastes.

   Internal floating roofs are applied to uncovered vertical tanks in conjunction with a fixed roof to suppress the uncovered tank organic emissions. For this combination, the emission reductions achievable are a combination of the reduction from application of the fixed roof to the

(continued)

uncovered tank, plus application of an internal floating roof to a fixed-roof tank. The range of emission reductions achievable based on combination of the fixed roof with the internal floating roof is 96 to 99.

3. Existing Control Device--Venting organic emissions to an existing control device is assumed to achieve an overall emission reduction of 95 percent; this includes both capture and control efficiencies.

4. Fixed Roof--Emission reductions for application of fixed roofs to uncovered tanks ranged from 25 to greater than 99 percent depending on waste form for both storage and treatment tanks.

5. Membrane--Floating synthetic membranes are applicable to quiescent impoundments and uncovered storage tanks. Emission reductions are determined by the fraction of surface area covered and by the permeability of the membrane. An emission reduction of 85 percent was used for floating synthetic membranes for purposes of estimating emission reductions from membrane-covered impoundments.

6. ASP--This control alternative involves installing an air-supported structure (ASP) and venting emissions to a carbon adsorption system. The efficiency of air-supported structures in reducing or suppressing emissions is determined by the combined effects of the capture efficiency of the structure and the removal efficiency of the control device. An overall control efficiency of 95 percent is used for air-supported structures vented to carbon adsorber.

7. HDPE--In this control technique, flexible covers are used to suppress or limit organic emissions from area sources. A typical cover material is 30-mil high-density polyethylene (HDPE). For the purposes of estimating emission reductions, control efficiencies of 0, 49.3, and 99.7 percent were used for 30-mil HDPE covers, depending on characteristics of the waste (i.e., permeability). Emission reductions of 0, 84.8, and 99.9 percent were selected for the model wastes with a 100-mil HDPE cover. The variations in emission reductions are attributable to differences in composition and concentrations of the model wastes.

[c]Uncontrolled emissions were estimated for each model unit and waste type using the appropriate TSDF air emission models as described in Section C.1; the model unit design and operating parameters described in Section C.2.1; and the waste compositions listed in Appendix C, Table C-5.

[d]Emission reductions achievable through application of the emission control technologies are calculated on the basis of the control efficiencies presented in Chapter 4.0. These emission reductions can be grouped into three broad categories based on the technologies involved:

(1) Suppression Controls-- Emission reduction are achieved by controls that contain the organics within a confined area and prevent or limit volatilization of the organics. Unless used in combination with add-on control devices, the organics may be emitted from a

(continued)

downstream TSDF waste management process. Suppression devices include internal floating roofs for covered or closed tanks and floating synthetic membranes for impoundments.

(2) Add-on Controls--Emission reductions are achieved by add-on controls that adsorb, condense, or combust the volatile organics and as a result prevent their release to the atmosphere. Examples include fixed-bed carbon adsorbers, condensers, thermal or catalytic incinerators.

[e]The total capital investment and total annual costs for the Container Loading Model Units are the same for drum loading, tank truck loading, and rail tank car loading.

of different compositions and forms are managed in that unit. The table also shows that control costs for certain controls are independent of waste composition, e.g., fixed roof for storage tanks and floating synthetic membranes. At the opposite extreme, the costs for fixed-bed carbon adsorption controls (e.g., those applied to uncovered, aerated treatment tanks model unit T01G) are highly sensitive to composition; i.e., bed size is a function of the level or quantity of uncontrolled emissions.

The emission reductions reported in Table C-6 are achieved through application of control technologies that can be classified into two broad categories based on the control mechanisms. Suppression controls contain the organics within a confined area and prevent or limit volatilization. Add-on controls are typically conventional air pollution control devices that adsorb, condense, or thermally destroy the volatile organics to prevent release to the atmosphere.

The footnotes to Table C-6 explain an important point about the reported emission reductions. Controls, such as a fixed roof applied to a storage tank, suppress organic emissions from that tank by the amount indicated in the table. The emissions prevented by installation of a fixed roof may escape from the waste at some downstream waste processing step unless emissions from that downstream process are also controlled. The emission reductions achieved through suppression controls are truly emission reductions only if the suppressed emissions are prevented from escaping the waste processes at other downstream processing steps. Add-on controls (such as carbon adsorption and vapor incineration) and/or biological decay to less volatile compounds are the principal approaches to avoid ultimate discharge to the atmosphere.

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16. ABSTRACT

Air emission standards are being proposed under the Resource Conservation and Recovery Act for hazardous waste treatment, storage, and disposal facilities (TSDF) to reduce emissions of ozone precursors (volatile organic compounds) and exposures to hazardous air pollutants. This document contains background information and environmental and economic assessments of regulatory alternatives considered in developing the proposed standards. The regulatory alternatives consider application of air pollution controls on tanks, surface impoundments, and containers used to manage hazardous waste at TSDFs, as well as at generators using tanks and containers to accumulate large quantities of waste on site. This document is divided into a three volume set.

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