UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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ANNOUNCEMENT OF DISTRIBUTION OF DRAFT HOSPITAL
WASTE INCINERATOR REPORT AND REQUEST FOR COMMENTS

Enclosed for your review is a copy of the final draft report entitled "Hospital Waste Combustion Study - Data Gathering Phase" prepared for the Environmental Protection Agency (EPA) by the Radian Corporation. This draft report summarizes readily available information on the hospital waste combustion industry including waste characterization, industry technology, multipollutant air emissions data, emission control technologies, current regulation and control strategies, and hospital waste combustor population characteristics, including suggested model plant parameters for use in exposure modeling.

This study of multipollutant emissions from the combustion of hospital waste was initiated by EPA's Office of Air Quality Planning and Standards in response to increasing concerns over the potential public health impacts from the disposal of hospital wastes, including incineration and other methods of disposal. Hospital wastes contain many of the materials found in municipal waste in addition to the "red" and "orange" bag waste. These hospital wastes contain both potentially toxic and infectious material. Concerns are not only for the release of toxic air emissions such as dioxins and dibenzofurans, other products of incomplete combustion, and inorganic pollutants such as hydrogen chloride, but also for the possibility that infectious micro-organisms (e.g., viruses) may survive the combustion processes.

We would like for you and your staff to review, use and comment, on this draft hospital waste combustion report. We would like for you to provide not only your comments and suggestions but also any additional data or information you might have concerning facility population, trace air emissions, process and control equipment, proposed or projected control regulations and control technology, etc. We plan to revise the draft report to address your comments and suggestions and include, where applicable, the information and data you send. Since there is a general lack of information and data pertaining to hospital waste combustion, the additional information and data you provide will be most useful in addressing the need to regulate hospital waste combustion emissions.

Please forward by April 29, 1988 your comments, suggestions and data to: Rayburn Morrison, Acting Chief, Program Analysis and Technology Section, MD-12, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711.

If you have any questions please contact me (919-541-5330; FTS 629-5330) or David Cleverly (919-541-5332; FTS 629-5332).

Sincerely,

Rayburn Morrison, Acting Chief
Program Analysis and Technology Section
Pollutant Assessment Branch

Enclosure

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

TABLE OF CONTENTS (CONTINUED)

LIST OF FIGURES

LIST OF FIGURES (CONTINUED)

LIST OF TABLES

LIST OF TABLES (CONTINUED)

1.0 INTRODUCTION

This report contains the results of a study of air emissions from hospital waste combustion. It represents an effort to gather currently available data in a manner that will allow the EPA to assess the need for and feasibility of regulating multipollutant emissions from hospital waste combustion. The work was performed by Radian Corporation under contract to EPA's Pollutant Analysis Branch of the Office of Air Quality Planning and Standards

During the course of this study, information was gathered from state and local environmental agencies, from vendors of incineration equipment, from the open technical literature, from the American Hospital Association, and from visits to three incineration facilities. Information was sought concerning feed characteristics, combustor designs and operating characteristics, emissions of air pollutants, applied and potential control technology, numbers and locations of hospital waste combustors, and applicable regulations. In addition, parameters needed to model exposure and health risk have been developed for use in EPA's Human Exposure Model.

The remainder of Section 1 is devoted to a description of the industry (Section 1.1) and characterization of hospital waste (Section 1.2). Section 2.0 contains information about the processes and equipment used for hospital waste combustion. Data gathered concerning air pollutants emitted from hospital waste incinerators and their formation in the combustion process are presented in Section 3.0. Section 4.0 contains a discussion of control techniques and possible control efficiencies. Environmental regulations affecting hospital waste combustion are presented in Section 5.0. Model plants suitable for EPA's use in assessing regulatory strategies are developed in Section 6.0.

1.1 DESCRIPTION OF THE INDUSTRY

"Hospital waste incineration" refers to the combustion of wastes produced by a hospital or hospital-type facility. These wastes include both

infectious wastes (i.e., materials which come in contact with hospital patients and which have a potential to carry disease-producing organisms) and non-infectious or general housekeeping wastes. Based on the experience of hospitals in Illinois, only about 15 percent of a typical hospital's waste is considered infectious while the remaining 85 percent can be considered to be general refuse.[1] However, because of the difficulty (and expense) in segregating infectious from non-infectious waste, the two waste types are generally mixed together, resulting in a considerably larger volume of waste which is considered infectious. In many States, laws have been enacted in the past ten years which prohibit the disposal of infectious wastes in landfills. To qualify for disposal, wastes must first be rendered innocuous. The three methods commonly available to hospitals for sterilization are autoclaving, treatment with ethylene oxide, and incineration. Due to limitations associated with autoclaving (i.e., limited capacities, handling problems, and questionable effectiveness) and ethylene oxide units (i.e., worker health risks), incineration has become the most practical waste sterilization and disposal option for many hospital facilities.[2]

Incineration reduces waste volumes by up to 90 percent. Hence, the volume and cost of ultimate disposal of residual wastes in a landfill can be reduced significantly by this method. An additional benefit of incineration systems, in some cases, is that they can be designed for heat recovery with the potential to supply a portion of the hospital's steam or hot water requirements.

The total capacity for hospital waste incinerators in the United States is uncertain. As of 1985, there were a reported 6,872 hospitals in the nation with 1,318,000 beds.[3] Estimates of waste generation rates (taken from References 15 and 16) range from about 8 to 13 lb/bed/day. Using the high end of this range and an occupancy rate of 69 percent, the total hospital waste generation rate is estimated at about 5,900 tons per day. However, not all of this waste is sent to incinerators, as discussed above. To estimate total incinerator capacity, this waste rate would need to be reduced by the amount of general waste that is segregated and sent via trash

disposal to landfills. Unfortunately, it is not possible to estimate these quantities based on the information gathered to date. As a point of reference, however, the total capacity of municipal solid waste incinerators in the United States in 1986 was estimated at about 49,000 tons of refuse per day out of a total national refuse production rate of about 340,000 tons per day.[4]

With regard to geographic distribution, hospitals are located in every State as well as the District of Columbia. At least one hospital was located in almost all metropolitan and non-metropolitan statistical areas in 1985 according to American Hospital Association statistics in Reference 2. Of the total number of hospitals, approximately 53 percent were located in metropolitan statistical areas with the balance in non-metropolitan areas.

Detailed statistics are available only for community hospitals, which comprised over 83 percent of the total hospital population in 1985. During the 1975 to 1985 period, the number of community hospitals declined by 2.4 percent; the total number of beds increased by 6.2 percent, however, reflecting hospital closures, mergers, and conversion to nonacute-care facilities.[5] Although the occupancy rate for community hospitals declined from 75 to about 65 percent, the number of surgical operations (which produce higher levels of infectious waste) increased by almost 21 percent. Taking these off-setting factors into account, the overall hospital waste generation rate appears to have remained relatively constant over this 10-year period. No factors were identified which would significantly change this trend in the near future.

No comprehensive information was found during this study regarding the total population of hospital waste incinerators in the nation. One manufacturer's representative estimated that over 90 percent of operating hospitals have an incinerator on-site, if only a small retort-type unit for pathological or special wastes.[6] The number of larger, controlled air type incinerators operating on hospital wastes was not known. However, based on discussions with two of the leading controlled-air incinerator manufacturers, it is estimated that at least 1,200 of these systems have been installed at United States hospitals over the past 20 years.[7,8] This

implies that there are approximately 5,000 or more retort-type incinerators which have been installed. While some of these units have been retired, a great majority are felt to be currently in operation.[9]

Some insight into population patterns among hospital waste incinerators was gained by examining a recent New York (NY) State database which was developed from an in-state survey of over 400 incinerator units. This database, and the analysis conducted by Radian Corporation during this study, are described in detail in Section 6.1. Highlights of the analysis are as follows:

- Almost 60 percent of the NY incinerators have design feed capacities of less than 200 lb/hr.
- The population distribution is bimodal with respect to feed capacity, with peaks in the 50 to 74 lb/hr range and in the 100 to 124 lb/hr range.
- About one-half of the NY incinerator capacity is above 600 lb/hr feed rate and about one-third is above 1,000 lb/hr feed rate.

A comparison of the New York and total U.S. hospital populations indicates that the two populations have similar overall shapes although there is a greater proportion of large hospitals above the 500-bed size in NY than in the nation as a whole.

1.2 WASTE CHARACTERIZATION

Hospital waste is characteristically heterogeneous, consisting of objects of many different sizes and composed of many different materials. The daily activities and procedures within a hospital can vary dramatically from day-to-day, thus making it difficult to predict what will be thrown away. During the course of this study, very little data were found to be available on the composition of hospital waste. This is due to the fact

that the amount of sampling and analysis required to generate representative characterization data would be extensive and costly. In addition, industry practice for many years has been to utilize the simplified waste classification system developed by the Incinerator Institute of America (IIA), discussed below, rather than sample and analyze waste. Table 1-1 contains one general breakdown of the composition of typical hospital waste.

Based on the experience of hospitals in Illinois, it is estimated that about 85% of a hospital's waste stream can be categorized as general refuse, while the remaining 15% is contaminated with infectious agents.[10] This is only a generalization, however, and actual wastes from a given hospital can vary significantly from day to day and from hour to hour. For example, refuse collected after a major surgical procedure, such as a heart transplant, may contain significantly more infectious wastes and disposable plastics than is usually generated in a routine operation.[11] Also, because of the difficulty in effectively segregating infectious and non-infectious waste at the point of generation, the infectious waste is generally mixed with a considerably larger portion of the hospital's general waste, thereby creating more waste that is considered infectious.[12]

Most of the public attention concerning hospital waste management has centered on the infectious waste portion. Unfortunately, a number of general and vague terms are used to refer to these wastes including "pathological waste," "biological waste," "hazardous waste," "biomedical waste," and "contaminated waste." In Canada, the term biomedical waste is popular and a color-code classification scheme for the waste has been developed as shown in Table 1-2. In the United States, all these categories of wastes are generally classified as "red bag" waste.[14]

In Europe, hospital wastes are divided into the general categories of normal housekeeping wastes and "hazardous" wastes. The latter category consists of bacterially infected pathological waste, oil and chemical waste, and radioactive isotopic contaminated waste.[15] A typical cross-section of this type of waste has included the following items:

TABLE 1-1. HOSPITAL WASTE CHARACTERIZATION[a]

Product	Approximate Percent by Weight[b]
Paper	65
Plastic	30
Moisture	10
Other	5

[a]Reference 13.

[b]Percentages do not necessarily add to 100 since they are approximations.

TABLE 1-2. CANADIAN CHARACTERIZATION OF BIOMEDICAL WASTE[a]

Waste Class	Component Description	Typical Component weight percent (as fired)
A1 (Red Bag)	Human Anatomical	95-100
	Plastics	0-5
	Swabs, Absorbents	0-5
	Alcohol, Disinfectants	0-0.2
A2 (Orange Bag)	Animal Infected Anatomical	80-100
	Plastics	0-15
	Glass	0-5
	Beddings, Shavings, Paper, Fecal Matter	0-10
A3a (Yellow Bag)	Gauze, Pads, Swabs Garments, Paper, Cellulose	60-90
	Plastics, PVC, Syringes	15-30
	Sharps, Needles	4-8
	Fluids, Residuals	2-5
	Alcohols, Disinfectants	0-0.2
A3b (Yellow Bag) Lab Waste	Plastics	50-60
	Sharps	0-5
	Cellulose Materials	5-10
	Fluids, Residuals	1-20
	Alcohols, Disinfectants	0-0.2
	Glass	15-25
A3c (Yellow Bag) R&D on DNA	Gauze, Pads, Swabs	5-30
	Plastics, Petri Dishes	50-60
	Sharps, Glass	0-10
	Fluids	1-10
B1 (Blue bag)	Non-infected Animal Anatomical	90-100
	Plastics	0-10
	Glass	0-3
	Beddings, Shavings, Fecal Matter	0-10

[a]Reference 16.

Artificial linens
Paper
Flowers
Waste food
Cans
Diapers
Plastic cups
Syringes
Scalpels
Tweezers
Rubber gloves
Pathological objects
Blood test tubes
Test tubes from miscellaneous service
Petri dishes
Dropper bottles
Medicine bottles
Drop infusion equipment
Transfusion equipment
Suction catheters
Bladder catheters
Urinal catheters
Colostomi bags

The general practice in the United States is to classify wastes according to the IIA system described in Table 1-3. The popularity of this system is reinforced by the fact that most incinerator manufacturers rate their equipment in terms of these categories.[17]

While useful for general design purposes, the IIA classification scheme does not address concerns such as the plastics content of waste or possible hazardous components. Hospital wastes typically can contain about 20 percent plastics with levels as high as 30 percent being reported.[18] The types of plastic most commonly encountered include polyethylene,

TABLE 1-3. INCINERATOR INSTITUTE OF AMERICA SOLID WASTE CLASSIFICATIONS[a]

Type 0	Trash, a mixture of highly combustible waste such as paper, cardboard, cartons, wood boxes, and combustible floor sweepings from commercial and industrial activities. The mixtures contain up to 10 percent by weight of plastic bags, coated paper, laminated paper, treated corrugated cardboard, oily rags, and plastic or rubber scraps. This type of waste contains 10 percent moisture, 5 percent incombustible solids and has a heating value of 8,500 Btu per pound as fired.
Type 1	Rubbish, a mixture of combustible waste such as paper, cardboard cartons, wood scrap, foliage, and combustible floor sweepings, from domestic, commercial, and industrial activities. The mixture contains up to 20 percent by weight of restaurant or cafeteria waste, but contains little or no treated papers, plastic, or rubber wastes. This type of waste contains 25 percent moisture, 10 percent incombustible solids, and has heating value of 6,500 Btu per pound as fired.
Type 2	Refuse, consisting of an approximately even mixture of rubbish and garbage by weight. This type of waste is common to apartment and residential occupancy, consisting of up to 50 percent moisture, 7 percent incombustible solids, and has a heating value of 4,300 Btu per pound as-fired.
Type 3	Garbage, consisting of animal and vegetable wastes from restaurants, cafeterias, hotels, hospitals, markets and like installations. This type of waste consists of up to 70 percent moisture, up to 5 percent incombustible solids, and has a heating value of 2,500 Btu per pound as-fired.
Type 4	Human and animal remains, consisting of carcasses, organs, and solid organic wastes from hospitals, laboratories, abattoirs, animal pounds, and similar sources, consisting of up to 85 percent moisture, 5 percent incombustible solids, and having a heating value of 1,000 Btu per pound as fired.

TABLE 1-3. INCINERATOR INSTITUTE OF AMERICA SOLID WASTE CLASSIFICATIONS[a] (CONTINUED)

Type 5	Byproduct waste, gaseous, liquid or semiliquid, such as tar, paints, solvents, sludge, fumes, etcs., from industrial operations. Btu values must be determined by the individual materials to be destroyed.
Type 6	Solid bydproduct waste, such as rubber, plastics, wood waste, etc., from industrial operations. Btu values must be determined by the individual materials to be destroyed.

[a]Reference 22.

polypropylene, and polyvinyl chloride.[19] Potential combustion products from the burning of these plastics, including hydrochloric acid and toxic air contaminants, are discussed in Section 3.1. Ultimate analyses for four common plastics are shown in Table 1-4.

Hospital waste may contain potentially toxic components. For example, red bag waste in the United States may contain potentially toxic compounds generated by hospital operations that are currently exempt from regulations under the Resource Conservation and Recovery Act (RCRA).[20] Such chemicals include waste pharmaceuticals, cytotoxic agents used in chemotherapy, and anti-neoplastic agents.[21] Mercury from dental clinics and other heavy metals used in hospitals may also be air emission concerns if they enter the combustor along with other hospital wastes.

TABLE 1-4. ULTIMATE ANALYSES OF FOUR PLASTICS[a]
(Weight Percent)

	Polyethylene	Polystyrene	Polyurethane	Polyvinyl Chloride
Moisture	0.20	0.20	0.20	0.20
Carbon	84.38	86.91	63.14	45.04
Hydrogen	14.14	8.42	6.25	5.60
Oxygen	0.00	3.96	17.61	1.56
Nitrogen	0.06	0.21	5.98	0.08
Sulfur	0.03	0.02	0.02	0.14
Chlorine	tr	tr	2.42	45.32
Ash	1.19	0.45	4.38	2.06
Higher heating value, Btu/lb	19,687	16,419	11,203	9,754

[a]Reference 23.

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13. Jenkins, A.C. "Evaluation Test on a Hospital Refuse Incinerator at Saint Agnes Medical Center, Fresno, CA." California Air Resource Board, Stationary Source Division, January 1987.

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22. Reference 16.

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2.0 PROCESSES AND EQUIPMENT

The primary objectives of hospital waste incinerators are (1) to render the waste innocuous, and (2) to reduce the size and mass of the waste. These objectives are accomplished by exposing the waste to high temperatures over a period of time long enough to destroy threatening organisms and by burning all but the incombustible portion of the waste. As discussed in Section 1.1, incineration has become the most practical sterilization and disposal option for many hospital facilities.

The design of a hospital waste incinerator, like any combustion system, requires consideration of a number of interrelated factors including residence time, temperature, and turbulence (i.e., the three "T"'s of combustion). Other factors which can influence combustion performance are fuel feeding patterns, air supply and distribution, heat transfer, and ash disposal.[1] Like municipal solid waste (MSW), hospital waste is a difficult fuel to combust relative to conventional fuels such as oil, gas, coal, or wood. Some of the problems associated with hospital wastes which must be considered by the combustion system designer and equipment operator are:

- Fuel of non-homogenous and variable composition - The physical and chemical composition of hospital waste is highly variable. Furthermore, the waste feed consists of chemically diverse articles of different sizes and shapes. Hospital waste is seldom pre-processed; it is burned in bulk on a mass feed basis. These factors pose problems in feeding, flame stability, particle entrainment and emissions control.

- Variable ash content - Hospital waste contains varying amounts of glass, metals and ceramics which are not consumed in the combustion process. Fluctuations in ash composition and combustion temperatures can lead to clinker formation, slagging and fouling in some systems. To avoid these problems, primary combustion chamber temperatures are generally maintained below about 1800°F.[2] However, this tends to reduce carbon burnout and the overall energy utilization efficiency.

- Low heating value - Hospital wastes often have low heating values due to excessive moisture contents. This causes flame stability problems and, in some cases, it becomes necessary to fire an auxiliary fuel to maintain proper combustion conditions. Alternately, dry waste batches (especially those with a high plastics content) can produce high flame temperatures which result in overheating of the hearth or other combustion system components. To avoid these problems, the combustion conditions (principally excess air, air distribution, and auxiliary fuel firing rate) must be controlled closely.

- Corrosive materials - Hospital wastes contain varying amounts of fluorine and chlorine, principally from plastics. These materials can corrode combustion equipment, especially convective heat transfer tubes. To avoid corrosion, it is necessary to use corrosion-resistant materials of construction and to maintain steam temperatures and pressures at low levels.

2.1 INCINERATOR TECHNOLOGY

There are three major types of incinerators currently used to incinerate hospital wastes in the United States: excess air, starved air, and rotary kiln. The design and operating principles for each of these three major types are discussed in this section.

2.1.1 Excess Air Incinerators

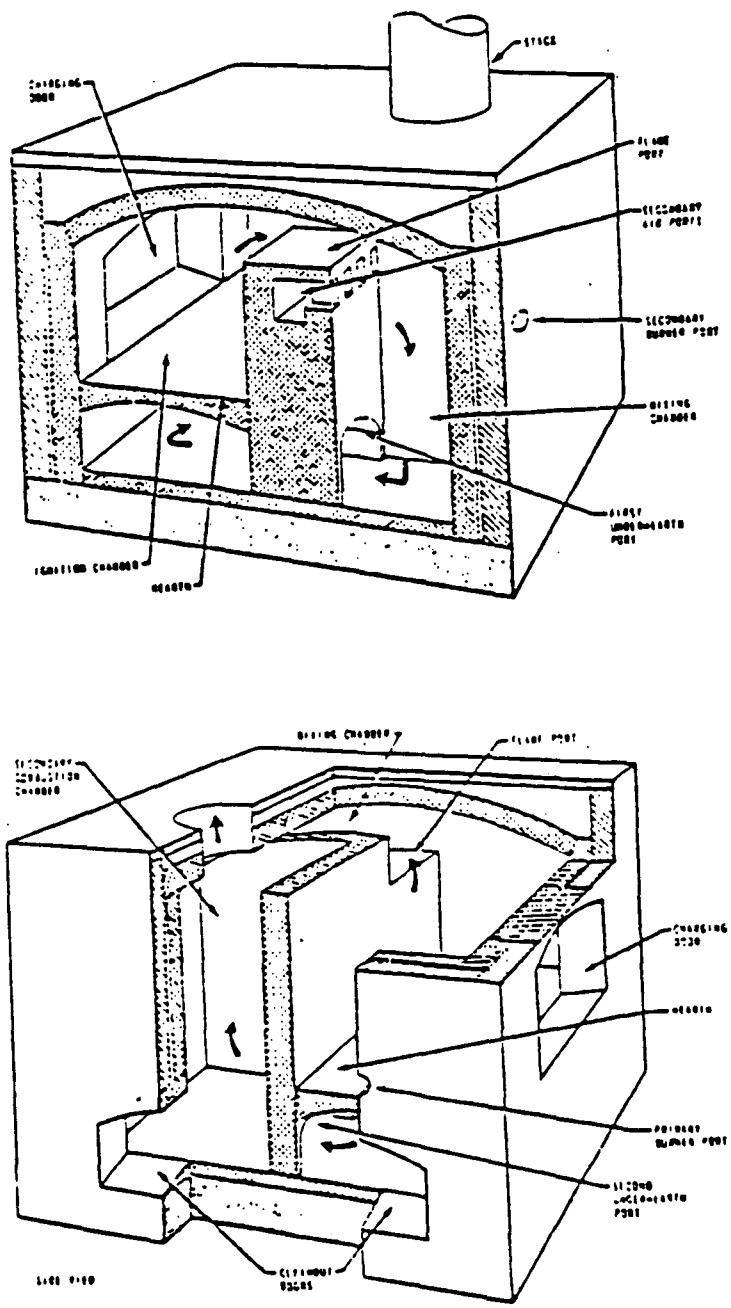
Excess air incinerators are small modular units which typify older, existing hospital incinerators. They are also referred to as "pyrolitic incinerators" and "multiple chamber incinerators" in the literature. These incinerators appear as a compact cube from the outside with a series of chambers and baffles on the inside. The two principal design configuration

for excess air incinerators, the in-line and retort types, are illustrated in Figures 2-1 and 2-2, respectively.

In both types of excess air incinerators, combustion of the waste begins in the primary, or ignition, chamber. The waste is dried, ignited, and combusted by heat provided by a primary chamber burner as well as by hot chamber walls heated by flue gases. Moisture and volatile components in the waste feed are vaporized and pass, along with combustion gases, out of the primary chamber and through a flame port connecting the primary chamber to the secondary or mixing, chamber. Secondary air is added through the flame port and is mixed with the volatile components in the secondary chamber. Burners are also fitted to the secondary chamber to maintain adequate temperatures for combustion of the volatile gases. Incinerators designed to burn general hospital waste operate at total excess air levels of up to 300 percent; if only pathological wastes (i.e., animal and human remains) are combusted, excess air levels near 100 percent are more common.[5]

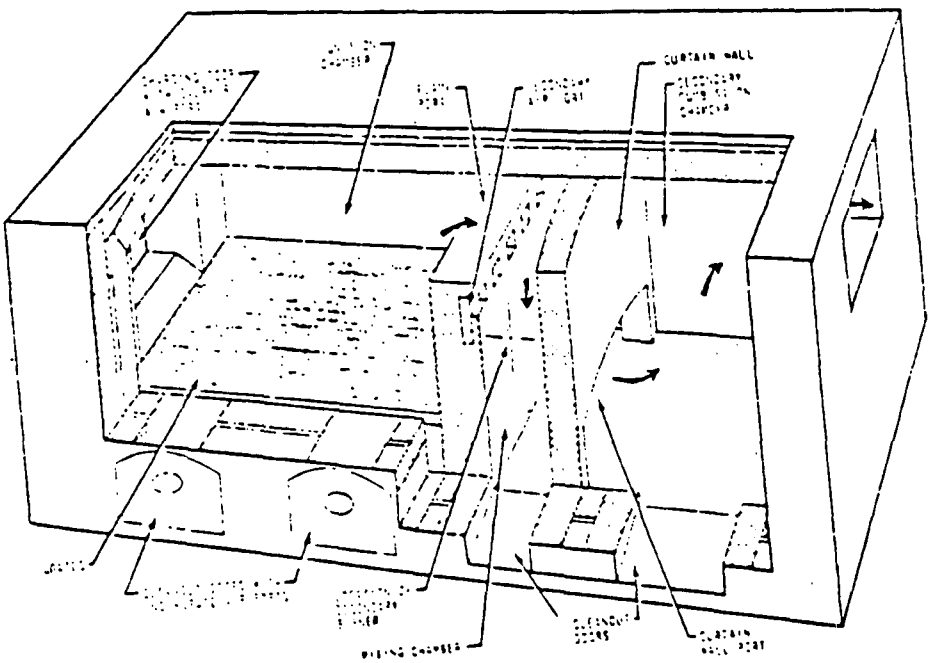
For in-line incinerators, combustion gases pass in a straight-through fashion from the primary chamber to the secondary chamber and out of the incinerator with 90 degree flow direction changes only in the vertical direction. The configuration of retort incinerators, on the other hand, causes the combustion gases to follow a more "tortuous" path through the incinerator with 90 degree flow direction changes in both the horizontal and vertical directions. These flow direction changes, as well as contraction and expansion of the combustion gases, enhance turbulent mixing of air and gases.[6] In addition, fly ash and other particulate matter drop from the gas stream as a result of the direction and gas velocity changes and collect on chamber floors. Gases exiting the secondary chamber are directed to the incinerator stack.

Retort incinerators are described as "unwieldy" by one source in sizes above 500 lb/hr capacity while in-line incinerators are felt to be most suitable in capacities of 750 lb/hr or greater.[7]



Source: Reference 3.

Figure 2-1. Multiple-chamber pathological waste incinerator.



Source: Reference 4.

Figure 2-2. In-line multiple-chamber incinerator.

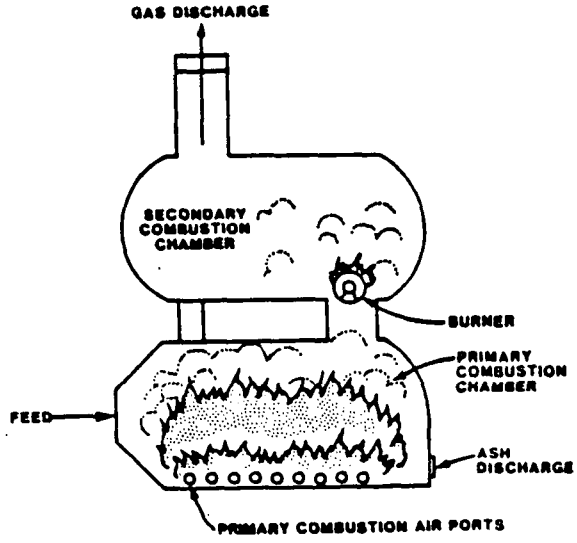
2.1.2 Controlled Air Incinerators

Controlled air incineration has become the most widely used hospital waste incinerator technology over the past 10 to 15 years and now dominates the market for new systems at hospitals and similar medical facilities.[8] This technology is also known as "starved air" incineration, "two-stage" incineration, and "modular" combustion. While there are some similarities in operating principles between excess air and controlled-air incinerators, overall equipment design and appearance are quite different, as illustrated in Figure 2-3.

Like excess air incinerators, combustion of waste in controlled air incinerators occurs in two stages. Waste is fed into the primary, or lower, combustion chamber which is operated, as the name implies, with less than the full amount of air required for combustion. Under these sub-stoichiometric conditions, the waste is dried, heated, and pyrolized, thereby releasing moisture and volatile components. The non-volatile, combustible portion of the waste is burned in the primary chamber to release heat while the non-combustible portion accumulates as ash. Depending on the heating value of the waste and its moisture content, additional heat may be provided by auxiliary burners to maintain desired temperatures. Combustion air is added to the primary chamber either from below the waste through the floor of the chamber or through the sides of the chamber. The air addition rate is usually 40 to 70 percent of stoichiometric requirements.[9]

Because of the low air addition rates in the primary chamber, and corresponding low flue gas velocities and turbulence levels, the amount of solids entrained in the gases leaving the primary chamber are minimized. As a result, most controlled air incinerators can meet current State and local particulate matter emission limits without add-on gas cleaning devices.

Moisture, volatiles, and combustion gases from the primary chamber flow upward through a connecting section where they are mixed with air prior to entering the secondary, or upper combustion chamber. If the primary chamber gases are sufficiently hot, they will self-ignite when mixed with air. A second burner is located near the entrance to the upper chamber, however, to



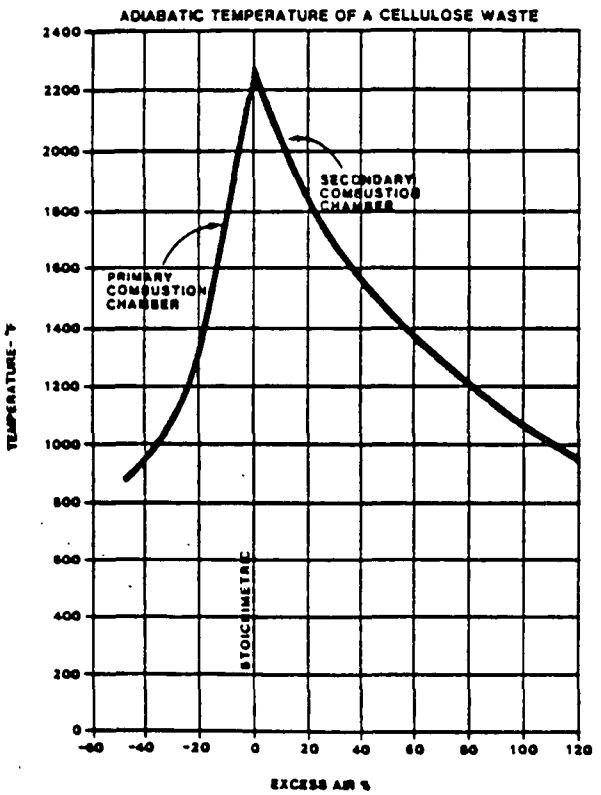
Source: Reference 10.

Figure 2-3. Schematic for controlled air incinerator.

provide additional heat for ignition of the combustible gases and to maintain a flame in the chamber at all times of operation. Mixing of these gases with air is enhanced by the flow direction changes and contraction/expansion step which the gases undergo as they pass from the lower to upper chambers. The air injection rate in the secondary chamber is generally between 100 and 140 percent of total stoichiometric requirements (based on the waste feed).[11] Thus, the total air added to both chambers can vary between 140 and 210 percent of stoichiometric requirements (i.e., between 40 and 110 percent excess air).

The secondary chamber burner is located near the entrance to this chamber to maximize the residence time of gases at high temperatures in this chamber. Bulk average gas residence times in the secondary chamber typically range from 0.25 to 2.0 second. Design exit gas temperatures generally range from 1400 to 2000°F.[12] Natural gas or distillate oil are the normal fuels used for both primary and secondary chamber burners. Temperatures in the primary and secondary chambers are monitored by thermocouples and controlled automatically by modulating the air flow to each chamber. Thermocouples are normally located near the exits of these chambers. In the primary (air-starved) chamber, combustion air flow is increased to increase temperature; in the secondary (excess air) chamber, air flow is decreased to increase temperature. The logic for this control scheme is illustrated in Figure 2-4. Flue gases exiting the secondary chamber are sent either directly to a stack, to air pollution control equipment (if required), or to a waste heat recovery boiler.

Both the primary and secondary chambers are usually lined with refractory material. One manufacturer, however, offers a membrane water wall in the primary chamber. Most chambers are cylindrical although some are rectangular or box-like. Smaller units (i.e., with waste feed capacities less than 500 lb/hr) are usually vertically oriented with both chambers in a single casing. Larger units generally include two separate horizontal cylinders located one above the other.[13] Some manufacturers offer a third chamber for final air addition to the combustible gases and a



Source: Reference 15.

Figure 2-4. Adiabatic temperature versus excess air for a controlled air incinerator.

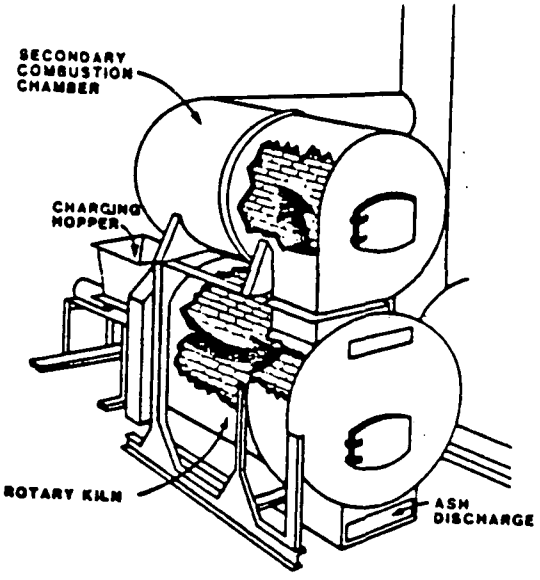
fourth chamber for gas conditioning (i.e., gas cooling and condensation of vapors) to minimize effects on downstream heat recovery equipment.[14]

Waste feed capacities for controlled air incinerators range from about 75 to 6500 lb/hr of Type 0 waste (at 8500 Btu/lb). Capacities for lower heat content wastes may be higher since feed capacities are limited by primary chamber heat release rates. Heat release rates for controlled air incinerators typically range from about 15,000 to 25,000 Btu/hr-ft^3.[16]

2.1.3 Rotary Kiln Incinerators

Like other incinerator types, rotary kiln incineration consists of a primary chamber in which waste is heated and volatized and a secondary chamber in which combustion of the volatile fraction is completed. In this case, however, the primary chamber consists of a horizontal, rotating kiln. The kiln is inclined slightly so that the waste material migrates from the waste charging end to the ash discharge end as the kiln rotates. The waste migration, or throughput, rate is controlled by the rate of rotation and the angle of incline, or rake, of the kiln. Air is injected into the primary chamber and mixes with the waste as it rotates through the kiln. A primary chamber burner is generally present for heat-up purposes and to maintain desired temperatures. Both the primary and secondary chambers are usually lined with refractory brick, as shown in the schematic drawing in Figure 2-5.

Volatiles and combustion gases from the primary chamber pass to the secondary chamber where combustion is completed by the addition of additional air and together with the high temperatures maintained by a second burner. Like other incinerators, the primary chamber is operated at sub-stoichiometric conditions and the secondary chamber at above-stoichiometric conditions. Due to the turbulent motion of the waste in the lower primary chamber, particle entrainment in the flue gases is higher for kiln incinerators than for controlled-air or excess air incinerators. As a result, rotary kiln incinerators generally require stack gas clean-up to meet applicable particulate matter and/or opacity limits.[17]



Source: Reference 18.

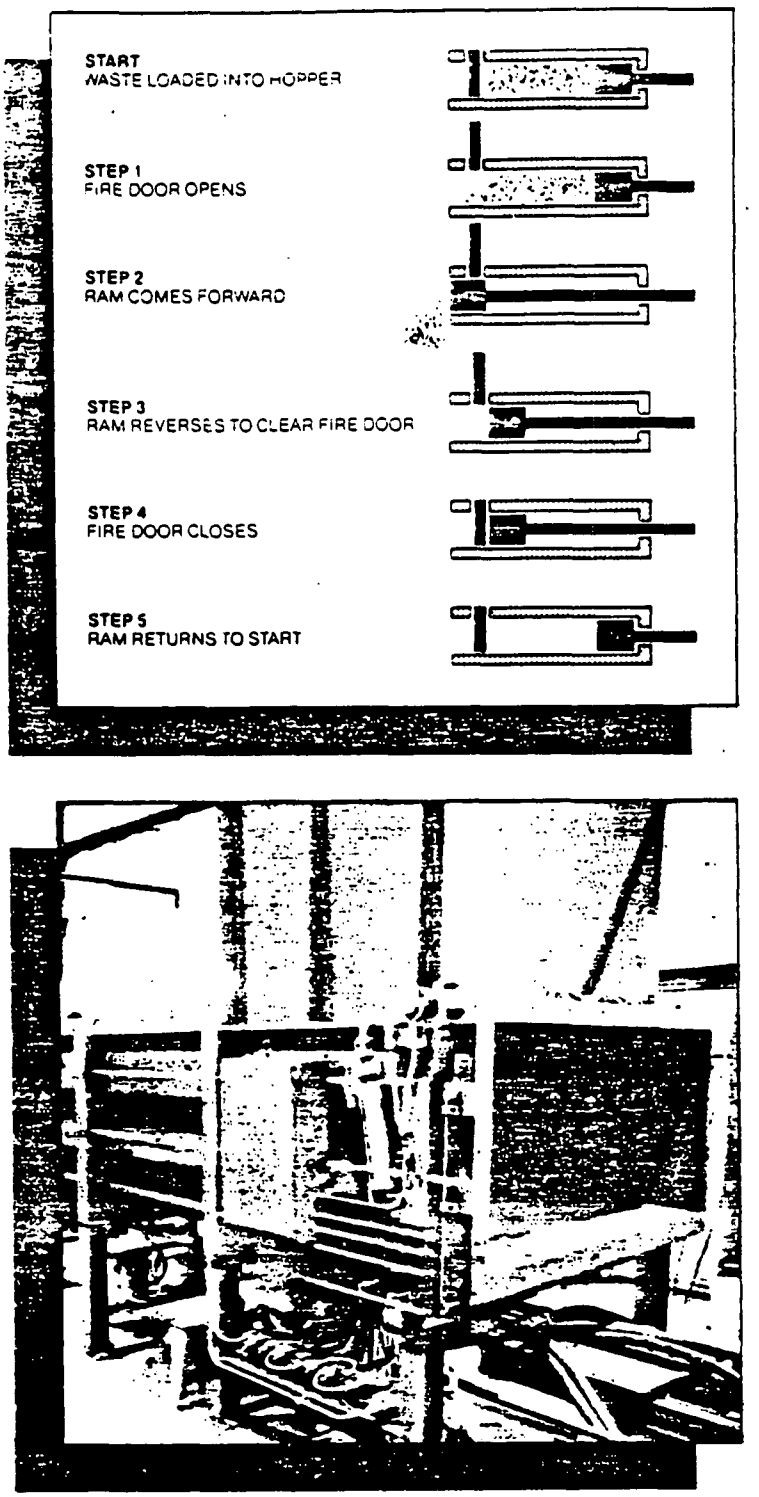
Figure 2-5. Schematic for rotary kiln incinerator.

2.2 WASTE FEED AND ASH HANDLING SYSTEMS

Feed systems for hospital waste incinerators range from manually operated charging doors to fully automatic systems. Ash removal systems also range between periodic manual removal of ash by operators to continuous automated quench and removal systems. In general, automated systems are prevalent among large continuously-operated incinerators while manual systems are employed on smaller incinerators or those which operate on an intermittent basis. Waste feed and ash removal systems are discussed below for each of the major incinerator design types.

For excess air incinerators, waste loading is almost always accomplished manually by means of a charging door on the incinerator. The charging door is attached to the primary chamber and may be located either at the end farthest away from the flame port (for burning general wastes) or on the side (for units handling pathological wastes such as large animals or cadavars). As much as 10 percent of the total air supplied to excess air units is drawn through these charging doors.[19] Ash removal from excess air units is accomplished manually with a rake and shovel at the completion of the incinerator cool-down period. Typical operation for an excess air incinerator calls for incinerator heat up and waste charging at the end of the operating day, waste combustion and burnout by morning, and cool-down and ash cleanout during the following day.[20]

Controlled-air incinerators may be equipped with either manual or mechanical loading devices. For units with capacities less than 200 lb/hr, manual loading through a charging door in the primary chamber is the typically the only option. Mechanical loaders, on the other hand, are standard features for incinerators with capacities above 500 lb/hr waste. For units between these size ranges, mechanical feed loaders are usually available as an option.[21] Most mechanical loader designs currently offered employ a hopper and ram assembly, as illustrated in Figure 2-6. In this system, waste is loaded into a charging hopper and the hopper cover is closed. The fire door isolating the hopper from the incinerator opens and a ram comes forward to push the waste into the front section of the



Source: Reference 22.

Figure 2-6. Schematic and example picture of a mechanical loading system.

incinerator. After reaching the end of its travel, the ram reverses and retracts to the point where it just clears the fire door. The fire door closes and the ram retracts to its starting position. These operations are normally controlled by an automatic control panel. For smaller incinerators, waste loading into the charging hopper is usually accomplished manually, bag by bag. Larger systems frequently use such waste loading devices as car dumpers, conveyors, skid-steer tractors, or pneumatic systems.[23]

In addition to improving personnel and fire safety, mechanical loaders limit the amount of ambient air which can leak into the incinerator during waste feeding operations. This is important for controlled air incinerators since excess air in-leakage can cause lower temperatures, incomplete combustion, and smoking at the stack. Mechanical loaders also permit the feeding of smaller waste batches at more frequent, regular intervals. As the intervals become shorter, this feeding procedure approximates continuous or steady-state operation and helps to dampen fluctuations in combustion conditions.[24]

Ash removal techniques for controlled air incinerators also range from manual to mechanical systems. For smaller units below about 500 lb/hr capacity (and units constructed before the mid-1970s), operators must rake and shovel ash from the primary combustion chamber into disposal containers. For larger systems, mechanical ash removal may be accomplished by extension of the waste charging ram, augmented by internal transfer rams. The positive displacement action of the rams pushes the ash along the bottom of the primary chamber until it reaches a drop chute. Another mechanical system offered by one manufacturer uses a "pulsed hearth" whereby ash is moved across the chamber floor by pulsations created by end-mounted air cushions.[25] After falling through the drop chute, ash either falls into a drop cart positioned within an air-sealed enclosure or into a water quench trough. The drop cart is removed manually, generally after spraying the ash with water for dust suppression. In the water trough system, quenched ash is removed either by a drag conveyor or a backhoe trolley system.[26]

When estimating air emissions for controlled air incinerators with manual ash removal, it is important to recognize that operating, and hence emission, rates will vary over time. A typical operating cycle for such a unit is given by:[27]

Operation	Duration
Ash-clean-out	15-30 minutes
Preheat	15-60 minutes
Waste loading	12-14 hours (maximum)
Burn-down	2-4 hours
Cool-down	5-8 hours

The waste loading period of 12 to 14 hours per operating day is a maximum value; a more typical value would be 5 to 6 hours since this corresponds to waste incineration during one shift per day.[28]

Since rotary kiln systems operate in a continuous mode, the waste feed system and ash removal system which service these incinerators must also be of a continuous or semi-continuous type.[29] A charging hopper and ram system is commonly used to load waste into the kiln. After travelling through the kiln, ash is discharged on a continuous basis either into an ash cart or water quench system. Both this feed system and ash removal system are described above for controlled air incinerators.

2.3 WASTE HEAT RECOVERY

Waste heat recovery operations are generally not considered for excess air incinerators due to the smaller gas flow rates, lower temperatures, higher particulate matter loadings, and intermittent operations that characterize these systems. For controlled air and rotary kiln incinerators, however, the relatively higher stack gas temperatures and flow rates can make heat recovery economically attractive in cases where steam or hot water generation rates can be matched with the needs of the hospital. For most systems, heat is recovered by passing hot gases through a waste

heat boiler to generate steam or hot water. Boiler equipment can range from a spool piece with heat exchange coil inserted in the stack to a single-drum D-type watertube waste heat boiler. Most manufacturers, however, use conventional firetube boilers because they are low in cost and simple to operate.[30] Options for these boilers include supplemental firing of oil or natural gas and automatic soot-blowing systems. Outlet temperatures from waste heat boilers are generally limited to about 400°F by stack gas dew point considerations. As mentioned above, one manufacturer also offers a waterwall membrane in the primary chamber to enhance heat recovery.

Other methods to improve overall system efficiency in controlled air incinerators and, thereby, to reduce the need for expensive auxiliary fuels, are modulating burners and air preheating.[31] EPA-sponsored testing programs of controlled air incinerators equipped with these types of systems have shown that heat recovery efficiencies are typically limited to about 50 to 60 percent of the theoretical maximum.[32]

2.4 REFERENCES

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17. Reference 14.

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32. Reference 8. p. 9.

3.0 AIR EMISSIONS/FACTORS FOR HOSPITAL WASTE INCINERATORS

Many sources of information were used to collect available hospital incinerator emissions data. A survey of pertinent literature was performed and contacts were made within EPA, State and local government organizations, trade organizations, and incinerator vendors.

Table 3-1 contains a list of pollutants covered by this study. The compounds shown here are those for which emissions data could be located for hospital incinerators. As expected, data for some pollutants was plentiful, while few data were found for others. One large data gap in the current hospital waste incinerator emissions data base is for lower molecular weight organic compounds. In addition, emission data were located only for larger controlled air incinerators; data were not located for the smaller retort-type incinerators which comprise a large portion of the total population by number.

This section contains brief descriptions of formation mechanisms for pollutants for which data were found in this study. Where applicable, information on formation mechanisms for these compounds has been borrowed from the municipal solid waste (MSW) literature. Next, the emissions test data are presented along with other data which were found as part of the study. A discussion relating emissions data to design and operating factors follows. Finally, the emissions factors developed for each pollutant are presented.

3.1 FORMATION MECHANISMS

3.1.1 Acid Gases

The acid gases considered in this study were hydrogen chloride, sulfur dioxide, and nitrogen oxides. A brief description of the formation mechanism and factors which influence their formation is presented next.

TABLE 3-1. POLLUTANTS MEASURED/TESTED

Trace Metals	Polycyclic Organic Matter	Low Molecular Weight Organic Compounds	Acid Gases	Others
Arsenic	Dioxins	Ethane	Hydrochloric Acid	Particulate Matter
Cadmium	Furans	Ethylene	Sulfur Dioxide	Carbon Monoxide
Chromium		Propane	Nitrogen Oxides	Pathogens
Iron		Propylene		Viruses
Manganese		Trichlorotrifluoroethane		
Nickel		Trichloroethylene		
Lead		Tetrachloroethylene		

3.1.1.1 Hydrogen Chloride. Based on thermodynamic considerations, chlorine which is chemically bound within the hospital waste in the form of polyvinyl chloride (PVC) or other compounds will be predominately converted to hydrogen chloride (HCl), assuming there is hydrogen available to react with the chlorine. Considering the high hydrogen content of hospital waste due to its high paper, plastics, and moisture content, there should be a ready supply of hydrogen available in most cases.

Swedish studies have found that 60 to 65 percent of the fuel-bound chlorine in MSW is converted to HCl.[1] There is no apparent thermodynamic reason for the less than full conversion. HCl has also been shown by other studies to be the predominate chlorine product at high temperatures.[2]

3.1.1.2 Sulfur Dioxide. Sulfur, which is chemically bound within the materials making up the hospital waste, is oxidized during the combustion process to form SO_2. The rate of SO_2 emissions is, therefore, directly proportional to the sulfur content of the waste. Some SO_2 removal may take place through reaction of the SO_2 with alkaline reagents also present within the waste; however, the amount of removal is expected to be negligible due to the high HCl content of the flue gas. Because it is a stronger acid than SO_2, HCl will react more quickly with available alkaline compounds than SO_2 and, because of the high HCl content of flue gases, will likely tie-up the alkaline compounds before they have a chance to react with SO_2.

3.1.1.3 Nitrogen Oxides. Nitrogen oxides or NO_x represent the mixture of NO and NO_2. However, in combustion systems, predominantly NO is produced due to kinetic limitations in the oxidation of NO to NO_2. NO_x is formed by one of two general mechanisms. "Thermal NO_x" is the result of the reaction between molecular nitrogen and molecular oxygen, both of which enter the combustion zone in the combustion air. "Fuel NO_x" results from the oxidation of monoatomic nitrogen which enters the combustion zone chemically bound within the fuel structure.

Although the detailed mechanism of thermal NO_x formation is not well understood, it is widely accepted that the thermal fixation in the combustion zone is described by the Zeldovich equations:

$$N_2 + O \longrightarrow NO + N$$

$$N + O_2 \longrightarrow NO + O$$

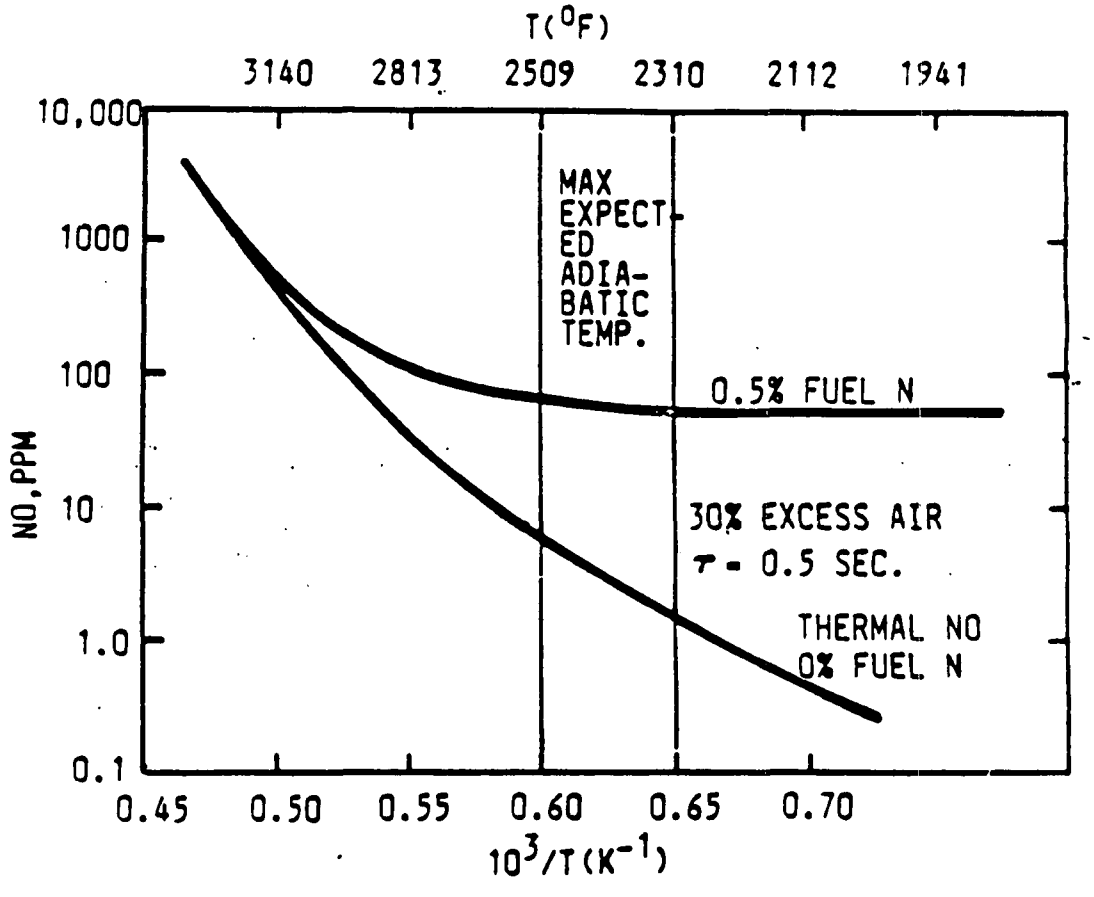
The first reaction is the rate limiting step and is strongly endothermic due to the requirement of breaking the N_2 triple bond. It is the high endothermicity of this process which has led to the term thermal NO_x. The reaction rates of these equations are highly dependent on both the mixture stoichiometric ratio (i.e., the molecular equivalent air-to-fuel ratio, with rich and lean describing the fuel amount) and the flame temperature. The maximum NO_x occurs at slightly lean fuel mixture ratios due to the excess availability of oxygen for reaction within the hot flame zone. A rapid decrease in NO_x formation is seen for ratios which are slightly higher or lower than this. The rate of thermal NO_x formation is extremely sensitive to the flame temperature, dropping almost an order of magnitude with every 100°C drop in flame temperature.

The mechanisms by which nitrogen compounds (primarily organic) contained in liquid and solid fuels evolve and react to form NO_x are much more complex than the Zeldovich model, and the empirical data are less conclusive.

The impact of temperature and fuel nitrogen on NO_x emissions for excess air conditions is shown in Figure 3-1. The figure indicates that thermal NO_x formation is extremely sensitive to temperature, but fuel NO_x formation is not.

3.1.2 Particulate Matter

Particulate matter (PM) is emitted as a result of incomplete combustion and by the entrainment of noncombustibles in the flue gas stream. PM may



Source: Reference 3.

Figure 3-1. Impact of temperature and fuel nitrogen on NO_x emissions for excess air conditions.

exist as a solid or an aerosol, and may contain heavy metals or polycyclic organics. Depending on the method used to measure the PM in the flue gas, lower boiling point volatile compounds (i.e., boiling point below 100°C) may or may not be included in the measurement.

There are three general sources of PM[4]:

- o inorganic substances contained in the waste feed that are carried into the flue gas from the combustion process,
- o organometallic substances formed by the reactions of precursors in the waste feed, and
- o uncombusted fuel molecules.

Inorganic matter is not destroyed during combustion; most of this material leaves the incinerator as ash. Some, however, becomes entrained in the stack gas as PM.

Organometallic compounds present in the waste stream which is being incinerated can be volatilized and oxidized under the high temperatures and oxidizing conditions in the incinerator. As a result inorganic oxides or salts of metals can be formed from the metallic portion. Elemental analysis of flyash from MSW incinerators has shown that particulate emissions are largely inorganic in nature and that they are from one-third to one-half soluble in water. The water soluble phase is principally chloride and sulfate salts of Na, P, Ca, Zn, and NH_4^+. The insoluble phase is comprised of oxides, silica, and phosphate salts of Al, Si, Ca, Pb, Zn, and Fe along with some insoluble carbon compounds.[5] To the extent that a particular hospital waste is similar to municipal waste, the resulting ash might be expected to be similar. (See Section 1.2 for discussion of hospital waste composition and categorization.) The fuel molecules themselves can also contribute significantly to PM formation. It is known that pyrolitic reactions can lead to the formation of large organic molecules. Inorganics,

which may act as nucleation sites, may then further induce growth. The result can then be an organic particle with an inorganic core.[6]

In general, good combustion conditions which depend on residence time, temperature, and turbulence lead to lower PM emissions. As the residence time increases, particle size and the mass of PM tend to decrease. Smaller particulate sizes and lower PM emissions are also associated with higher temperatures since, at higher temperatures, oxidation rates are increased so that more of the combustible PM is oxidized to gaseous products.

3.1.3 Trace Metals

The amount of trace metals in the flue gas is directly related to the quantity of trace metals contained in the incinerator waste. Some of the trace metal sources in the waste include surgical blades, foil wrappers, plastics, and printing inks. Plastic objects made of PVC contain cadmium heat stabilizing compounds. In addition, cadmium, chromium, and lead may also be found in inks and paints.

Some metals are selectively deposited on the smaller particulate sizes which are emitted. This is known as fine-particle enrichment. Although such data were not found for hospital incinerators, metals generally thought to exhibit fine-particle enrichment are As, Cd, Cr, Mn, Ni, Mo, Pb, Sb, Se, V, and Zn.[7] Results of one study performed at a MSW facility indicate that trace metals are found predominately in the respirable particulate fraction, even when the bulk of the particulate matter emissions are in the nonrespirable fraction.[8]

There are three general factors affecting enrichment of trace metals on fine particulate[9]:

- o particle size,
- o number of particles, and
- o flue gas temperatures.

The influence of particle size on trace metal enrichment of fine particles is thought to be due to specific surface area effects (i.e., the ratio of particle surface area to mass). Particles with large specific surface areas are expected to show more enrichment since there is more surface area for condensation per unit mass of PM. The influence of the number of particles is simply due to the increased probability of contact associated with higher particle population. There is some evidence that less enrichment occurs at higher flue gas temperatures.[10] Higher temperatures are thought to lead to increased activity levels which in turn makes the metals less likely to condense and bond with PM. Mercury, due to its high vapor pressure, does not show significant particle enrichment; rather it is thought to leave largely in the vapor form due to high typical exit gas temperatures. For example, the results of one study performed at a MSW facility indicated that less than 25 percent of the mercury emissions were found to be in the particulate phase of the stack gas.[11]

3.1.4 Organic Emissions

Figure 3-2 presents a schematic of the processes which are involved during hospital waste combustion in a two-stage incinerator. After startup, the hospital waste is heated by the burning gases being combusted in the primary chamber and by the natural gas or oil burner operating in that chamber. During startup, heat is supplied by the fossil fuel burner alone. Upon heating, waste fragments emit steam, volatile matter, and PM. These materials are swept from the bed by natural convection and by entrainment with underfire air. It is the burning of volatile matter above the waste bed which provides the heat which continues the pyrolysis and volatile matter evolution from the waste. The amount of radiant heat transfer to the waste is strongly dependent on the local flame temperature of the compounds being combusted; the flame temperature, in turn, is a function of moisture content, volatile matter heating value, and the local air stoichiometry. Not all the volatile matter is combusted in the primary chamber. Combustion gases are swept from the primary chamber to the secondary chamber where

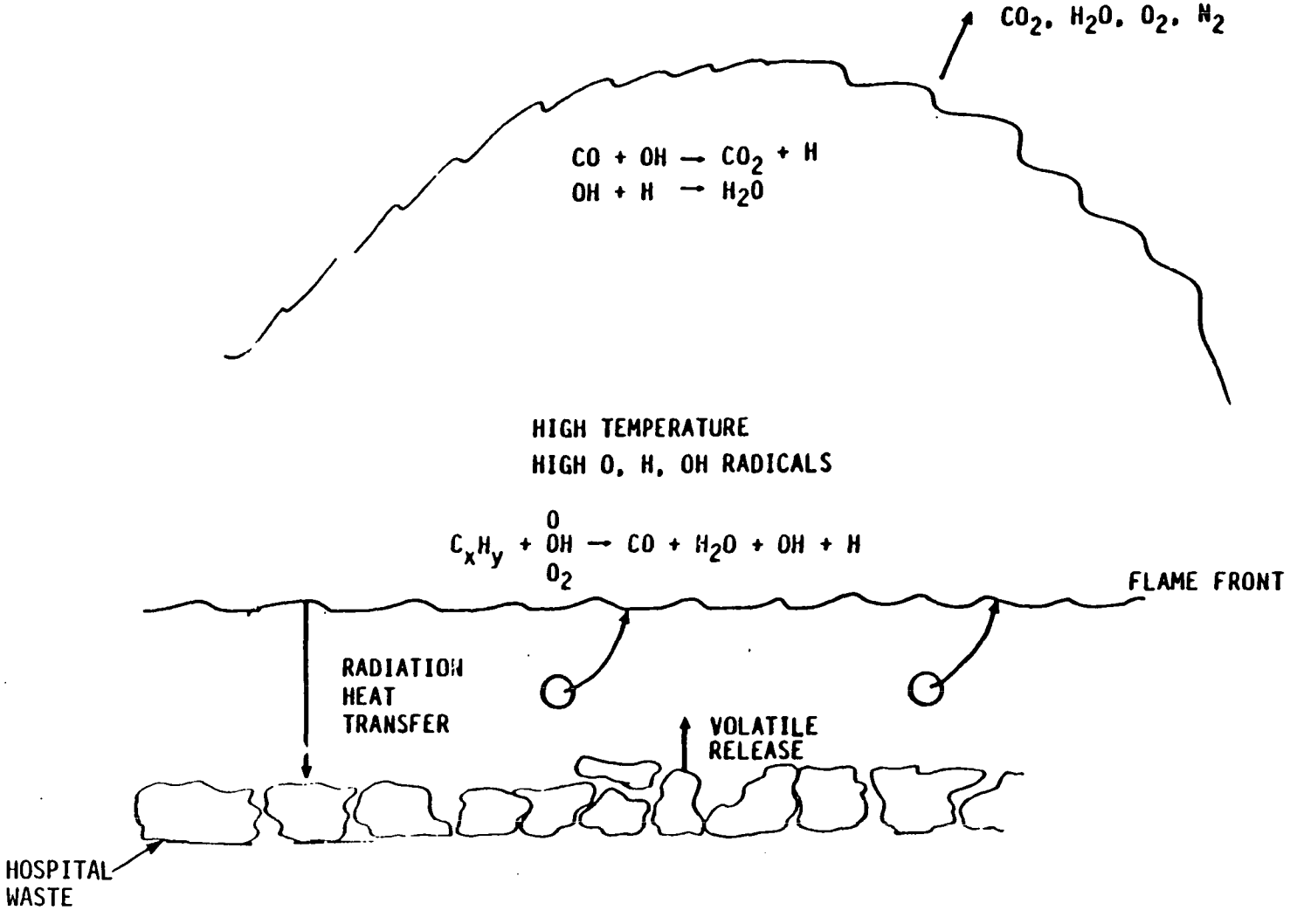


Figure 3-2. Process schematic for primary chamber hospital waste combustion.

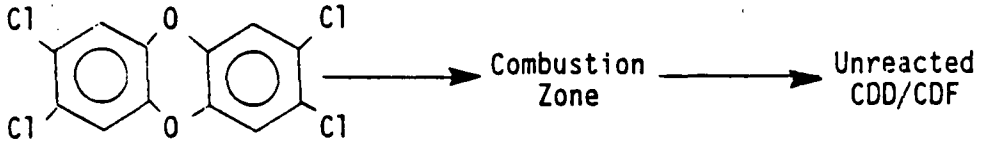
volatile matter combustion continues, augmented by the heat generated by a second fossil fuel burner. The volatile matter combustion process is controlled by chemical kinetics and proceeds through complex reactions involving O, H, and OH radicals. The kinetics of these processes is strongly temperature dependent. An efficient burning process will result in a high degree of conversion of volatile organics to CO_2 and H_2O. Failure to achieve the requirements which lead to efficient combustion can result in high emission rates of combustion products in an unreacted or partially reacted state.

The unreacted or partially reacted combustion products discussed in this report include the chlorinated isomers of dibenzo-p-dioxin (CDD) and dibenzofuran (CDF), lower molecular weight organic compounds for which emissions data were available, and carbon monoxide (CO). A brief description of the formation mechanism and factors which influence the formation of these compounds is presented in the following subsections. Other important classes (e.g., PICs, BaP, PCBs, PAH, POM) are not included due to lack of emissions data.

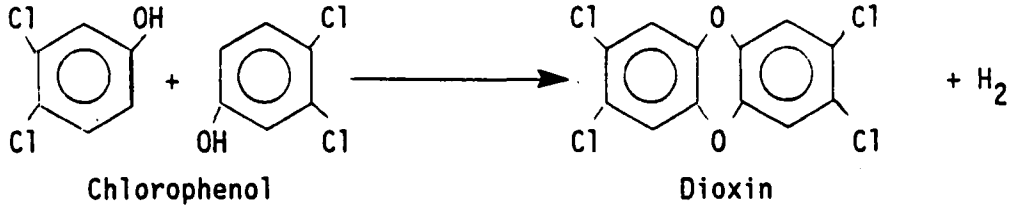
3.1.4.1 Dioxins and Furans. Many factors are believed to be involved in the formation of CDDs and CDFs and many different theories exist concerning the formation of these compounds. The best supported theories are illustrated in Figure 3-3.[12] The first theory shown involves the breakthrough of unburned CDD/CDF present in the feed.[13] A few measurements of MSW feed streams have indicated the presence of trace quantities of CDD/CDF in the refuse feed. No such measurements have been made for hospital waste streams but some potential for CDD/CDF in the feed may exist due to similarities in the wastes.

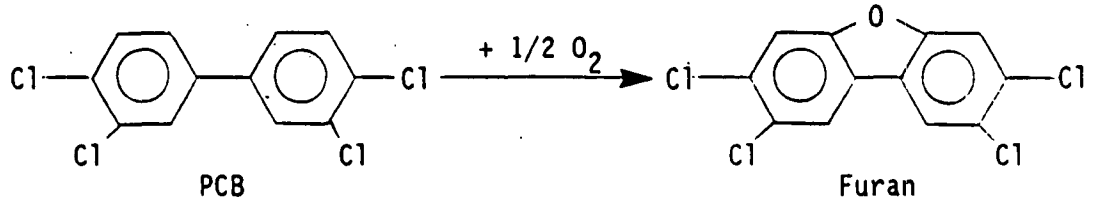
The second mechanism shown in Figure 3-3 involves the more plausible combination of precursor species which have structures similar to the dioxins and furans to form the CDD/CDF compounds. Such a reaction would involve the combination of chlorophenols or polychlorinated biphenyls to form CDD/CDF. These precursors can be produced by pyrolysis in oxygen-starved zones, such as those which exist in multichamber

I. DIOXIN IN REFUSE

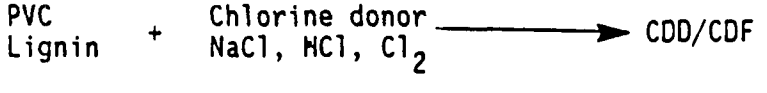


II. FORMATION FROM RELATED CHLORINATED PRECURSORS

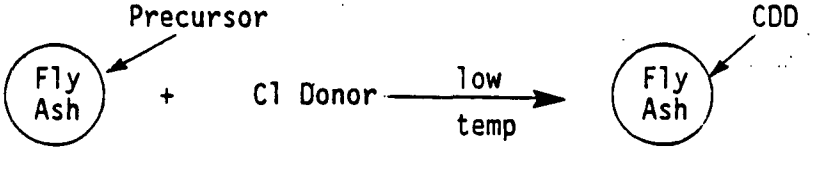




III. FORMATION FROM ORGANICS AND CHLORINE DONOR



IV. SOLID PHASE FLY ASH REACTION



Source: Reference 12.

Figure 3-3. Hypothetical Mechanisms of CDD/CDF Formation Chemistry.

incinerators.[14] The potential for PVC-bearing wastes, a typical component of hospital waste, to form precursors during combustion has been studied by several researchers.[15,16]

The third mechanism shown in Figure 3-3 involves the synthesis of PCDD/PCDF from a variety of organics and a chlorine donor.[17] The simplest mechanisms here involve the combination of those species which are structurally related. Many plausible combustion intermediates can also be proposed which lead to precursors and eventually to CDD/CDFs. Analysis of intermediates formed during the combustion of complex fuels such as coal or wood indicate yields of unchlorinated dioxin and furan species. These compounds could become chlorinated in systems such as hospital waste incinerators where high concentrations of molecular chlorine exist in the combustion zone.

The final mechanism presented in Figure 3-3 involves catalyzed reactions on fly ash particles at low temperatures. In research sponsored by the Ontario Ministry of Environment, formation of CDDs/CDFs were observed when the thermolysis products of PVC combusted in air were heated to 300^{o}C in the presence of clean fly ash.[18] These results are not yet published, pending attempts to reproduce these findings.

There is a growing consensus of opinion that the formation of dioxins and furans in combustion furnaces requires excess air.[19] Excess air combustion leads to lower combustion temperatures which favor in-situ chlorine formation over HCl. The additional presence of chlorine is then believed to promote the formation of dioxins and furans.

CDDs and CDFs may exist in both the vapor phase and as fine particulate in hospital waste incinerator emissions. They may be split between phases with as much as 80 percent in the vapor phase.[20] At temperatures below 300^{o}F, they condense onto the fine particulate.

3.1.4.2 Low Molecular Weight Organic Compounds. Low molecular weight organic compounds (LC) are a product of incomplete combustion of the volatiles which are evolved from the waste. They may be present due to some of the same mechanisms previously discussed above for dioxins and furan

(i.e., they may be compounds which were present in the fuel, combinations of precursors, or the dioxin and furan precursors themselves). LCs are produced when the combustion conditions are other than optimal. In general, the optimum combustion conditions can be characterized by the three T's; time, temperature, and turbulence. Time refers to the amount of time which the fuel is subject to combustion conditions; temperature refers to the temperature at which the combustion takes place or that combustion products are exposed to; and turbulence refers to the degree of mixing between oxygen and the fuel. The longer the time, the higher the temperature, and the greater the degree of turbulence in the zone where the organics are combusted, the better the combustion and the lower the LC emissions will be.

3.1.4.3 Carbon Monoxide. Carbon monoxide (CO) is also a product of incomplete combustion in the final combustion zone depicted in Figure 3-2. As shown, CO is one chemical reaction away from being CO_2 which represents complete combustion. Its presence can also be related to the time, temperature, and turbulence conditions of combustion. In this case, the three T's are specific to the conditions which exist above the region in which the LCs are oxidized.

3.2 EMISSIONS TEST DATA

Data were acquired from four comprehensive emissions tests of hospital incineration units.[21,22,23,24] In addition, results of several less detailed tests at hospital incinerator units were located through the literature. A description of each of the four units for which comprehensive information was obtained and the operating conditions recorded during the emissions tests are presented in Table 3-2. As shown, all of the units are large incinerators near the upper end of the size range for hospital incinerators. The smallest unit for which comprehensive test results were found is an 800 lb/hour unit and the largest was a 2000 lb/hr unit. Over the period of the comprehensive emissions tests, the units operated at 82 to 98 percent of feed rate design capacity. The Illinois

TABLE 3-2. TEST SITE DESIGN AND OPERATING PARAMETERS FOR COMPREHENSIVE EMISSION TESTS

	Cedar Sinai[a] Medical Center Los Angeles, CA	St. Agnes[b] Medical Center Fresno, CA	Royal Jubilee[c] Hospital Victoria, BC	Illinois Hospital Test
Incinerator Mfg.	Ecolaire	Ecolaire	Consumat	N/A
Model #	1,500 TES	1,000 TE	C-760	N/A
Design Feed Rate (lb/hr)	1,200	800	2,200	N/A
Actual Feed Rate (lb/hr)	980	783	1,930	500-800
Incinerator Load (%)	82	98	88	N/A
Operating Temperature (^{o}F):				
Primary Chamber	1,600-1,800	1,500-1,600	1,400	1,350-1,900
Secondary Chamber	1,800-2,000	1,800-2,000	1,700	1,200-1,950
Stack Parameters:				
Temperature (^{o}F)	332	238	312	390-500
Flowrate (DSCFM)	2,710	2,766	7,000	N/A
Velocity (ft/s)	43	34.7	37.9	N/A
Diameter (in.)	18	19	29	N/A
Moisture (vol%)	9.3	9.6	6.4	N/A
No. of Tests	3	3	8	-

[a]Reference 21.

[b]Reference 22.

[c]Reference 23.

[d]Reference 24.

incinerator operated at 500 to 800 lb/hr feed rate during the test; its maximum design capacity is not known.

All of the units for which comprehensive emissions tests were conducted are starved air incinerators with two combustion chambers. The operating temperatures for the four units are similar. The secondary combustion chamber operating temperature range is slightly lower for the Illinois hospital incinerator than for the other units. It should be noted, that the secondary chamber temperature data for the Illinois unit include both start-up and shutdown periods. Thus, the lower end of this range most likely corresponds to these transient operating conditions.

The stack parameters for all of the units are within what was determined to be the normal design range (see Section 6.0). Unfortunately, little information is available regarding the operating conditions of the Illinois unit. No information was available regarding the characteristics of the hospital wastes which were incinerated by any of these units.

No emissions data were located for the smaller retort-type incinerators which comprise a large portion of the total population by number. In terms of waste throughput, and hence total emissions, they represent a smaller share. However, it is important to remember that the emission data and factors discussed in this section are based on the performance of relatively large controlled air incinerators. More data is needed to accurately characterize emissions from smaller retort incinerators.

3.2.1 Acid Gases

Hydrogen Chloride. Table 3-3 contains a summary of the hydrogen chloride (HCl) emissions data which were gathered during this study. Emissions factors are also shown for each of the units. Additional data beyond what is presented are also available through states which require testing for HCl emissions. The HCl emissions results of Table 3-3 are presented with the results of the comprehensive emissions tests placed above those units for which information was obtained from a survey article.[25] The emissions data obtained from the survey article are for units located in Canada. For the purposes of presentation, the results of the summary

TABLE 3-3. DATA/FACTORS FOR HYDROGEN CHLORIDE EMISSIONS FROM HOSPITAL WASTE INCINERATORS

Hospital	Add On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	HCl Concentration (ppmv)	Emissions Factor (lb/ton feed)
Cedar Sinai[a]	Fabric Filter	980		
High			521.0	17.6
Low			403.0	13.7
Average			462.0	15.7
St. Agnes[b]	None	783		
High			926.0	40.2
Low			764.0	33.1
Average			845.0	36.7
Royal Jubilee[c]	None	1,930		
High			1,520.0	65.7
Low			983.0	42.5
Average			1,252.0	54.1
Illinois Unit[d]	None	500-800		
High			1,490.0	10.6[e]
Low			170.0	6.6[e]
Average			550.0	8.6[e]
Athabasca[f]	None	85	41.0	68.1
Bonnyville	None	130	62.2	16.5
Willingdon	None	130	308.0	24.3
Lacombe	None	150	234.5	14.6
Ft. McMurray	None	265	700.0	48.6
St. Michaels	None	465	2,095.0	99.4
Queen Elizabeth II	None	575	115.0	22.3
Queen Elizabeth II	None	700	287.0	19.1
Queen Elizabeth II	None	700	378.0	25.3

TABLE 3-3. DATA/FACTORS FOR HYDROGEN CHLORIDE EMISSIONS FROM HOSPITAL WASTE INCINERATORS (CONTINUED)

Hospital	Add On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	HCl Concentration (ppmv)	Emissions Factor (lb/ton feed)
Misericordia	None	740	670.0	63.1
Misericordia	None	740	687.3	63.1
Royal Alex	None/Yes	1,160	553.0	84.5
Royal Alex	None/Yes	1,200	562.0	79.6
Foothills	None	2,500	702.0	72.8
Lethbridge Gen.	Wet Scrubber/Yes	1,060	44.6	5.9
Univ. of Alberta	Wet Scrubber/Yes	1,400	64.7	0.7
Univ. of Alberta	Wet Scrubber/Yes	1,400	25.4	4.4

[a]Reference 21.

[b]Reference 22.

[c]Reference 23.

[d]Reference 24.

[e]Based on emissions factors presented in Reference 24.

[f]Reference 25.

article are shown in order of ascending feed rate. As shown, there is no correlation between the unit feed rates and the HCl emissions. This is understandable because, as previously stated, the level of HCl emissions should be directly related to the percentage of chlorine-containing compounds in the waste fed to the unit. Unfortunately, no information was given regarding the percent chlorine in the wastes being burned.

Two of the units for which emissions data are available have scrubbers which are used for acid gas control. These units have the lowest emissions rates of those shown. The type of scrubbers used was not identified in Reference 25.

Sulfur Dioxide and Nitrogen Oxides. Table 3-4 summarizes the emissions data and calculated emission factors for SO_2 and NO_x. As can be seen, there are limited data available for these compounds. The only two sources found were the state of California test reports.

On a concentration basis, the emission rates for the pollutants in Table 3-4 are relatively low. For the highest SO_2 concentration, 50 ppmv, an equivalent SO_2 emissions rate of 0.15 lb/million Btu is determined by assuming a mean heat content of 10,000 Btu/lb for hospital waste. A mean heating value of 5,000 Btu/lb corresponds to an SO_2 emissions rate of 0.3 lb/million Btu. The corresponding maximum NO_x emissions rates (based on the 270 ppmv rate) are 0.4 and 0.8 lb/million Btu for heat contents of 10,000 and 5,000 Btu/lb, respectively.

3.2.2 Particulate Matter

A great deal of PM emissions data have been collected. Some of the most readily available data are shown in Table 3-5. Much of this data has been collected because many states require hospital incineration units to meet PM emission limits. Testing is, therefore, carried out on a routine basis. In addition, as previously stated, vendors frequently offer guarantees regarding PM emissions.

their two-stage design. This discussion will therefore also have some relevance to excess air units. The discussion will be presented by discussing the design and operation of these units by combustion stage.

Primary Combustion. As stated in Section 2.1.2, waste is fed into the primary combustion chamber which is operated with less than the full amount of air required for combustion. The air addition rate is usually 40 to 70 percent of stoichiometric requirements. Under these sub-stoichiometric conditions the waste is dried, heated, and pyrolized, thereby releasing moisture and volatile components. The primary chamber can therefore be considered a large fuel-rich pocket from the standpoint of POM, PCDD and PCDF formation. The production of these compounds and their precursors can therefore be considered optimum in the primary stage.

Waste is fed to the primary combustion chamber by either manual or mechanical loading devices. Manual loading is done by charging a bag at a time into the primary chamber while most mechanical loaders employ a hopper and ram assembly. Both feed mechanisms are non-continuous feed processes which deliver the feed in a batch-type manner. Therefore, the potential for an extremely fuel-rich system exists when waste is initially charged to the incinerator. A dynamic air supply system which can follow the transient is required if the system is to maintain its stoichiometric set point. Failure to maintain a consistent air fuel ratio will make control in the secondary combustion chamber more difficult.

Most incinerators control combustion in the primary combustion chamber by measuring the temperature in the primary chamber and adjusting the air flow rate to that chamber to meet a temperature set-point. When temperatures are too low, air is added to accelerate the burning process. Conversely, the air rate is decreased when the temperature is too high.

In conclusion, the operation of the primary combustion chamber is such that a fuel-rich combustion environment exists. Smooth control of the air-to-fuel ratio, accounting for transients due to the feed mechanism, are needed in order to minimize the amount of fluctuation in the gas rate and conditions entering the secondary combustion chamber.

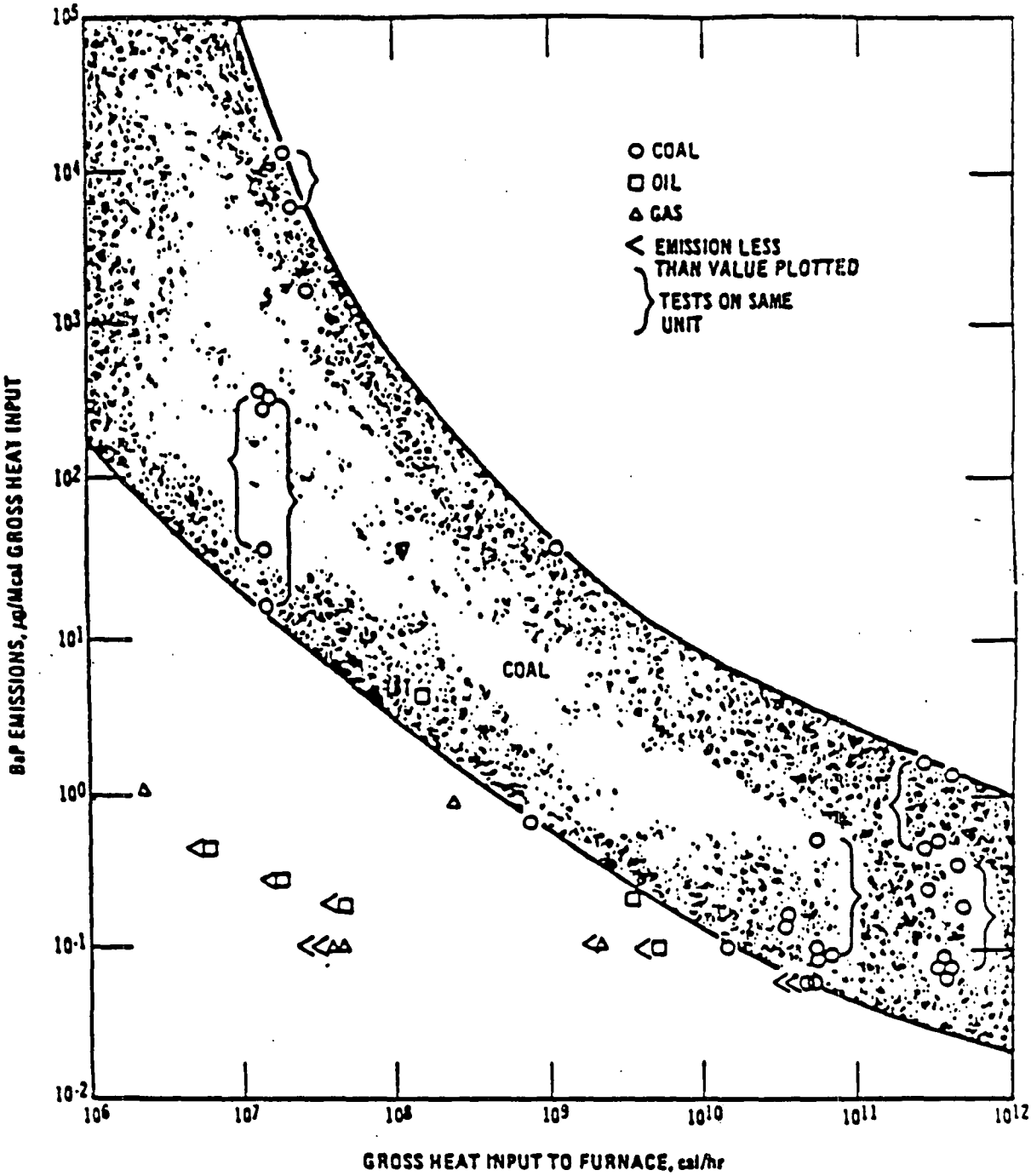
from gas and oil-fired boilers were generally on the same order as those from coal-fired utility boilers.

Utility boilers burn pulverized coal in large diffusion flames which are very similar to the flame types in gas- and oil-fired boilers. The flame produced by a hand-stoked boiler is similar to that in a poorly designed and operated mass fed MSW incinerator.

As noted in Figure 4-6, the BaP emission rates from gas-, oil- and coal-fired boilers with similar flame shapes are generally below 1 g/Mcal.[3] For comparison with other data in this report 1 g/Mcal is approximately equal to 500 ng/m^3 which is on the same order as the PCDD and PCDF emission rates indicated in Tables 3-7 and 3-8 for hospital incinerators. The BaP emission rates from the hand-stoked coal boilers are as much as 5 orders of magnitude above the levels produced by the diffusion flames. These comparisons suggest that the chemical structure of the fuel may have a relatively minor influence on POM emissions but that other parameters related to the manner in which the fuel is burned can have a significant influence. This underlines the fact that combustion controls, through careful incinerator design and operation, have the potential to achieve significant PCDD and PCDF emission reductions.

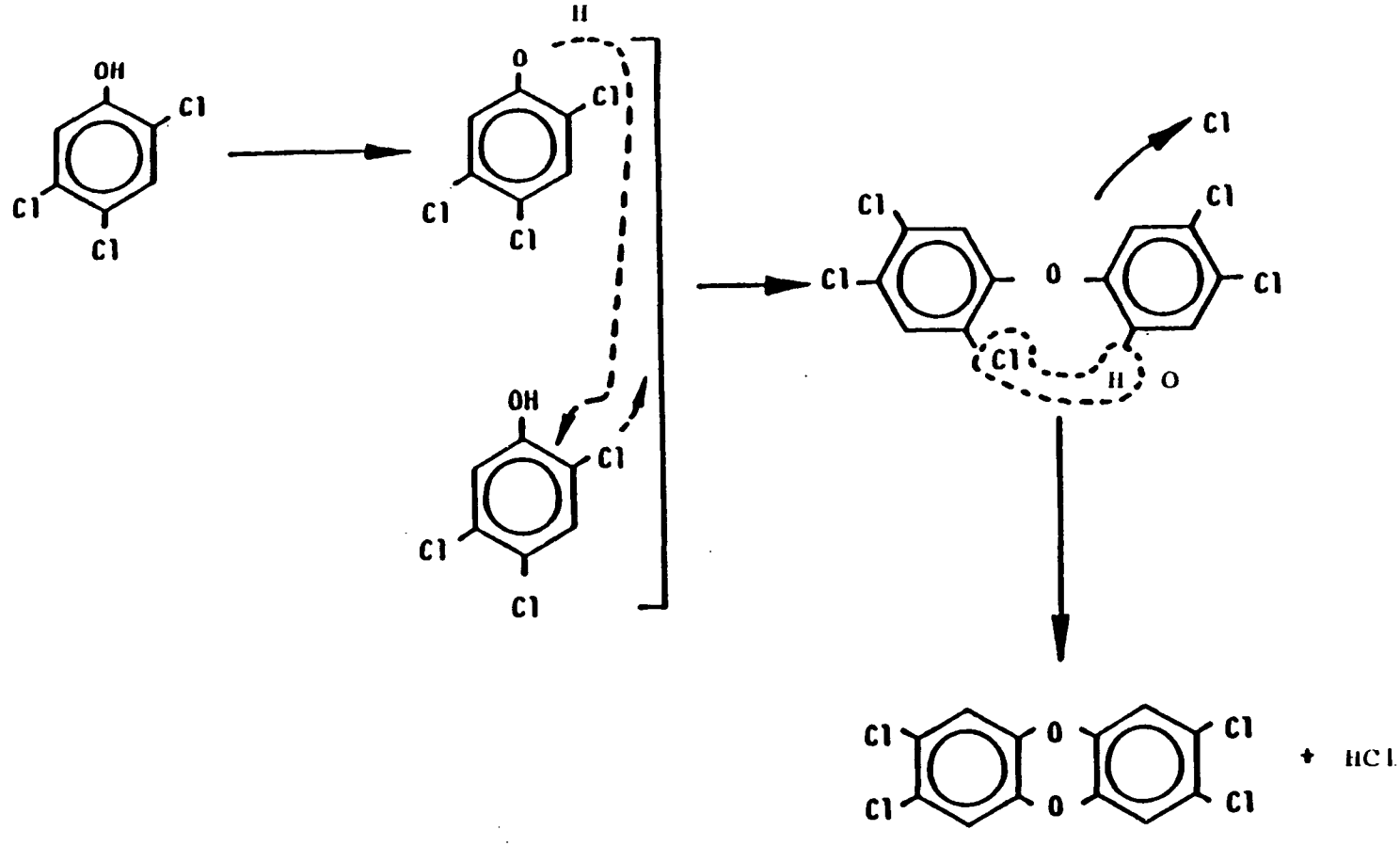
Using the waste burning process description of Section 3.1.4.1 in conjunction with the equilibrium, chemical kinetic, and fuel composition considerations of this section, it is possible to identify a variety of combustion control approaches for POM, PCDD and PCDF emissions. A discussion of the design or operating conditions which lead to the formation of the fuel-rich pockets which improve the potential for POM, PCDD and PCDF formation follows.

4.2.4.4 Air Distribution Effects in Controlled Air Incinerators. Controlled air incinerators will be used for the purpose of discussing air distribution effects on combustion control techniques for control of POM, PCDD, and PCDF. This type unit is chosen because of its wide use in the past 10 to 15 years and because currently it is the most widely sold design type. These units are also similar to excess air incinerators because of



Source: Reference 8.

Figure 4-6. Benzo(a)pyrene emissions from coal, oil, and natural gas heat-generation processes.



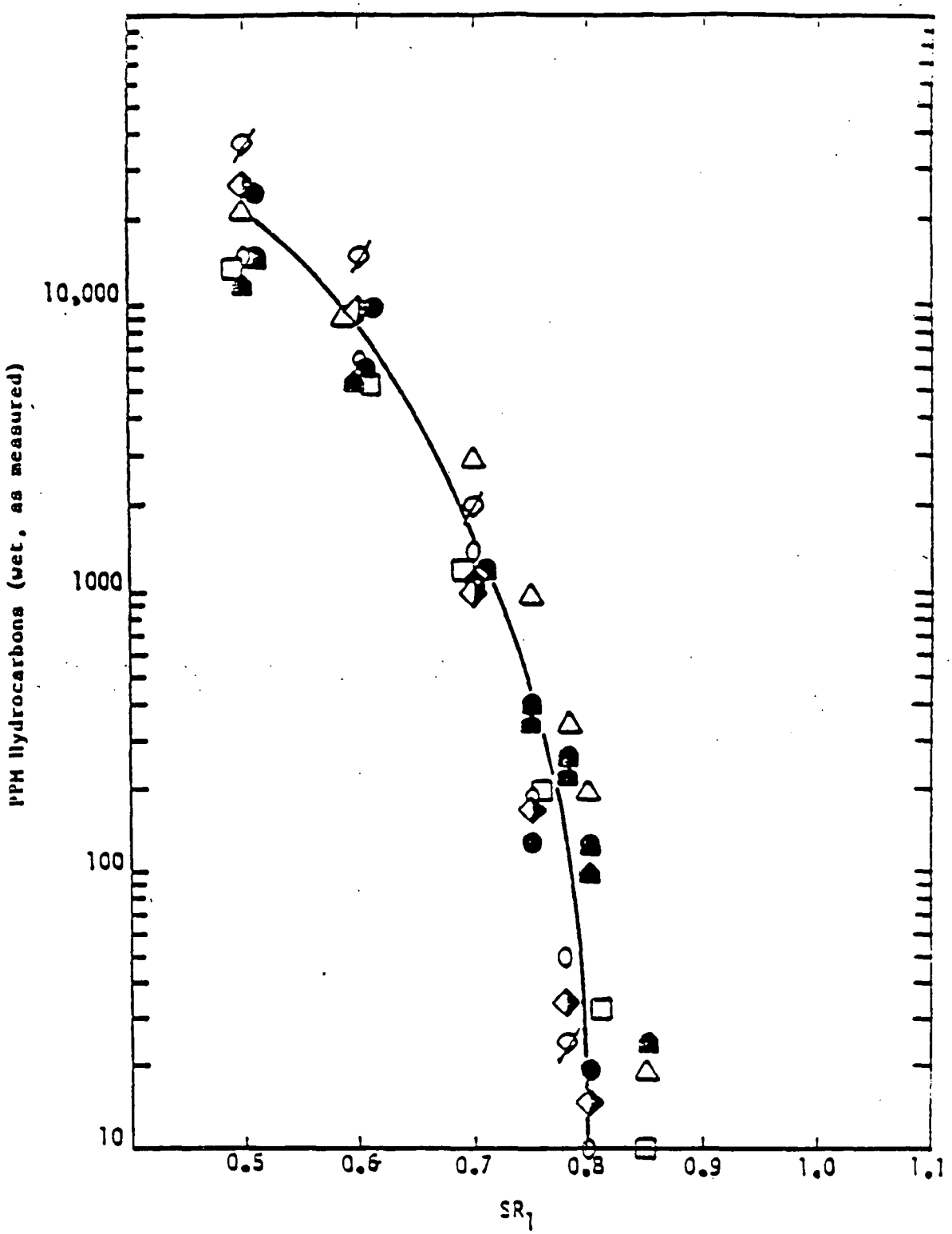
Source: Reference 7.

Figure 4-5. One possible formation mechanism for 2,4,7,8 - TCDD.

dioxin precursors are chlorinated phenols.[7] They suggested a kinetic path for forming 2,4,7,8-TCDD, as illustrated in Figure 4-5. The process proceeds by removal of hydrogen from the OH group; joining of two phenols to form a reactive 2-phenoxyphenol; followed by an elimination reaction to form dioxin.

The above discussion provides several important insights into the combustion processes controlling the formation of POM, dioxins and furans. Those same insights indicate important incinerator design and operating parameters which can be used to minimize emission of those species. Equilibrium and kinetic considerations both indicate that an essential feature required for the formation of POM, dioxin or furans is a fuel-rich pocket of gas. Defining how rich that pocket must be to form these species will depend on the local gas temperature. Increased temperature reduces the thermodynamic stability of the species (and their precursors) as well as accelerating the kinetic rate of destruction reactions. The discussion suggests that these POM compounds are, in all likelihood, formed in the primary chamber of controlled air hospital incinerators. However, these compounds must pass through the secondary chamber before being emitted to the atmosphere. The residence time and temperature characteristics of this second chamber will dictate, in large measure, the extent to which these materials are destroyed before flue gases are emitted.

4.2.4.3 Fuel Effects. A third issue to be examined is whether the chemical form of hospital waste has a significant impact on POM, dioxin or furan emissions. It is difficult (if not impossible) to accurately quantify the chemical form of this waste being fed into an incinerator over the time period required to extract a sample for POM analysis. There are, however, data quantifying POM emissions from gas, oil and coal-fired boilers. Figure 4-6 shows benzo(a)pyrene (BaP) emission data from different size boilers firing coal, oil or natural gas. The shaded area in this figure represents coal-fired boiler results. Units with heat inputs greater than 10^{10} cal/hr were utility boilers while units in the 10^{7} cal/hr range were small stoker-fired or hand-stoked coal furnaces. The measured BaP emissions



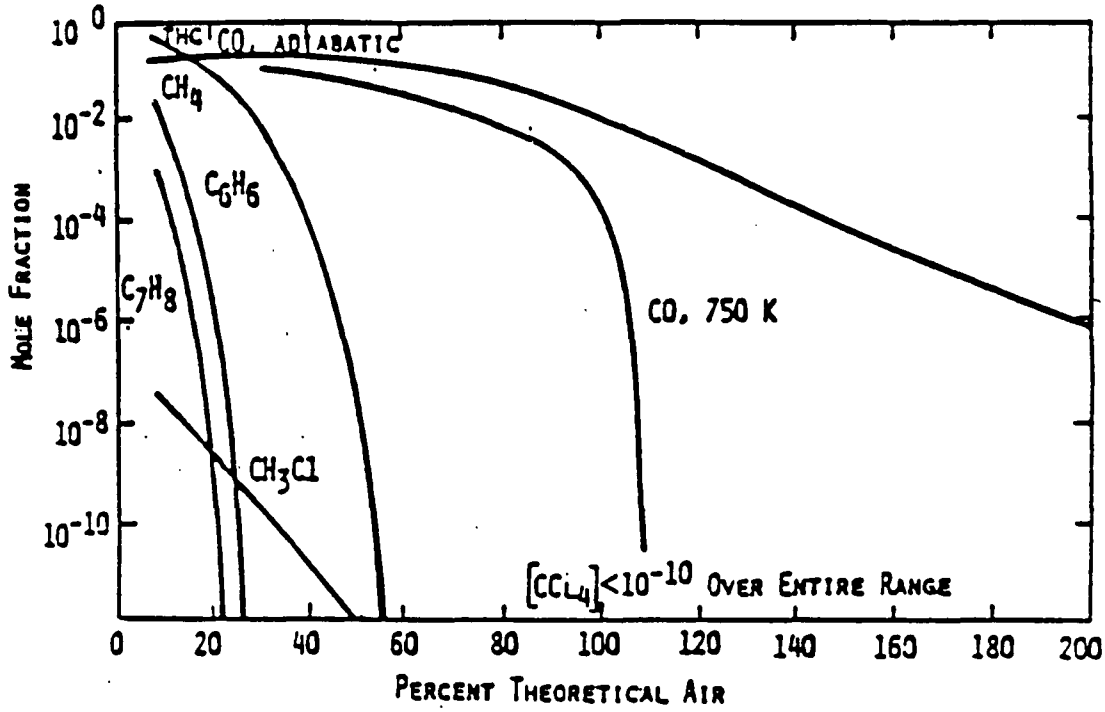
Source: Reference 6.

Figure 4-4. First stage hydrocarbon production.

above 45 percent theoretical air. Chemical kinetic limitations may, however, result in substantial concentrations of unburned hydrocarbon at stoichiometric ratios well above 45 percent. Experimental data obtained in the development of the EPA's low-NO_x heavy oil burner may be used to illustrate this fact.[6] Figure 4-4 indicates the measured total hydrocarbon (THC) concentration exiting the fuel-rich zone of a two-stage heavy oil flame. As shown, substantial THC was detected at first stage stoichiometric ratios below 80 percent theoretical air. The principal factor responsible for this hydrocarbon breakthrough was depressed flame temperature due to heat loss through the furnace walls. The kinetic rates of chemical processes vary exponentially with local temperature. Similar experiments, conducted in a higher temperature environment, showed negligible THC concentrations until the fuel-rich zone stoichiometry was less than about 60-65 percent theoretical air.

In the above tests, the transition from fuel-rich to fuel-lean conditions was achieved through the use of multiple air jets designed to achieve thorough mixing of air with the effluent from the fuel-rich zone. By changing the split between primary and secondary air, it was possible to vary the fuel-rich zone stoichiometry while maintaining a constant overall excess air condition. In many respects, this is similar to the basic design in a controlled air incinerator. An important observation is that whenever the primary zone stoichiometry was sufficiently fuel-rich to cause hydrocarbon breakthrough in the primary zone exhaust, there was a precipitous increase in the boiler exhaust smoke level. The important point relative to hospital incineration is that the presence of substantial hydrocarbon concentrations in fuel-rich regions can easily result in the formation of soot and organic particulate matter. The secondary chamber must be designed to accommodate these materials to achieve complete burn-out.

Equilibrium product distribution calculations for very fuel-rich conditions indicate ppm level concentrations of chlorobenzenes and chlorophenols. In one study, the likely chemical kinetic processes leading to formation of PCDDs was reviewed and it was concluded that the prime



Source: Reference 5.

Figure 4-3. Adiabatic equilibrium species distribution.

The issue of poor mixing can also be addressed by examining the equilibrium product distributions for various chlorinated benzene/air mixtures.[5] Sample results are shown in Figure 4-3 as concentration versus percent theoretical air assuming that the mixture is at the adiabatic flame temperature. With at least 45 percent theoretical air, formation of light hydrocarbon gases (CH_4, C_2H_2, etc.) is avoided. At 20 percent theoretical air, the formation of benzene or toluene as equilibrium products is avoided. This leads to the postulation that POM, dioxins and furans are thermodynamically favored only if the incinerator creates very fuel-rich (and hence oxygen-poor) pockets of gas at low temperatures in the presence of chlorine.

The above discussion illustrates two significant aspects of combustion control for POM. First, existence of these species (either in the flame or the exhaust) indicates a combustion process characterized by insufficient mixing and by local fuel-rich pockets of gas. These are the conditions which characterize the primary combustion chambers of controlled air incinerators. However, at reasonable temperature levels, there is no thermodynamic barrier to achieving essentially zero emission levels for these species and their precursors.

4.2.4.2 Kinetic Considerations. However, at reasonable temperature levels, there is no thermodynamic barrier to achieving emission levels for these species and their precursors that are below the current limits of detection (i.e., part per trillion levels). The preceding discussion addressed equilibrium formation of POM under excess air and starved air conditions. It is important to recognize that combustion of any fuel proceeds through a complex series of reaction steps leading toward (but not necessarily reaching) the product distribution predicted by equilibrium calculations. Some of these steps may be kinetically limited, however, causing certain reactions to be effectively terminated at an intermediate state.

Consideration of equilibrium conditions (see Figure 4-3) indicate that light hydrocarbon gases are thermodynamically not favored at mixture ratios

where P represents the partial pressure of a given constituent and K_p is the equilibrium constant. The equilibrium constant is related fundamentally to a measurable thermodynamic property called the Gibbs free energy (ΔG) by:

$$K_p = EXP\ (\Delta G/RT)$$

where T is temperature and R is the universal gas constant. Gibbs free energy values are compiled in many sources. For typical stack gas CO_2, H_2O and O_2 concentrations of 8 percent, the Gibbs free energy required for there to be 1 ppb equilibrium level of waste at 1,000^{0}K is roughly 40 Kcal/mole. The Gibbs free energy of furan at 800^{0}K is reported to be 492 Kcal/mole.[3] Thus, Gibbs free energy considerations predict an equilibrium furan partial pressure of less than 10^{-100}. The Gibbs free energy values for dioxins are even larger than that for furan; thus, the equilibrium concentration under oxidizing conditions is even less. These considerations show that given sufficient reaction time and mixing, the fundamental equilibrium limit for dioxins and furans may be considered zero for overall fuel-lean conditions, even at moderate incineration temperatures.

Since PCDDs and PCDFs can be formed in hospital incinerators, it is important to identify conditions where their presence is thermodynamically favored. An obvious area to examine is the high temperature, oxygen starved environment which is characteristic of isolated regions within poorly mixed combustion processes. An initial area to examine is high temperature pyrolysis without air which is the limit case for poor mixing.

TRW, Inc. performed an extensive series of equilibrium calculations for incineration of military pesticides.[4] An initial set of calculations indicated that solid carbon (graphite) was a predominant species. Recognizing the kinetic limitations of graphite formation, a second set of calculations were performed eliminating graphite as a possible product species. Those results indicated greater than 1 ppm concentrations of a wide variety of POM species as well as chlorobenzenes and chlorophenols (potential precursors to dioxins and furans).

combustion modification may be used to control PCDD or PCDF emissions must be considered theoretical in nature.

The PCDD and PCDF compounds are dicyclic, nearly planar, aromatic hydrocarbons within the broad category of POM. Polycyclic organic matter emissions have been the subject of intense investigation for many years with multi-ring compounds such as benzo(a)pyrene (BaP) being the primary species of interest. Therefore, the following discussion is based on available information on how POM emissions are influenced by the combustion process and makes the implicit assumption that variation in POM emission implies variation in dioxin and furan emission.

4.2.4.1 Equilibrium Considerations. If waste material is mixed with air and allowed to react for sufficient time, the concentration of the resultant products is determined by the elemental composition of the mixture (moles of C, H, N, O, Cl, etc.), the reaction temperature, and the thermodynamic properties of the species. Consider first the case of oxidizing conditions (excess air) in which the overall oxidation process is represented by:

$$\text{Waste} + n_1 O_2 \longrightarrow n_2 CO_2 + n_3 H_2O$$

where n_1, n_2 and n_3 are the stoichiometric coefficients required to balance the reaction and are dependent on the chemical structure of the waste. The equilibrium level of the unreacted waste in the combustion products is related to the concentrations of CO_2, O_2 and H_2O by the equilibrium constant:

$$K_p = \frac{P_{CO_2}^{n_2} \, P_{H_2O}^{n_3}}{P_{waste} \, P_{O2}^{n_1}}$$

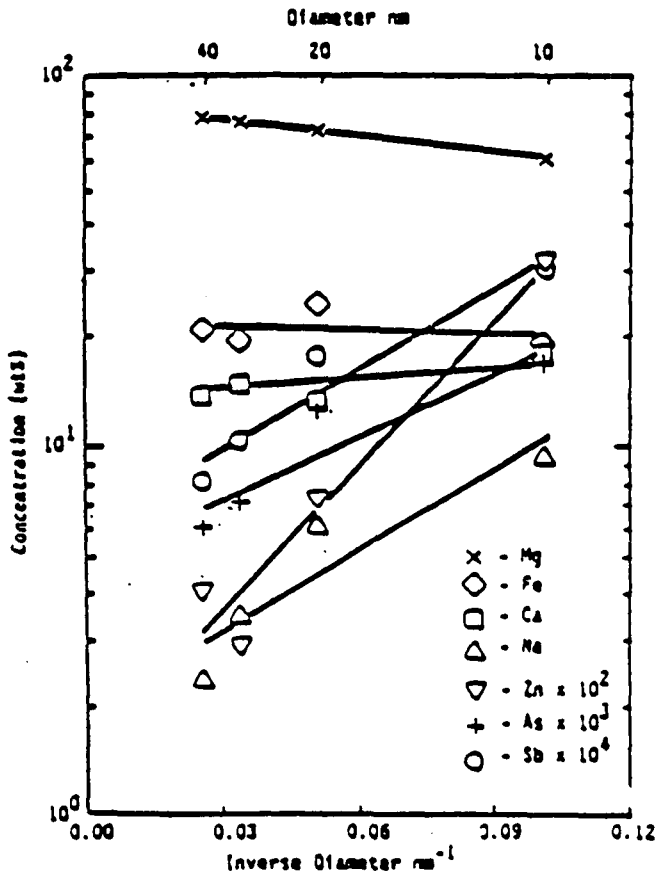
the convective section of a well-defined pilot scale facility operated under a variety of combustion conditions. Their results indicate that staged combustion conditions increased the sub-micron particulate matter concentration by 50 percent when firing lignitic coals.

The above information provides important clues relative to the mechanisms responsible for trace metal enhancement on sub-micron particles. It does not, however, define a combustion control approach to minimize trace metal emissions. Incinerators operated with extremely high temperatures in fuel-rich zones should have relatively higher concentrations of sub-micron particles which could potentially increase the trace metal enrichment process. Therefore, the use of controlled air, or two-stage, incineration with its lower primary combustion temperatures should reduce or minimize trace metal emissions.

4.2.4 Polycyclic Organic Matter (POM), PCDDs, and PCDFs

Available data from MSW incinerators indicate that the PCDD and PCDF emission rate is closely related to efficiency of the combustion process. Generally speaking, when the flame temperature and combustion efficiency are increased, PCDD and PCDF emission rates are seen to decrease. Due to the overriding toxiological importance of these pollutant species, an extensive discussion will be presented on how poor combustion conditions can lead to POM, dioxin and furan emissions and how the combustion process may be controlled to minimize these emissions.

The vast majority of the information on dioxin and furan emissions has been obtained only recently and primarily consists of stack emission rate measurements from municipal waste combustors. This information is taken primarily from testing results at large industrial and municipal incinerators; little work has been done on smaller hospital waste incinerators. There is also essentially no data from experimental programs specifically designed to identify the combustion processes responsible for PCDD/PCDF formation or to verify the effectiveness of proposed combustion control approaches. In the absence of direct data, discussion of how



Source: Reference 1.

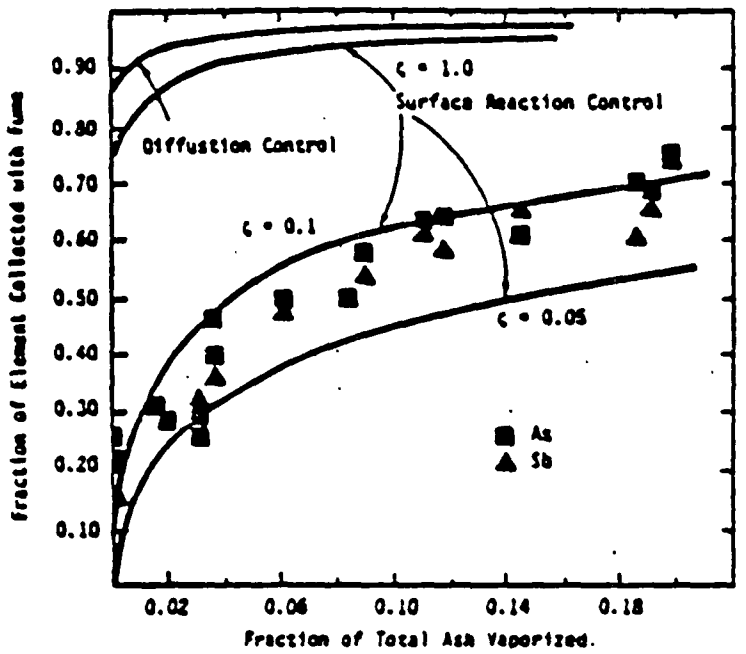
Figure 4-2. Concentration of selected elements in ultrafine particulates as a function of reciprocal particle diameter.

species to condense and would become the nuclei for the fine particulate matter. As the combustion gases cooled, volatile salts of alkali metals and other volatile trace species would be expected to condense on the outer surface of these particles. A group at MIT, led by Professor Adel Sarofim, has confirmed this theory in several experimental studies. Figure 4-2 illustrates their findings in a plot of the concentration of selected species versus reciprocal particle diameter. The elements Fe and Mg, which form the core of the particles, show no size dependence while those present as a surface coating show concentration variation proportional to 1/d. Note that the trace metals of concern for hospital incinerators were largely present as surface coatings.

The key to the above observation is that the ultra-fine particles present a very high specific surface area and thus receive a disproportionate share of the condensing elements. Any process that enhances refractory oxide vaporization would be expected to increase the number of sub-micron particles and to enhance the fine particle enrichment process. It has been speculated that fuel-rich combustion, used for NO_x control in boilers and also used in controlled air incinerators, could increase the refractory oxide vaporization rate. The basis of this speculation was contained in models used to successfully predict the extent of refractory oxide vaporization under excess air conditions. These oxides (SiO_2, MgO, CaO, Fe_2O_3) were assumed to vaporize at combustion conditions as a result of chemical reduction to the more volatile suboxide (SiO) or metal (Mg, Ca, Fe) within the locally reducing atmosphere within a coal particle. These models assumed that the following reaction reached equilibrium

$$MO_n + CO \longrightarrow MO_{n-1} + CO_2$$

at the surface of mineral inclusions and that the reduced oxide or metal (MO_{n-1}) then diffused to the char particle surface. Under fuel-rich conditions, the gases surrounding the coal particle would be reducing, which should accelerate the vaporization process. Experiments to confirm this speculation were performed. They measured the aerosol size distribution in



Source: Reference 1.

Figure 4-1. Fraction of As and Sb collected with fume as a function of the extent of total ash vaporization (data points).

Thus, combustion modifications to minimize PCDD and PCDF emissions should also be effective for other organic particulate emissions.

4.2.3 Trace Metals Control

In Section 3.0, the available trace metal emissions data from hospital incinerators were discussed and it was pointed out that many of the volatile metals of concern tend to selectively deposit on the smaller particles. The physical processes responsible for these phenomena are extremely complex, as is the potential influence of combustion processes on the associated phenomena. The following will provide only a brief review of key features which may be significant relative to hospital incineration combustion control.

The majority of the available research concerning the process of fine particle metal enrichment has been performed on pulverized coal-fired utility boilers. Those conditions are somewhat different than the conditions found in hospital incinerators but the basic processes should be similar in both systems. It has been found that the distribution of volatile metals among the different size fractions of ash is influenced by the amount of ultra-fine particles produced during combustion. Figure 4-1 illustrates this point in a plot of the fraction of arsenic and antimony collected with the ultra-fine particles (referred to as fume) versus the fraction of the total ash appearing in the ultra-fine mode. A surface deposition model to interpret these data was developed and its predictions for the amount of trace metal deposited in the small size mode is presented as the solid lines on Figure 4-1.[1]

The issue of how uniformly the metals are distributed as a function of particle size has health effect implications as well as being an issue of engineering significance. Based on the probable mechanism of fine particulate formation, it was suspected that the trace metals would tend to concentrate on the surface of fine particles rather than being uniformly distributed throughout the particle size range. The reasoning was that refractory oxides which were vaporized in the flame would be the first

simply gravitational acceleration times particle density times particle volume. Assuming a spherical particle, the gravity force varies with the diameter cubed. The ratio of drag force to gravity force will vary inversely with particle diameter. Thus, particles with relatively large surface-to-volume ratio are more likely to be entrained into the primary chamber flow field.

If it is assumed that the ash content of hospital waste is approximately 25 percent and that emitted PM is totally inorganic, then the uncontrolled PM emission rate data presented earlier in Table 3-5 may be used to estimate the extent of entrainment. The PM emission rates were shown to vary from 36.5 to 1.37 lb/ton refuse. This indicates that between 92.7 and 99.7 percent of the ash remains in the ash pit.

Before addressing the volatile inorganic and organic fractions, it is important to place the PM emission rate data into perspective. As discussed above, available data indicate that less than 10 percent of the input ash exits the furnace as PM and, in some instances, that fraction is less than one percent. In a pulverized coal-fired utility boiler, however, approximately 80 percent of the coal ash exits the furnace as fly ash. Even accounting for the lower ash content and higher heating value of coal relative to hospital waste, the PM emission rates (on either a gr/DSCF or $lb/10^6$ million Btu basis) will be much lower for a hospital incinerator than for a utility boiler.

The volatile inorganic material in the feed will also contribute to the total PM emission rate. It is convenient to discuss combustion control of this PM fraction in the context of trace metal emission even though all of the trace metals emitted may not be associated with the particulate. A discussion of trace metal emissions is presented in Section 4.2.3.

Finally, organic compounds are also associated with emitted PM. The organic components are generally heavy hydrocarbons such as soot, products of incomplete combustion (PICs), or polycyclic organic matter (POM). An extensive discussion of POM emissions and potential combustion control is presented in Section 4.2.4. Combustion phenomena responsible for POM, dioxin, and furan formation are also responsible for the formation of soot.

concentration of O, H and OH radicals. Even though the local stoichiometry is fuel-rich the high radical concentrations drive the gas speciation towards the equilibrium state. Thus, reburning not only provides an approach for destroying NO, it also creates an environment which should destroy any dioxins or furans created in the primary flame zone. Extensive research and development efforts would be required to develop reburning for hospital incineration but the potential exists for a multi-purpose combustion control technology.

4.2.2 Particulate Matter Control

As stated previously, particulate matter exiting the furnace consists of both inorganic material entrained into the combustion gases and organic materials which were not completely burned. In evaluating the influence of combustion control on PM emissions, it is necessary to separate the organic and inorganic fractions and to distinguish between the volatile and non-volatile inorganic contributions.

When waste is fed into an incinerator, it is heated by radiant energy from the hot furnace walls and from burning combustion products above the bed. The waste is dried and, as the temperature increases, a devolatilization (pyrolysis) process begins. The released volatile matter is entrained by the underfire air and begins to burn. Heat transfer from the burning volatiles to the bed material helps to ignite the waste in the bed and sustain the combustion process. The non-volatile, inorganic constituents of the waste generally remain in the ash pit. Non-volatile inorganics can contribute to the PM emission rate if an ash-containing particle is entrained by the underfire air and bed combustion products as they pass through the waste bed into the primary chamber.

An ash-containing particle in the bed will be subjected to a series of forces including a drag force tending to accelerate the particle to the local air velocity and a gravity force tending to hold the particle in the bed. The drag force is proportional to the frontal area of the particle times the velocity differential squared. The opposing gravity force is

Pittsfield MSW incinerator by the State of New York could provide information addressing the impacts of FGR when they become available. Information gained from this test and other future tests could be used to further evaluate the potential application of FGR to hospital incinerator units.

Reburning is a term used for a control technique which uses a hydrocarbon-type fuel as a reducing agent. Hydrocarbon radicals react with NO_x to form nitrogen-containing radicals which, in turn, form N_2 by reaction with NO_x in the absence of oxygen. This control technology is being developed for use in fossil fuel-fired boilers because only minor modifications are required to the main heat release zone. Thus, with reburning the main heat release zone can be optimized for efficient combustion, eliminating problems with impact on PCDD/PCDF emissions. The effectiveness of reburning for NO_x control in boilers has been shown to be a function of:

- Initial NO level: the reduction decreases as the initial NO level decreases.

- Fuel type: nitrogen-free reburning fuels are most effective, particularly at low initial NO levels.

- Temperature: reburning effectiveness increases as the temperature of the reburning zone increases.

- Residence time: gas residence time in the reburning zone of approximately 0.5 seconds is required to maximize the effectiveness of reburning.

Two aspects of the reburning process make it attractive for hospital incinerators. First, it is a relatively effective control technique, providing NO_x reductions on the order of 50 percent. Second, the process of burning the secondary fuel results in a significant increase in the

4.2.1 Acid Gas Control

The primary acid gas that will be emitted from a hospital waste incinerator is hydrochloric acid. As stated in Section 3.1, based on thermodynamic equilibrium considerations, any chlorine content in the waste will be effectively converted to HCl, assuming that there is sufficient hydrogen available. Therefore, based on the thermodynamic and kinetic consideration presented in Section 3.1, combustion modification does not appear to be a viable control approach for hydrochloric emissions from hospital incineration units.

From a combustion control standpoint, emissions of SO_2 are similar to HCl. Therefore, combustion modification is not a viable approach for SO_2 emissions.

The NO_x emissions from a hospital waste incinerator are relatively low when compared to those from a pulverized coal-fired boiler (0.9 to 1.0 lb/million Btu, uncontrolled). NO_x emissions from hospital waste incinerators are low because of their low combustion temperatures and two-staged combustion design. The low temperatures decrease the thermal NO_x production and the two-staged design helps to reduce the fuel NO_x which is formed. However, in some regions even the NO_x levels which are shown in Section 3.0 are of concern. In such cases there are two potential control options which may be considered.

The two options available control NO_x emissions in the combustion zone where they are created. Neither are presently being applied to hospital incinerators but both could potentially be used. The first is flue gas recirculation (FGR) which retards NO_x formation; the second is reburning which destroys the NO_x which is created in the combustion zone.

Flue gas recirculation is a technology which has been used for the control of NO_x in boilers. FGR introduces a thermal diluent and reduces combustion temperatures. However, lowering of flame and furnace temperatures could be counter to the control of PCDD/PCDF. The significance of the detrimental impact of reduced bulk temperatures on PCDD/PCDF emissions has yet to be determined. Testing recently completed on the

After segregation of infectious and non-infectious wastes, further segregation of the non-infectious portion could be possible. Plastics and metal-containing components of the waste could be segregated and possibly lower HCl, polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzo-p-furans (PCDFs), and trace metal emission rates. However, no data are available on the effectiveness of such practices at hospital waste incinerators in lowering these emissions. Another approach to possibly lower HCl and PCDD/PCDF emission rates would be to use low chlorine content plastics within hospitals. This could be accomplished if the health care industry were to use plastics such as polyethylene and polystyrene in place of polyvinyl chloride, which contains over 45 weight percent chlorine. Again, no data are available to indicate the effectiveness of such practices on emissions from hospital waste incinerators.

4.2 COMBUSTION CONTROL

Data presented in Section 3 illustrate that there is significant variation in the uncontrolled emission rates from hospital incinerators. These variations are partially due to variability in chemical and physical properties of hospital wastes, partially due to variations in incinerator design, and partially due to variation in operating practices. This section addresses how waste combustion processes influence emission rates for the pollutants of interest and how combustion process control may be used as an emission control strategy. The general format is to address each pollutant group separately, discussing how combustion processes influence the emission rate and how the adjustable process parameters may be used to reduce emissions and achieve emission control.

The following sections provide discussions of the relationships between combustion processes and emissions of major pollutants of concern, namely:

- acid gases,
- particulate matter,
- trace metals, and
- polycyclic organic matter (including dioxin and furans).

4.0 CONTROL TECHNOLOGIES AND EFFICIENCIES

To date, hospital waste incinerators have operated largely without requirements for add-on pollution control equipment or special combustion modification techniques. Municipal waste incinerators, on the other hand, have received closer scrutiny in recent years and consideration has been given to potential emission control techniques. The process equipment and systems used to incinerate these two types of wastes are similar in design and operation, at least for the larger controlled air incinerators. This section extrapolates knowledge which has been gained from municipal waste incinerators to hospital waste incinerators and considers the applicability of various emission control techniques.

There are three broad categories of methods which may be applied to the control of emissions from waste incinerators:

(1) Source Separation,
(2) Combustion Control, and
(3) Flue Gas Controls (add-on control devices).

The application of each of these categories of emission control to hospital waste incinerators is addressed in this section.

4.1 SOURCE SEPARATION

Source separation refers to both the segregation of infectious and non-infectious wastes and the removal of specific compounds from the waste stream prior to incineration. As discussed in Section 1.2, it is estimated that about 85 percent of a hospital's waste stream can be categorized as general refuse, while the remaining 15 percent is contaminated with infectious agents (according to the experience of hospitals in Illinois). Thus, segregation of wastes at the point of generation can reduce the volume of infectious waste significantly. During a visit of project personnel to the Iredale Hospital in Statesville, North Carolina, such waste segregation practice was observed through the use of colored trash bags. The extent of infectious waste reduction was not known.

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TABLE 3-11. EMISSIONS/FACTORS FOR CARBON MONOXIDE AND HYDROCARBON EMISSIONS FROM HOSPITAL WASTE INCINERATORS

Pollutant	Cedar Sinai[a] Medical Center Los Angeles, CA (ppmv)	Cedar Sinai[a] Medical Center Los Angeles, CA (lb/ton feed)	St. Agnes[b] Medical Center Fresno, CA (ppmv)	St. Agnes[b] Medical Center Fresno, CA (lb/ton feed)	Emissions Factor (lb/ton feed)
Carbon Monoxide					
High	<50[c]	<1.32	<50	<1.69	<1.69
Low	<50	<1.32	<50	<1.69	<1.32
Average	<50	<1.32	<50	<1.69	<1.51
HC (as Propane)					
High	7	0.29	4	0.21	0.29
Low	3	0.12	1	0.05	0.05
Average	4	0.17	2	0.11	0.14

[a]Reference 21.

[b]Reference 22.

[c]Below the lower detection limit of 50 ppmv.

TABLE 3-10. EMISSION FACTORS FOR SELECTED ORGANIC LOW MOLECULAR WEIGHT ORGANICS FROM HOSPITAL WASTE INCINERATORS

	Emissions Factor (lb/ton feed)	Reference Source
Ethane	<0.003	23
Ethylene	<0.02	23
Propane	<0.024	23
Propylene	<0.022	23
Trichlorotrifluoroethane	8.25×10^{-5}	21, 22
Tetrachloromethane	9.91×10^{5}	21, 22
Trichloroethylene	2.39×10^{5}	21, 22
Tetrachloroethylene	2.49×10^{4}	21, 22

Low Molecular Weight Organics. Table 3-10 contains emissions factors for the low molecular weight organics for which emissions results were identified. These factors were determined from information collected at three of the comprehensive test sites.

Carbon Monoxide. The CO emissions data which were identified during this study are presented in Table 3-11. Also presented are the hydrocarbon (HC) data which were found. It should be noted that the HC data are reported as propane. The CO concentrations measured were below the detection limit of 50 ppmv and are, therefore, reported as less than 50 ppmv.

A comparison of the HC emissions factors of Table 3-11 to the LC factors of Table 3-10 suggests that only a small portion of the total HC measured is comprised of the compounds listed in Table 3-10. A definitive conclusion can not be reached, however, because the results presented are from different tests.

3.2.5 Pathogens

As part of a recent test, 15 samples were taken from the stack of a hospital waste incinerator which had been charged with hospital waste containing pathogenic material[28]. Bacteria with a mean concentration of 231 colonies/m^3 of gas sampled were found in the stack as opposed to an ambient mean level of 148 colonies/m^3. However, due to experimental uncertainty, no statistically significant difference could be found between the two measurements.

In another study, a two-stage hospital incinerator was charged with known concentrations of bacterial colonies in order to determine the minimum operating temperature required to prevent the release of bacteria or their spores to the environment[29]. The conclusions reached by the study were that, to prevent release of viable organisms to the atmosphere, a primary chamber operating temperature of 1400^{o}F is required and a secondary chamber operating temperature of 1600^{o}F is needed.

TABLE 3-9. FABRIC FILTER DIOXIN/FURAN ASH ANALYSIS FOR CEDAR SINAI INCINERATOR[a]

	Loadings (ng/g)
Dioxins	
Tetra	1.6
Penta	3.7
Hexa	8.9
Hepta	33.6
Octa	65.7
Total PCDD	114.0
Furans	
Tetra	13.6
Penta	19.0
Hexa	22.6
Hepta	42.2
Octa	43.5
Total PCDF	141.0

[a]Reference 21.

TABLE 3-8. DATA/FACTORS FOR CHLORINATED ~~DIBENZO-p-DIOXINS~~ EMISSIONS FROM HOSPITAL WASTE INCINERATORS

	Cedar Sinai[a,d] Medical Center Los Angeles, CA (Fabric Filter)		Cedar Sinai Medical Center Los Angeles, CA (Uncontrolled)		St. Agnes[b,d] Medical Center Fresno, CA (Uncontrolled)		Royal Jubilee[c,d] Hospital Victoria, BC (Uncontrolled)		Emissions Factor (Uncontrolled)
	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(lb/ton feed) ($x10^6$)
(Tetra) TCDD									
High	67.10	1.38	79.8	1.55	78.7	2.07	34.9	0.93	2.07
Low	56.50	1.17	35.5	0.65	64.9	1.81	18.9	0.50	0.50
Average	61.80	1.28	59.2	1.12	71.8	1.94	26.975	0.73	1.26
(Penta) PeCDD									
High	103.00	2.12	106.0	2.06	136.0	3.79	53.1	1.45	3.79
Low	80.40	1.67	68.9	1.91	130.0	3.42	48.3	0.90	0.90
Average	91.70	1.89	92.6	1.74	133.0	3.61	46.175	1.24	2.20
(Hexa) HxCDD									
High	118.00	2.44	163.0	3.03	202.0	5.63	57.5	1.51	5.63
Low	90.90	1.88	116.0	2.12	170.0	4.46	29.8	0.82	0.82
Average	104.45	2.16	144.0	2.71	186.0	5.04	42.925	1.15	2.97
(Hepta) HpCDD									
High	110.00	2.27	204.0	3.79	232.0	6.46	35.4	0.96	6.46
Low	109.00	2.25	152.0	2.82	160.0	4.19	20.8	0.55	0.55
Average	109.50	2.26	169.7	3.19	196.0	5.33	25.725	0.70	3.07
(Octa) OCDD									
High	49.10	1.02	163.0	3.03	166.0	4.35	27.7	0.75	4.35
Low	38.00	0.78	67.7	1.24	150.0	4.19	7.7	0.21	0.21
Average	43.55	0.90	105.1	1.97	158.0	4.27	13.8	0.37	2.21
Total PCDD									
High	435.00	8.98	695.0	10.74	785.0	21.87	196.5	5.36	21.87
Low	106.00	8.01	441.0	8.09	704.0	18.51	117.3	3.25	3.25
Average	270.50	8.50	570.7	10.74	744.5	20.19	155.6	4.19	11.71

[a]Reference 21.

[b]Reference 22.

[c]Reference 23.

[d]High and low values are results of individual test runs.

TABLE 3-7. DATA/FACTORS FOR CHLORINATED ~~DIBENZOFURANS~~ Dioxins EMISSIONS FROM HOSPITAL WASTE INCINERATORS

	Cedar Sinai[a,d] Medical Center Los Angeles, CA (Fabric Filter)		Cedar Sinai Medical Center Los Angeles, CA (Uncontrolled)		St. Agnes[b,d] Medical Center Fresno, CA (Uncontrolled)		Royal Jubilee[c,d] Hospital Victoria, BC (Uncontrolled)		Emissions Factor (Uncontrolled)
	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(ng/nM^3)	(lb/ton feed) ($x10^6$)	(lb/ton feed) ($x10^6$)
(Tetra) TCDF									
High	6.09	0.13	6.7	0.13	38.5	1.07	ND	ND	1.07
Low	5.85	0.12	2.1	0.04	3.3	0.09	ND	ND	0.04
Average	5.97	0.12	4.3	0.08	20.9	0.58	ND	ND	0.33
(Penta) PeCDF									
High	18.30	0.38	16.2	0.32	23.5	0.66	28.6	0.76	0.76
Low	14.50	0.30	11.0	0.20	18.2	0.48	4.1	0.11	0.11
Average	16.40	0.34	12.9	0.24	20.9	0.57	10.175	0.42	0.41
(Hexa) HxCDF									
High	27.40	0.57	36.3	0.71	54.4	1.52	9.7	0.52	1.52
Low	20.40	0.42	24.7	0.45	38.7	1.02	19.2	0.27	0.27
Average	23.90	0.49	31.9	0.60	46.6	1.27	13.775	0.37	0.75
(Hepta) HpCDF									
High	51.10	1.05	94.8	1.76	137.0	3.83	19.2	0.50	3.83
Low	49.40	1.02	62.1	1.14	85.5	2.25	11.4	0.32	0.32
Average	50.25	1.04	77.2	1.45	111.3	3.04	16.725	0.45	1.65
(Octa) OCDF									
High	39.20	0.81	114.0	2.12	196.0	5.47	26.7	0.74	5.47
Low	26.50	0.55	62.5	1.15	145.0	3.81	12.4	0.34	0.34
Average	32.85	0.68	83.8	1.58	170.5	4.64	22.825	0.61	2.28
Total PCDF									
High	130.00	2.69	259.0	4.82	450.0	12.52	83.5	2.23	12.52
Low	129.00	2.67	163.0	2.99	290.0	7.64	51.8	1.43	1.43
Average	129.50	2.68	210.3	3.96	370.0	10.08	68.9	1.85	5.30

[a]Reference 21.

[b]Reference 22.

[c]Reference 23.

[d]High and low values are results of individual test runs.

require testing, it can be assumed that future tests will be a source for additional data.

Analysis of the Cedar Sinai data indicate that there is a substantial reduction in trace element emissions across the fabric filter. No statements can be made relative to trends in the data relative to incinerator size.

3.2.4 Organic Emissions

Chlorinated Dibenzo-p-Dioxins (CDDs) and Chlorinated Dibenzofurans (CDFs). Tables 3-7 and 3-8 contain summaries of the available emissions data for CDD and CDF compounds from hospital incinerators. An emissions factor based on waste feed rate to the unit is also given for each of the emissions rates presented. The homolog emission data from three emissions tests are shown. Limited isomer emission data were available for the Cedar Sinai and St. Agnes tests. For the Cedar Sinai unit results from both upstream and downstream of the fabric filter are presented.

At this time, these are the only reported CDD and CDF emissions test results for hospital incinerator units which are known to exist. An additional unit located at Stanford University Medical Center in California was also recently tested for CDDs and CDFs.[27] The results of this test were not available as of the writing of this report. The California Air Resource Board (CARB) has recently begun to require testing for CDDs and CDFs at newly installed hospital incinerators so additional data will be available through CARB in the future.

Analysis of the emissions data presented for the unit at Cedar Sinai indicates that for most of the dioxin and furan homologs, a slight reduction occurs across the fabric filter. The subgroups for which this reduction was not seen are the TCDD and TCDF homologs. Results of ash analyses are presented in Table 3-9.

No statements can be made relative to trends in the data related to unit size or operating characteristics because too little is known about the operation of each of the facilities during testing.

TABLE 3-6. DATA/FACTORS FOR TRACE ELEMENT EMISSIONS FROM HOSPITAL WASTE INCINERATORS

	PM Device	As		Cd		Cr		Fe		Mn		Ni		Pb	
		gr/dscf ($x10^{-6}$)	lb/ton ($x10^{-4}$)	gr/dscf ($x10^{-6}$)	lb/ton ($x10^{-4}$)	gr/dscf ($x10^{-6}$)	lb/ton ($x10^{-4}$)	gr/dscf ($x10^{-6}$)	lb/ton ($x10^{-4}$)	gr/dscf ($x10^{-6}$)	lb/ton ($x10^{-4}$)	gr/dscf ($x10^{-6}$)	lb/ton ($x10^{-4}$)	gr/dscf ($x10^{-6}$)	lb/ton ($x10^{-4}$)
Cedar Sinai[a,d]															
High	Y	0.00086	0.00041	0.103	0.053	0.069	0.032	0.516	0.245	0.112	0.053	0.645	0.304	2.15	1.02
Low	Y	0.00079	0.00037	0.112	0.050	0.016	0.008	0.474	0.227	0.103	0.051	0.593	0.214	1.98	0.94
Average	Y	0.00084	0.00039	0.109	0.051	0.046	0.021	0.502	0.238	0.109	0.051	0.628	0.267	2.09	0.99
High	N	5.99	2.92	140	68.0	7.46	3.63	153	72.6	9.23	4.37	2.34	1.12	1190	580
Low	N	3.02	1.47	59	29.0	2.15	1.02	85	41.2	6.74	3.29	2.22	1.08	620	304
Average	N	4.30	2.08	92	44.4	4.09	1.98	65	55.3	8.30	1.96	2.28	1.10	896	434
St. Agnes[b,d]															
High	N	4	2.14	67	40.9	11	6.07	166	101.6	7	3.93	5	2.80	916	559
Low	N	1	0.71	46	24.8	5	2.88	68	39.8	3	1.58	3	1.58	532	310
Average	N	2	1.19	55	31.9	8	4.69	130	75.1	5	2.88	4	2.38	749	433
Royal Jubilee[c,d]															
High	N	N/A	N/A	52.4	33.2	30.9	19.5	292	183	18.1	11.4	8.0	5.0	686	434
Low	N	N/A	N/A	24.7	15.5	16.3	10.2	284	180	12.3	7.8	5.8	3.6	638	399
Average	N	N/A	N/A	38.6	24.4	23.6	14.9	238	182	15.2	9.6	6.9	4.3	662	417
Overall Uncontrolled[d]															
High	N	--	2.92	--	68.0	--	19.5	--	183	--	11.4	--	5.0	--	580
Low	N	--	0.71	--	15.5	--	1.02	--	39.8	--	1.58	--	1.08	--	304
Average	N	--	1.81	--	35.2	--	7.22	--	103	--	5.40	--	2.53	--	371

[a] Reference 21.

[b] Reference 22.

[c] Reference 23.

[d] High and low values are results of individual test runs.

The PM emission results in Table 3-5 include the results of the comprehensive emissions tests (the first four hospitals) and test results obtained from the survey article.[26] These units are the same units for which HCl data were presented. The data shown from the survey article are arranged in order of ascending feed rate to show any effect of unit size on PM emissions. The emission factors in Table 3-5 show no clear trend between specific PM emission rates and unit size. It is interesting to note that the highest emission factors (above 10 lb/ton feed) are associated with the smaller units (below 400 lb/hr). Based on the information in Section 2.1, these units may well be excess air incinerators. Unfortunately, no design information is available to confirm this hypothesis.

Emissions results for units operating with PM control equipment are also shown in Table 3-5. The Cedar Sinai unit, which was installed with a fabric filter for PM control, had the lowest PM emissions factor of those presented. The control efficiency for the filter was 98 percent. The other two units which had PM control equipment are the Lethbridge General and University of Alberta units. The emissions factors for these two units are considerably higher and are not markedly different from incinerators operated without PM control equipment. This may be explained by the fact that these units were operated for acid gas control and not for PM removal. Unfortunately no inlet data were given for these units so the control efficiency could not be determined.

3.2.3 Trace Metals

Table 3-6 contains a summary of the available trace metal emission data for hospital waste incinerators. An emissions factor based on the waste feed rate to the unit is also given for each of the emissions rates presented. In addition, for the Cedar Sinai unit, results for upstream and downstream of the fabric filter are presented.

No additional trace metals data were identified by the study. Because two of the reports are from California, a state recently beginning to

TABLE 3-5. DATA/FACTORS FOR PARTICULATE EMISSIONS FROM HOSPITAL WASTE INCINERATORS[g] (CONTINUED)

Hospital	Add-On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	Particulate Loading (gr/dscf)	Emissions Factor (lb/ton feed)
Queen Elizabeth II	None/No	700	0.030	2.70
Misericordia	None/No	740	0.060	2.97
Misericordia	None/No	740	0.100	4.76
Royal Alex	None/Yes	1,160	0.030	3.41
Royal Alex	None/Yes	1,200	0.070	3.30
Foothills	None/No	2,500	0.060	1.76
Lethbridge Gen.	Wet Scrubber/Yes	1,060	0.040	2.12
Univ. of Alberta	Wet Scrubber/Yes	1,400	0.020	1.23

[a]Reference 21.

[b]Reference 22.

[c]Reference 23.

[d]Reference 24.

[e]Based on emissions factors presented in Reference 24.

[f]All of the information from Athabasca to Univ. of Alberta are from Reference 25.

[g]All the incinerators identified in this table were two-stage controlled air units. The University of Alberta unit had a rotating hearth for a primary chamber; all other units had a fixed primary chamber.

TABLE 3-5. DATA/FACTORS FOR PARTICULATE EMISSIONS FROM HOSPITAL WASTE INCINERATORS[g]

Hospital	Add-On Control Device/ Heat Recovery	Incinerator Feed Rate (lb/hr)	Particulate Loading (gr/dscf)	Emissions Factor (lb/ton feed)
Cedar Sinai[a]	Fabric Filter/No	980		
High			0.002	0.10
Low			0.001	0.05
Average			0.001	0.07
St. Agnes[b]	None/No	783		
High			0.090	5.45
Low			0.080	4.84
Average			0.080	5.15
Royal Jubilee[c]	None/No	1930		
High			0.028	1.82
Low			0.022	1.37
Average			0.025	1.60
Illinois Unit[d]	None/No	500-800		
High			0.170	3.20[e]
Low			0.020	2.00[e]
Average			0.040	2.60[e]
Athabasca[f]	None/No	85	0.050	26.92
Willingdon	None/No	130	0.070	1.69
Bonnyville	None/No	130	0.080	11.85
Lacombe	None/No	150	0.070	5.87
Ft. McMurray	None/No	265	0.050	13.28
W.C. McKen.	None/No	275	0.020	3.20
Red Deer	None/Yes	410	0.080	36.49
St. Michaels	None/No	465	0.080	1.70
Queen Elizabeth II	None/No	575	0.030	6.12

TABLE 3-4. DATA/FACTORS FOR SO_2 AND NO_x EMISSIONS FROM HOSPITAL WASTE INCINERATORS

Pollutant	Cedar Sinai[a] Medical Center Los Angeles, CA (ppmv)	Cedar Sinai[a] Medical Center Los Angeles, CA (lb/ton feed)	St. Agnes[b] Medical Center Fresno, CA (ppmv)	St. Agnes[b] Medical Center Fresno, CA (lb/ton feed)	Emissions Factor (lb/ton feed)
Sulfur Dioxide					
High	50	3.01	20	1.54	3.01
Low	25	1.51	19	1.47	1.47
Average	37	2.22	19	1.47	1.85
Nitrogen Oxides					
High	270	7.82	155	5.75	7.82
Low	160	4.64	155	5.75	4.64
Average	217	6.29	155	5.75	6.02

[a]Reference 21.

[b]Reference 22.

Secondary Combustion. Moisture, volatiles and combustion gases from the primary chamber flow upward through a connecting section where they are mixed with air prior to entering the secondary combustion chamber. If the gases from the primary chamber are hot enough they will self-ignite when the additional air is added. However, a burner is located near the entrance to the secondary chamber to provide additional heat when it is needed. The air injection rate into the second chamber is generally between 100 and 140 percent of total stoichiometric requirements. Thus, the total combustion process in the incinerator operates at between 40 to 110 percent excess air.

If operation of the secondary air flow is kept at design levels, the amount of oxygen added to the combustion process is sufficient to complete the combustion process without exceeding the lean fuel flammability limits. The critical issue is that the fuel-rich exhaust from the primary chamber must be mixed on a molecular level for the complete destruction of all POM, PCDD and PCDF, and potential precursors to be destroyed. Simply blowing additional air into the secondary chamber is not sufficient to insure high combustion efficiencies. Consequently, great care must be taken in designing the secondary air chamber such that complete and thorough mixing will occur. One design approach to increase mixing currently in use is to introduce air at right angle to the flow of primary chamber gases and to use a series of staggered manifolds on either side of the gas. A second design approach is the enlargement of the secondary combustion chamber. This approach leads to greater residence times at temperature while also increasing the chance for mixing.

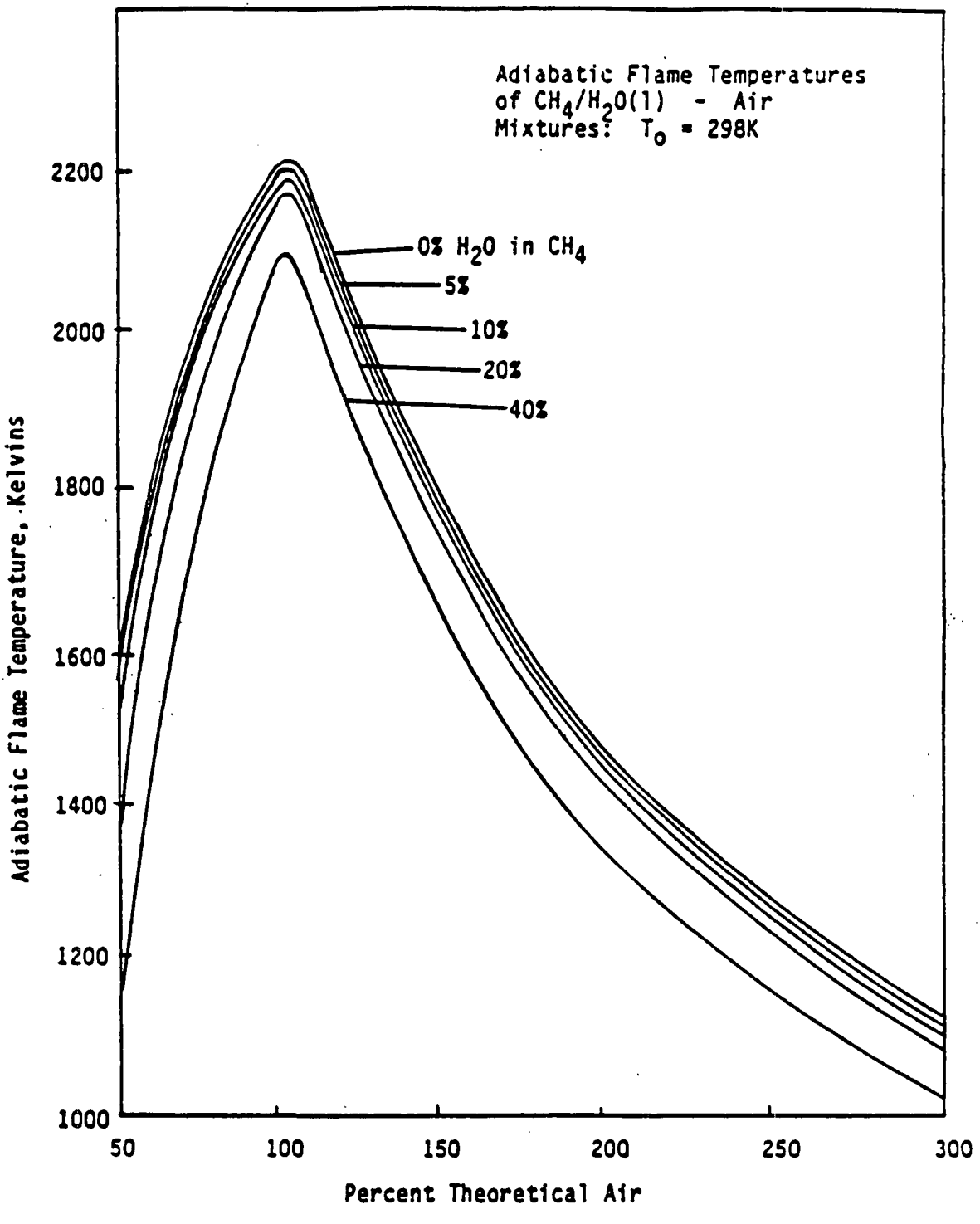
From an operational standpoint, the primary air flow rate control, proportionment of combustion air between the primary and secondary chambers, and the extent of mixing in the secondary chamber, all could have a significant impact on POM, PCDD and PCDF emissions. Further research is required to better understand how design and operating parameters influence these emissions.

4.2.4.5 Thermal Environment. In the EPA's Tier 4 study, it was observed that trends in PCDD and PCDF emissions could be detected based on

the combustion temperature (see Reference 9). It was also noted in this report that MSW incinerators burning high moisture content waste tended to have low combustion temperatures and higher PCDD/PCDF emissions. The following discussion considers the theoretical relationship between temperature and emission rates for PCDDs, PCDFs, and other POMs.

Thermal environment and chemical kinetic processes are intimately related to each other. Flame temperature rise is the result of chemically converting fuel to combustion products while the rate of the chemical reactions is exponentially dependent upon the local temperature. In the discussion of equilibrium considerations it was shown that formation of fuel-rich pockets of gas was an essential ingredient for production of POM, PCDD and PCDF. Figure 4-3 illustrated that the equilibrium total hydrocarbon concentration was less than 1 ppm for mixtures with more than 45 percent theoretical air. In the discussion of kinetic processes, Figure 4-4 showed that substantial hydrocarbons can persist in 80 percent theoretical air mixtures if there is heat extraction from the fuel-rich gases. Thus, removing heat from combusting gases tends to increase the stoichiometric ratio at which hydrocarbon species will persist.

An important set of variables influencing flame temperature is the excess oxygen level in the combustor and the moisture content of the waste. To illustrate these effects, a series of adiabatic flame temperature calculations were performed as a function of percent theoretical air. To demonstrate that flame temperature is controlled by combustion of waste volatile matter, methane was used as the fuel for these calculations. To simulate the moisture content of the waste, various quantities of liquid water (0-40 percent) was added to the "fuel." Results from these calculations are presented in Figure 4-7.[9] As shown, increasing the combustion air from 150 to 200 percent of the theoretical requirement decreases the adiabatic flame temperature by approximately 300°C (540°F). At 150 percent theoretical air (50 percent excess air), increasing the moisture content from 0 to 40 percent decreases the adiabatic flame temperature by approximately 150°C (270°F).



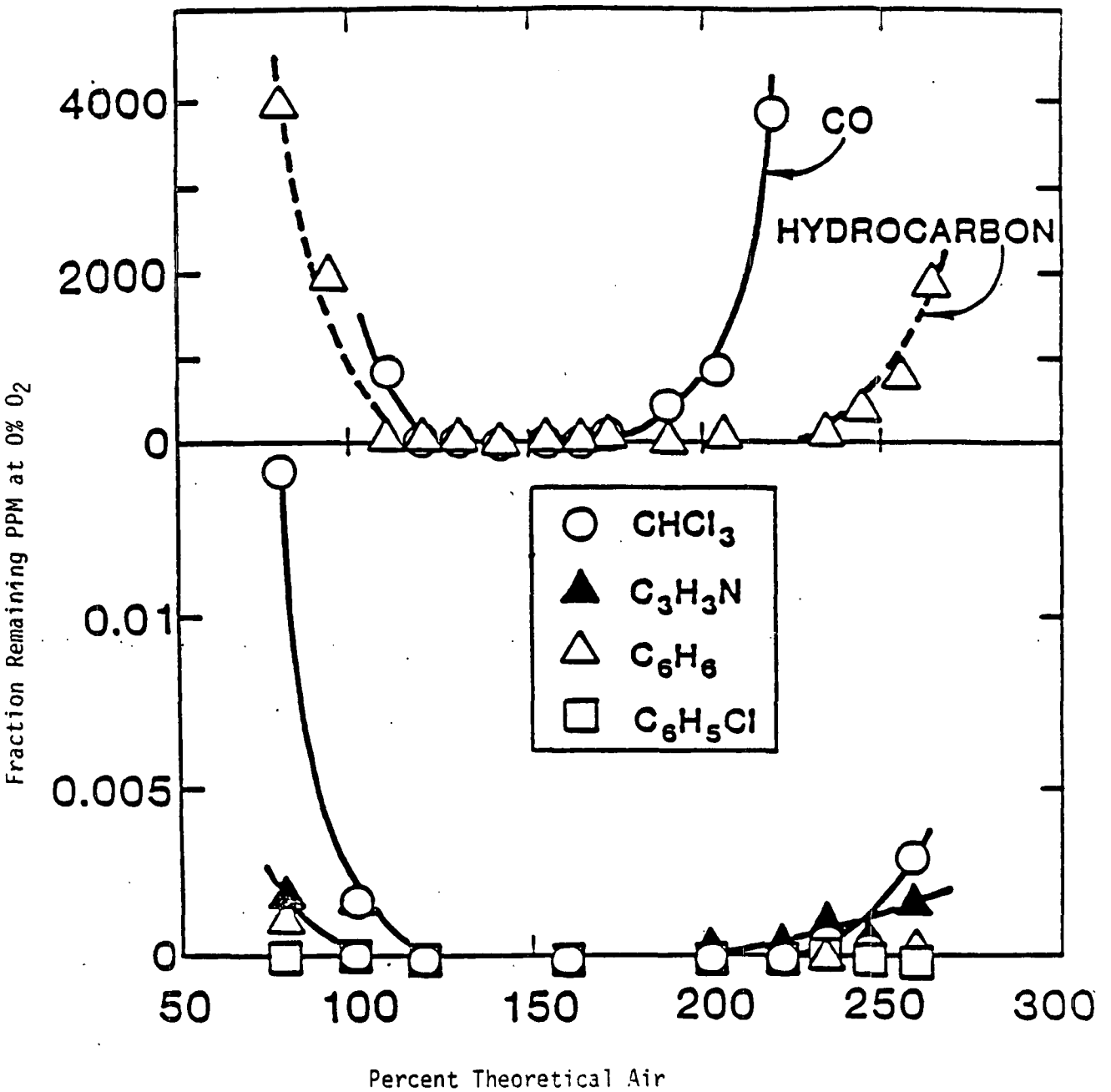
Source: Reference 9.

Figure 4-7. Variation of adiabatic flame temperature with percent theoretical air and percent moisture in the MSW.

The important operational consideration is to maintain the excess air in a range which is high enough to insure that oxygen is available for fuel burnout but low enough to prevent excessive depression of the flame temperature. The requirement for operation within an excess air window is illustrated in Figure 4-8 which shows the measured total hydrocarbons in the exhaust of a highly cooled laboratory furnace as a function of excess air level.[10] It should be noted that the data in this figure are hardware-specific and that the acceptable excess air operating window will vary with both incinerator design details and characteristics of the waste being burned (e.g., heating value, moisture content and halogen content).

The moisture content of hospital waste is dependent on the daily operation of the hospital. As illustrated in Figure 4-7, adjusting the excess air level can offset the thermal influence of large variations in moisture content. The thermal influence of adding 40 weight percent water to the fuel may be offset by decreasing excess air level by about 20 percent. From a combustion control standpoint, hardware could be developed to continuously monitor the exhaust gas H_2O content and that data used in a control system to appropriately adjust the excess air level. Research is required to define the proper mode of excess air control but it is likely that minimum POM, dioxin and furan emissions control would be achieved by adjusting excess air rates in the primary and secondary chambers.

An additional operational consideration influencing thermal environment and possibly having a major impact on POM, PCDD and PCDF emissions is the unit start-up procedure. Some facilities may have greatly different warm-up periods depending on operator awareness. Based on considerations presented earlier in this section, extensive warm-up using auxiliary fuel (natural gas or distillate oil) should be the preferable operating procedure. The start-up period may have little impact on steady-state emission rates but a substantial mass of POM, PCDD and PCDF could be emitted during start-up with cold walls. By the same token, sufficient air and temperature levels should be maintained during burn-down periods to assure complete combustion.



Source: Reference 10.

Figure 4-8. Hydrocarbon breakthrough as a function of percent theoretical air.

4.2.4.6 POM, Dioxin and Furan Summary. The above discussion illustrates that emissions of POM, PCDD and PCDF are the products of incomplete combustion. A critical component in the pollutant formation process is formation of fuel-rich pockets of gas. The primary combustion chamber in a controlled air incinerator is operated as a large fuel-rich pocket. To maximize the extent of combustion, the following steps can be taken:

- Control the combustion air supply to the primary chamber to minimize transients in the outlet flow rate and composition;
- Proportion combustion air between the primary and secondary chambers to maintain desired temperatures; and
- Promote efficient mixing of air and combustion gases in the secondary chamber.

Each of these combustion parameters are adjustable during the incinerator design and/or as part of the unit operating procedure. The assertion that PCDD and PCDF emission reduction can be achieved by combustion control is clear but the types of modifications likely to be effective will depend upon the specific design and operating conditions of a given model and size. That is, combustion modifications must be tailored to the specific type of incineration hardware under consideration. Appropriate control strategies for existing facilities must be evaluated on a case-by-case basis and some processes may require extensive hardware modification and/or altered operational procedures.

4.3 FLUE GAS CONTROLS

Add-on devices may be employed for post-combustion treatment of flue gas. As shown in Section 3.0, two devices presently in use on hospital incinerators are fabric filters (baghouses) and wet scrubbers. Due to

economic reasons, these techniques are presently only applied to units at the high end of the incinerator size range, if at all. Another potential add-on control not presently in use would be dry scrubbers. Dry scrubbers provide acid gas and organic emissions control and, when coupled with fabric filters, offer good particulate control as well. In addition, after-burners are potential controls for organic compound emissions.

4.3.1 Fabric Filters (Baghouses)

Fabric filters offer very high efficiencies for particle removal from flue gas with attainable efficiencies greater than 99.9 percent. At least one study concluded that baghouses are the best PM control device for refuse incinerators. Currently, there are at least four conventional incinerator installations utilizing baghouses in the U. S.[11] Similar efficiencies would be expected for hospital waste incinerators because of the similar nature of the wastes.

Fabric filters rely on porous glass fabric to facilitate removal of very fine PM. Figure 4-9 shows a typical arrangement. Collected PM is "shaken," either mechanically or by air, from the bag and disposed of with bottom ash from the incinerator. Some advantages and disadvantages of baghouses are as follows:[12]

Advantages

1. High PM removal efficiencies can be obtained.

2. High efficiencies for finer PM means good removal of those metals which concentrate on fine PM.

3. There are no wastewater disposal requirements.

4. Variations in flue gas flow rate or chemical composition do not usually affect fabric filter performance.

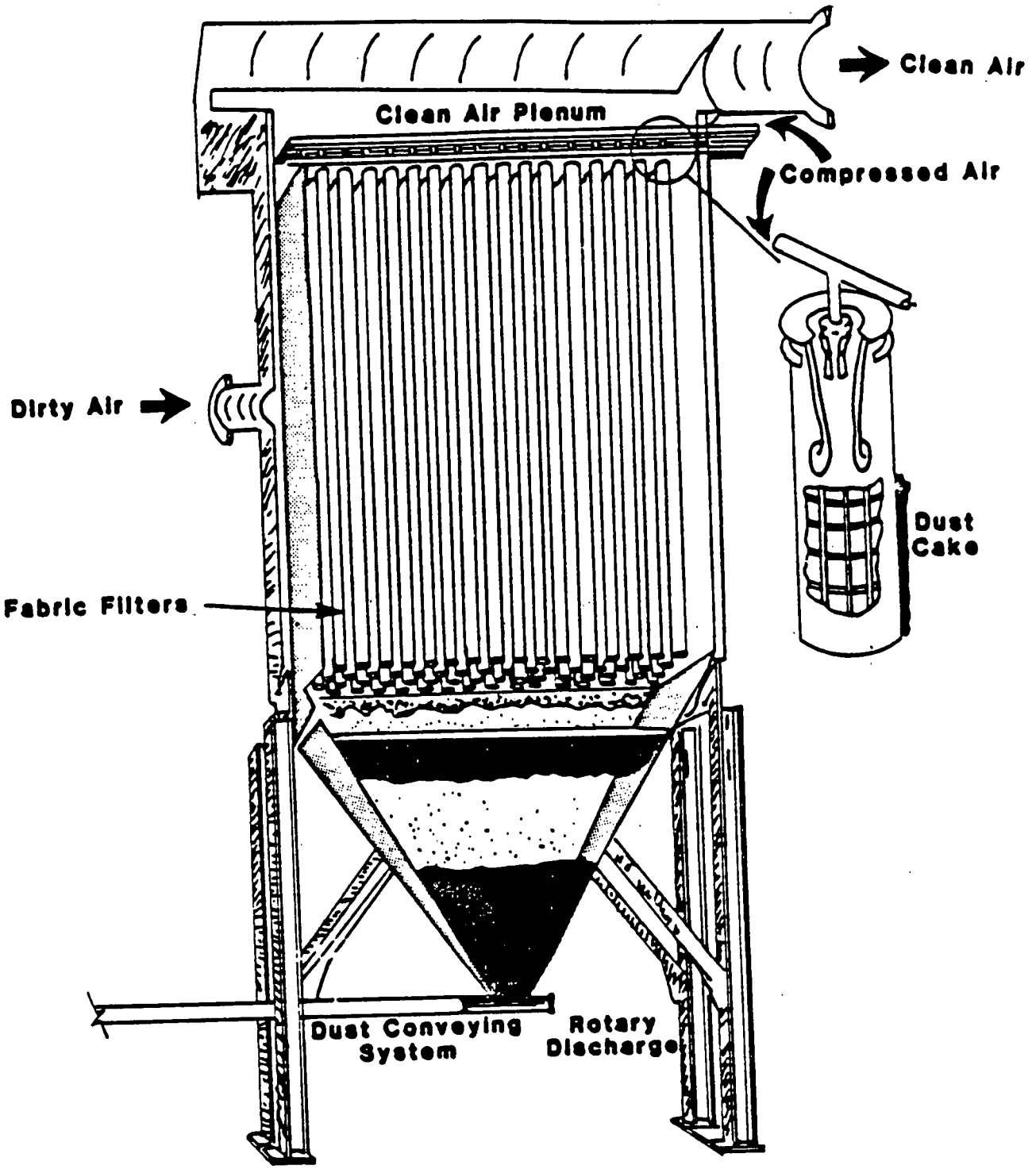


Figure 4-9. Typical fabric filter system.

5. Submicron particle collection improves as the thickness of the dust layer on the collection surface increases.

Disadvantages

1. Fabric filters are designed only for PM control and do little to control gaseous pollutants.

2. High pressure drops may occur if bags become plugged with solids which could lead to large power requirements.

3. The upper temperature limit of most widely used filter media is about 260°C (500°F).

4. Sparks carried by the flue gas can cause fires in the fabric filter.

5. The dew point of the flue gas must be considered. An excursion below the dew point can result in condensation and hence blinding of bags. In addition, due to the typically high HCl content of hospital waste incinerator flue gases, condensation can lead to the formation of corrosive HCl acid.

4.3.2 Scrubbers

Wet scrubbers currently in use offer lower efficiencies for the collection of PM but higher efficiencies for acid gas removal. Wet scrubbers basically use liquid to effect transfer of pollutants from a gas to a liquid stream. Scrubber design and the type of liquid solution used largely determine contaminant removal efficiencies. Plain water efficiencies for the removal of acid gases are in the range of 30 percent, while the addition of $Ca(OH)_2$ to the scrubber liquor has been shown to

result in efficiencies of 93-96 percent.[13] In general, high gas-side pressure drops must be used to obtain high efficiencies for PM control.

There are basically three types of wet scrubbers:

(1) low energy (spray tower),
(2) medium energy (impingement scrubbers such as packed column, baffle plate, and liquid impingement), and
(3) high energy (venturi).

Low energy scrubbers (spray towers) are usually circular in cross-section (see Figure 4-10). The liquid is sprayed down the tower as the gases rise. Large particles are removed by impingement on the liquor pool, and finer particles are removed as the flue gas rises through the tower. Low energy scrubbers mainly remove particles in the 5-10 micron range.[14]

Medium energy devices mostly rely on impingement to facilitate removal of PM. This can be accomplished through a variety of configurations, two of which are diagrammed in Figures 4-11 and 4-12.

High energy scrubbers utilize a venturi mechanism for PM removal (Figure 4-13). The flue gases impinge on the liquor stream in the venturi section. As the gases pass through the orifice, the shearing action atomizes the liquor into fine droplets. As the gas leaves the venturi section it decelerates, resulting in further contact between particles and liquid droplets. The droplets are then removed from the device by the centrifugal action in the de-entrainment section.[15]

Like baghouses, wet scrubbers offer both advantages and disadvantages. Some of the major advantages and disadvantages of wet scrubbers are:[16]

Advantages

1. Particle collection and gas absorption can be accomplished simultaneously with proper design.

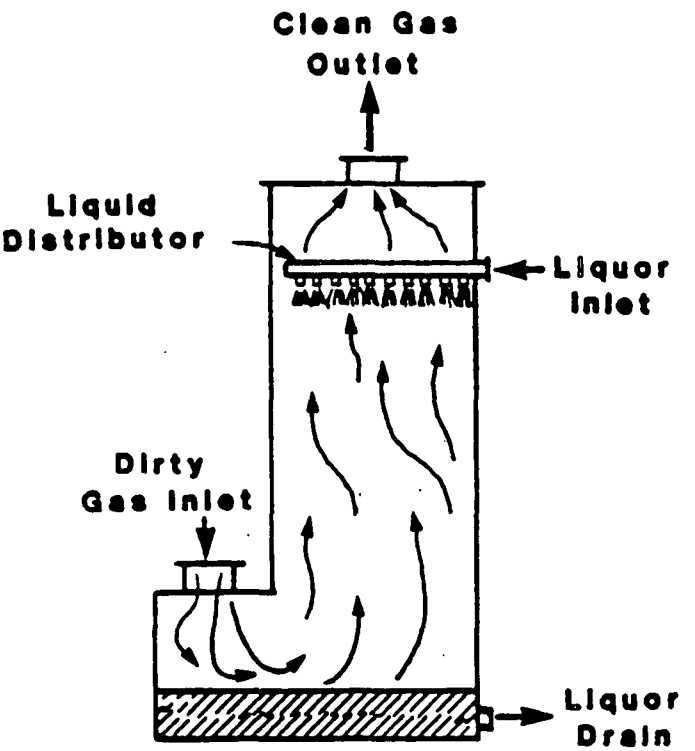


Figure 4-10. Open spray tower scrubber.

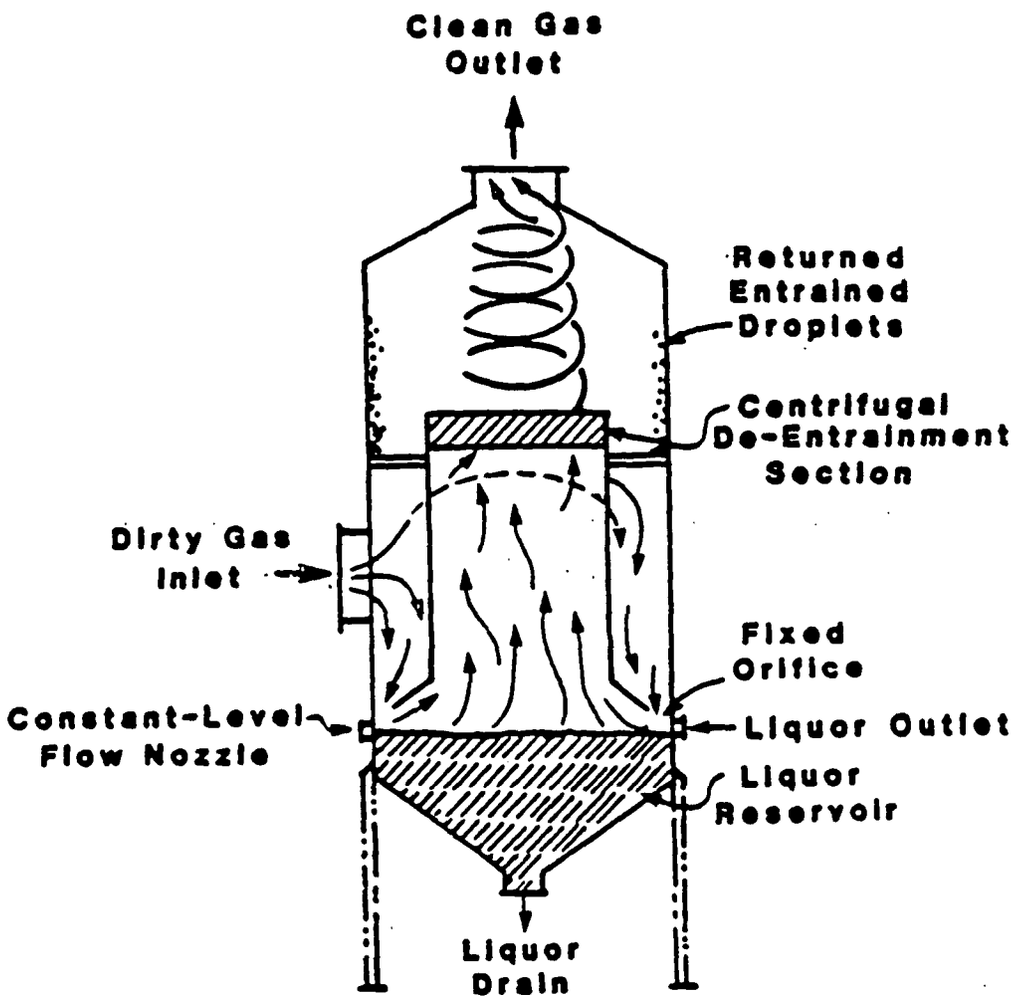


Figure 4-11. Fixed orifice scrubber.

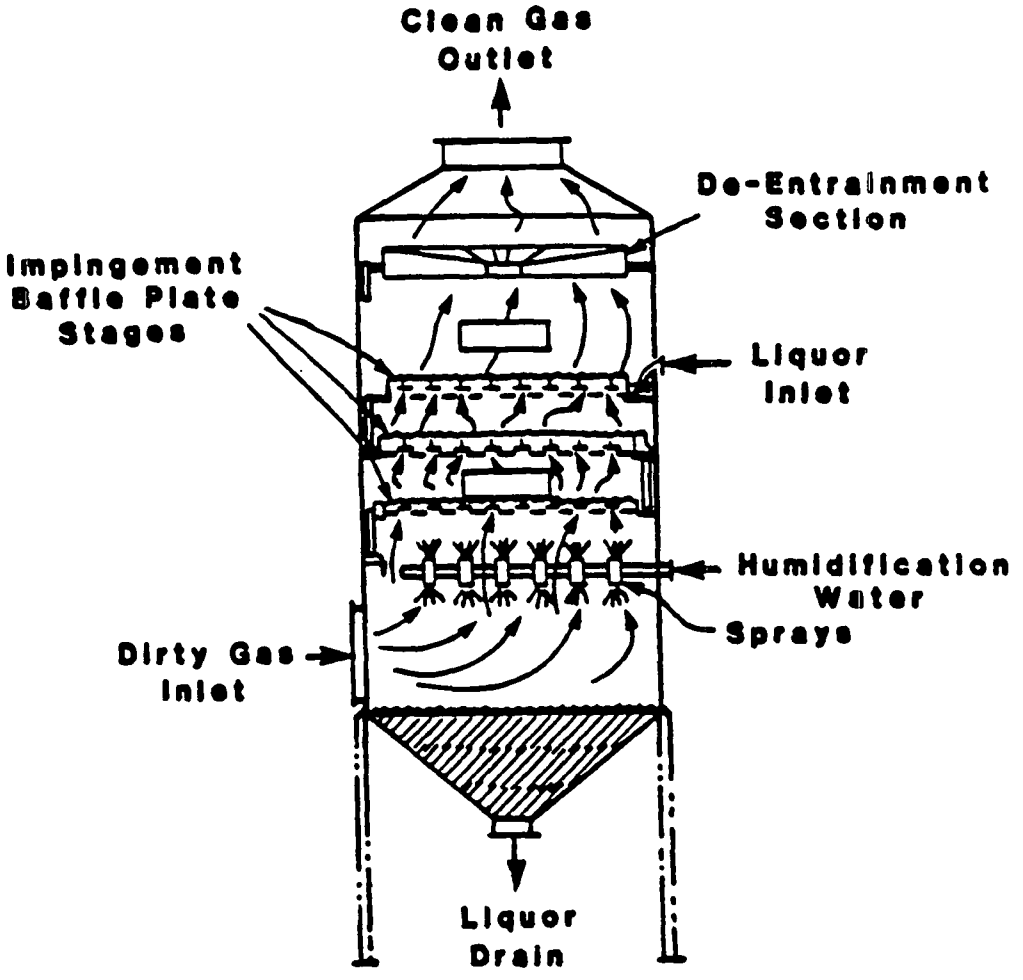


Figure 4-12. Baffle impingement scrubber.

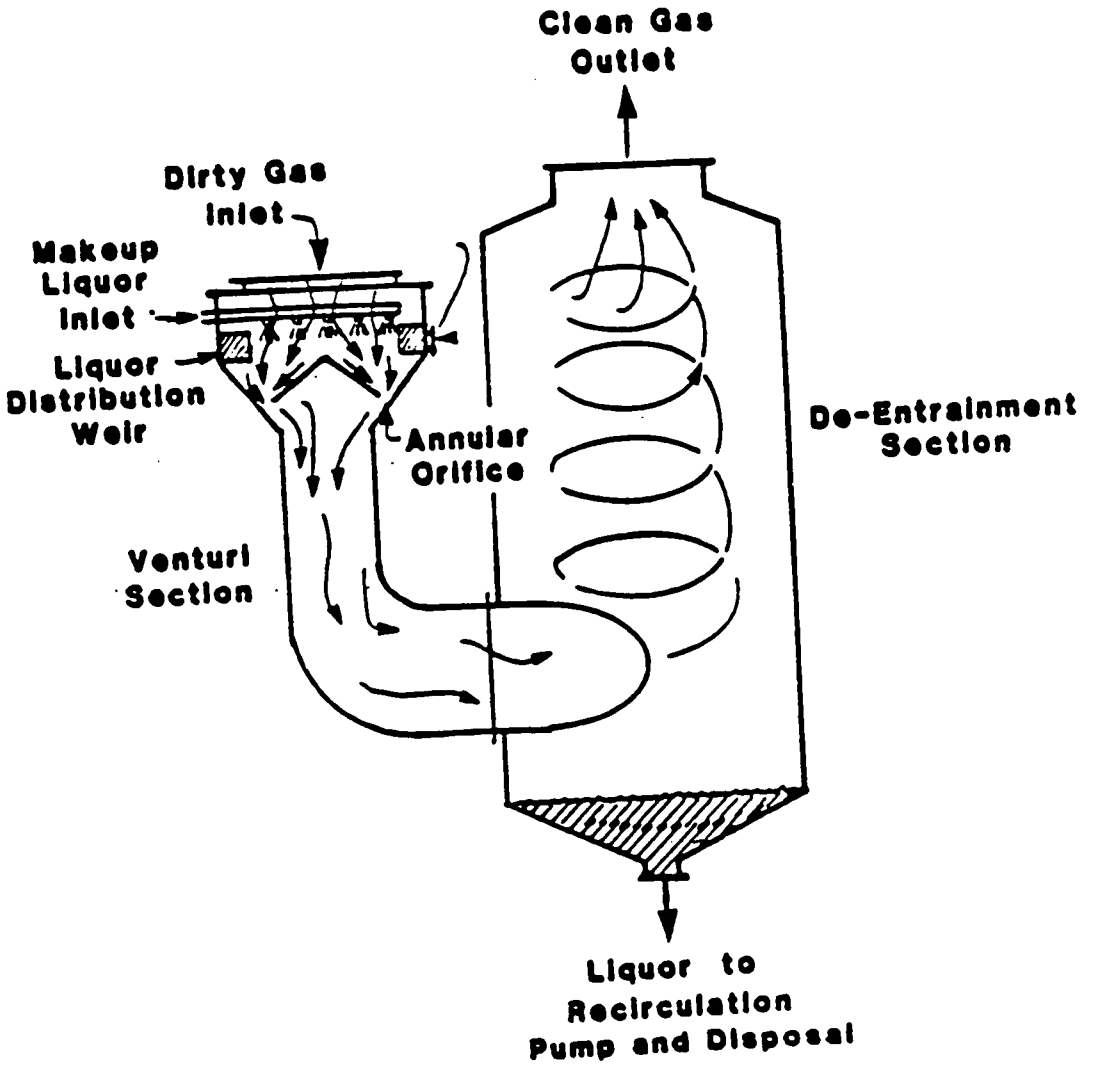


Figure 4-13. High energy venturi scrubber.

2. High collection efficiencies can be obtained for any particle size range with sufficient energy input.

3. Viscous materials can be collected without plugging.

4. High temperature gaseous effluent streams can be handled.

5. Moisture content and/or dew point of the effluent gas is not critical to scrubber operation.

6. Heat transfer, chemical reactions, and evaporation are characteristics of wet scrubber operations that can be varied to improve pollutant removal efficiencies.

7. Capital costs are relatively low.

Disadvantages

1. High energy input is required for collection of the finer dust particles.

2. Corrosion and erosion are characteristic of all wet processing.

3. An effluent liquor disposal system is required.

4. Discharge of a water-saturated gas stream can produce a visible steam plume.

5. Re-entrainment of PM may be a problem.

6. Wet scrubbers are not effective for control of insoluble gaseous organics.

Dry scrubbers combined with fabric filters applied to MSW incinerators have received considerable attention recently. In these systems, a lime slurry is injected into the scrubber where it contacts the flue gas. The water is evaporated and dry salts result from the reaction of lime with constituents of the flue gas. The salts, unreacted lime, and particulate matter are collected in fabric filters downstream of the reactor. It has been theorized that filter cake build-up provides available reaction sites for continued reaction with pollutants from the flue gas.

Test results from MSW incinerators for dry scrubbing/fabric filter systems show enhanced PM emission reduction in all particle size ranges compared to wet scrubbers operating with even larger pressure drops. Acid gas and metal removal efficiencies have also been high.[17-21] Also of interest are the low dioxin/furan emissions from the dry scrubbing system.

A diagram of a commercially available system, the Teller System, is shown in Figure 4-14.[22] In this system a dry venturi is located between the dry scrubber (quench reactor) and the baghouse. The dry venturi reportedly causes agglomeration of small particles formed in the dry scrubber which results in reduced pressure drop in the baghouse. This reduced pressure drop translates to longer cleaning cycles which are associated with higher removal efficiencies for small particles.

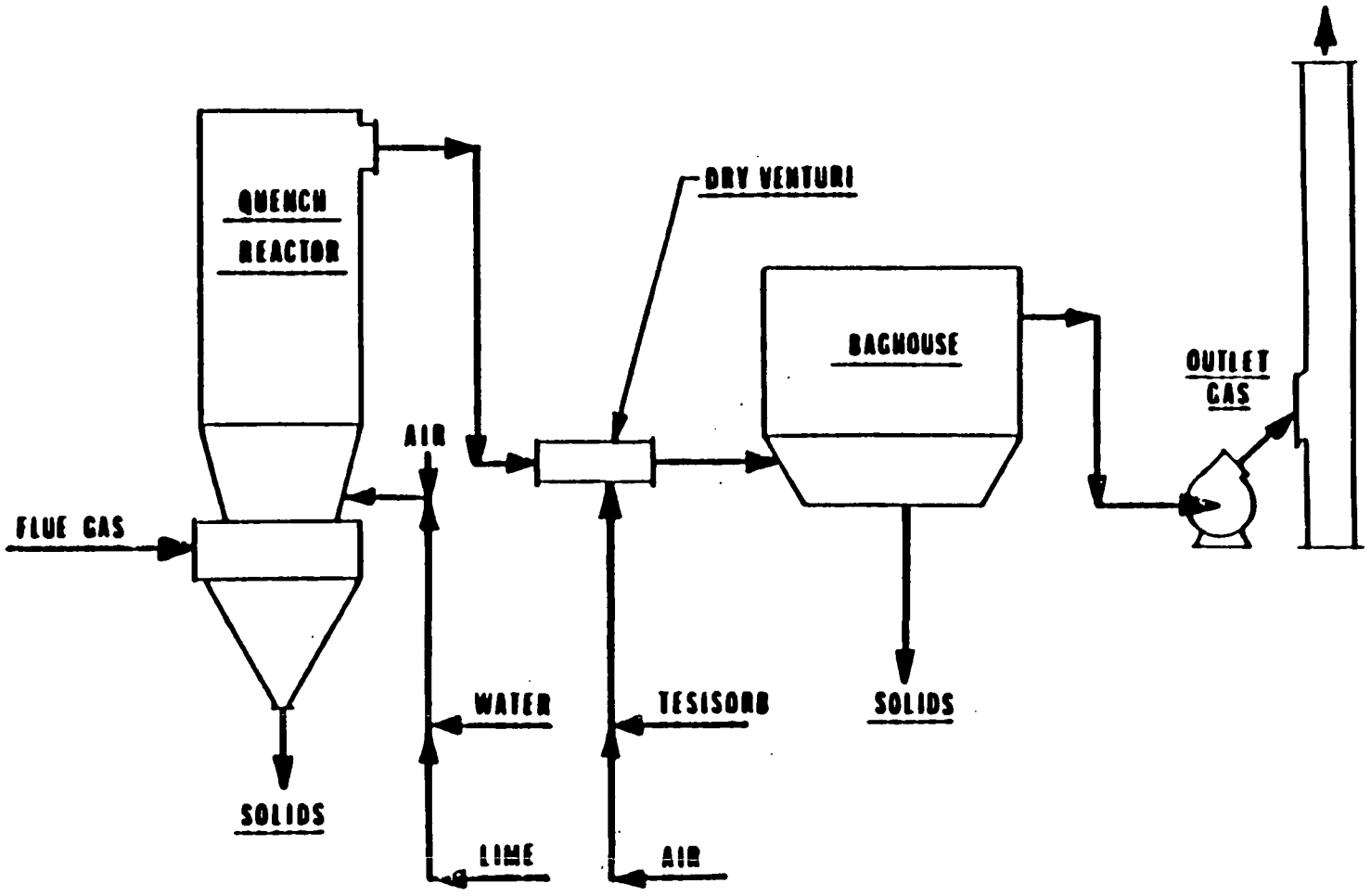
Advantages cited for dry scrubbing followed by fabric filtration include the following:

(1) Insensitive to changes in inlet particulate loading or characteristics within the combustion chamber.

(2) Effective and efficient particle capture in the submicron range.

(3) Efficient SO_2 and HCl removal.

(4) Produces agglomerated, dry particulates that can easily be disposed.



Source: Reference 23.

Figure 4-14. Teller dry scrubbing system.

(5) Because flue gas is not saturated with moisture, there is no visible plume exiting the stack.

(6) Reduction of organic emissions due to low operating temperatures.

Disadvantages cited include the following:

(1) Exit gases are reduced by an average of 180°F and this can affect gas plume rise, thus affecting pollutant dispersion.

(2) Reagents can be costly.

4.3.3 Afterburners

A third combustion chamber on some incinerators acts as an afterburner. This control device can be expected to further reduce organic emissions. The most likely location for such a device would be before the scrubber. Direct flame afterburners operating at a 2,000°F temperature and 1.0 second residence time can typically achieve greater than 98 percent destruction even for chlorinated organics.[23]

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5.0 REGULATORY STATUS AND STRATEGIES

Regulatory strategies in the United States to control air emissions from hospital waste incinerators have not been addressed to date at the Federal level but have been a focus of attention at the State level. Because of their relatively small size, emissions from hospital waste incinerators are not subject to Federal regulations which control emissions from larger MSW incinerators and solid waste-fired boilers. Instead, hospital waste incinerators are subject to a "patchwork quilt" of State and local guidance and regulations. Currently, most States recommend, but do not require, the control of particulate matter (PM) emissions and opacity for hospital waste incinerators. However, with the growing public concern over handling and disposal of hospital wastes, several States have developed emission limit regulations for incinerators which are now in the proposal stage.

This section discusses the current regulatory environment for hospital waste incinerators at both the Federal and State level. The information presented on State programs is accurate as of June 1987. However, due to the rapidly changing nature of these programs, this information is expected to become quickly out-of-date.

In addition to Federal and State regulations in the United States, this section also reviews regulations which have been established for hospital waste incineration in Canada and European countries.

5.1 FEDERAL REGULATIONS AND PROGRAMS

New Source Performance Standards

Hospital waste incinerators are not currently a source category subject to New Source Performance Standards (NSPS). However, they would be subject to NSPS for industrial, commercial, and institutional steam generating units (i.e., boilers) at 40 CFR Part 60 Subpart Db if units have a heat input capacity above 100 million Btu/hr and recover heat to generate steam or heat

water (or other heat transfer media). At 8,500 Btu per pound of Type 0 (see Table 1-3) waste, a hospital incinerator must be sized to feed over 11,700 lb/hr of waste to be subject to the boiler NSPS. The largest system offered for on-site hospital waste incineration is approximately 6,000 lb/hr capacity, and most units are well below this size. Hence hospital waste incinerators will not be impacted by the current boiler NSPS.

EPA is currently evaluating NSPS for smaller boilers with capacities below 100 million Btu/hr. The lower size cutoff is one of the factors to be determined during the rulemaking process although boilers as low as 10 million Btu/hr are being actively evaluated. A lower size cutoff below 50 million Btu/hr would affect at least a fraction of new, modified, or reconstructed hospital waste incinerators. The pollutants being evaluated for the small boiler NSPS are PM, opacity, NO_x, and SO_2. Proposal of this standard is scheduled for June 1989.

NSPS limiting PM emissions to 0.08 gr/dscf (equivalent to about 0.18 lb/million Btu) corrected to 12 percent CO_2 have been promulgated at 40 CFR Part 60 Subpart E for incinerators having a design capacity of 50 ton/day (i.e., 4,167 lb/hr) or greater and which burn more than 50 percent municipal type waste. This waste is defined as "waste consisting of a mixture of paper, wood, yard wastes, food wastes, plastics, leather, rubber, and other combustibles, and noncombustible materials such as glass and rock." Although hospital waste would seem to qualify under this definition, the size limit for Subpart E would apply to only the largest of hospital waste incinerators.

National Emission Standards for the Hazardous Air Pollutants

Of the 12 NESHAPs promulgated pursuant to Section 112 of the Clean Air Act, which address seven hazardous pollutants, none pertain to hospital incinerators.

Resource Conservation and Recovery Act Requirements

As a first step in fulfilling the Congressional mandate to establish a hazardous waste management system, EPA published proposed regulations in the Federal Register on December 18, 1978, which included a proposed definition and treatment methods for infectious waste.[1] During the public comment period for this rulemaking, EPA received approximately sixty comments which specifically addressed the infectious waste provisions of the proposed regulations.[2]

On May 19, 1980, EPA published the first phase of the hazardous waste regulations. The Agency stated in the preamble to the regulations that the sections on infectious waste would be published when work on treatment, storage, and disposal standards was completed. While the Agency has evaluated management techniques for infectious waste, considerable evidence that these wastes cause harm to human health and the environment is needed to support Federal rulemaking.[3]

Prevention or Significant Deterioration Requirements

Hospital waste incinerators are not among the 28 named prevention of significant deterioration (PSD) source categories. Even though waste generation rates vary among hospitals, emissions from incinerators are typically less than 250 tons per year. Therefore, in most states best available control technology (BACT) is not required for emitted pollutants. Pennsylvania is one of the few states that require BACT for all sources.

5.2 STATE REGULATIONS AND PROGRAMS

State Requirements for Waste Handling

Most states have requirements for licensing of hospital that may include general requirements for infectious waste disposal. Usually, these general requirements are limited in scope and do not apply to other sources

of infectious waste, such as crematoria.[4] The only restriction on the pathological or biomedical waste incinerators in many states is that they not create a public nuisance. That has meant that no odors are to be generated and that the opacity is to be low.[5]

A majority of states have passed hazardous waste legislation to control the treatment, storage, and disposal of infectious waste (as part of their hazardous waste program). Some states have already promulgated regulations controlling infectious waste, while other states are preparing such regulations. Since there is no unanimity of opinion on the hazards posed by infectious waste and appropriate techniques for safe disposal of these wastes, state control varies.[6] Most states do not have specific requirements for hospital incineration that limit pollutant air emissions.

To determine what efforts different states have taken to regulate infectious wastes, the National Solid Wastes Management Associations (NSWMA) Infectious Waste Task Force surveyed the state health and environmental agencies in January 1987. The general purpose of the survey was to determine where treatment and disposal of infectious waste are subject to regulations distinct from those that apply to municipal solid waste (MSW).[7] The survey's results indicated the following:[8]

- The solid waste and/or health departments in 28 states do define infectious waste items and subject these items to special rules or recommendations in management.

- Some states such as Massachusetts and Louisiana expect to revise their definitions soon to capture all generators of infectious wastes and not just hospitals.

- In general, hospitals and health-care facilities are prevented from disposing of wastes in a landfill without rendering the wastes non-infectious.

- Thirteen states have written or endorsed specific guidelines or requirements for transporting untreated infectious wastes.

State Air Emission Requirements

Radian has contacted several states to clarify their infectious waste management requirements; the information collected from the states is presented in Appendix A. The appendix contains an updated list of infectious waste regulations and requirements as well as a list of state offices that may be contacted for additional information. Where data were missing from non-contacted states, data available from the EPA Guide for Infectious Waste Management were listed. Most states did not list a specific regulation concerning the incineration of hospital or infectious waste.

Pennsylvania has recently established best available control technology guidance for hospital infectious waste incineration. These guidelines require stack emission limitations on particulate matter, carbon monoxide, hydrochloric acid and visible air contaminants. The guidelines are listed in Table 5-1 along with guideline emission limits set by New York, New Jersey, Connecticut, and Illinois.

State Air Toxics Programs

A majority of states and localities use some form of ambient guidelines or standards for the control of emissions of toxic air pollutants from hospital incinerators. Several states regulate new hospital waste incinerators in a manner similar to that required by the Resource Conservation and Recovery Act (RCRA) hazardous waste incineration regulations, i.e.; 100 ppm CO, 90% control or 4 lb/hr HCl emissions, and 0.08 gr/dscf (corrected to 12 percent CO_2) for particulates.[9] The city of Philadelphia is requiring that new hospital incinerators have scrubbers, which are used to control acid gases and toxic air contaminants.[10]

The State of Pennsylvania also requires ambient impact analyses for arsenic, cadmium, hexavalent chromium, lead, mercury, nickel, polychlorinated dibenzo-p-dioxins, and polychlorinated dibenzofurans. The acceptable ambient air concentrations for these pollutants are listed in

TABLE 5-1. GUIDELINE EMISSION LIMITS FOR INCINERATORS BURNING HOSPITAL WASTE[a]

State/Facility	Pollutant				
	Particulate Matter	Opacity	HCl	CO	SO_2
New York	0.10 gr/dscf (at 12% CO_2)	hourly average <10%; maximum continuous 6-minute average <20%	--	--	--
Pennsylvania (Facility with capacity ≤300 lb/hr)	0.08 gr/dscf (at 12% CO_2)	hourly average <10%; maximum continuous 3-minute average <30%	<4 lb/hr or shall be reduced by 90% by weight	100 ppmv hourly average (at 7% O_2)	--
Pennsylvania (Facility with capacity >300 lb/hr, ≤1000 lb/hr)	0.02 gr/dscf (at 7% O_2)	hourly average <10%; maximum continuous 3-minute average <30%	30 ppmv hourly average (at 7% O_2) or shall be reduced by 90% by weight	100 ppmv hourly average (at 7% O_2)	30 ppmv hourly average (at 7% O_2) or shall be reduced by 70% by weight
Pennsylvania (Facility with capacity >1000 lb/hr)	0.015 gr/dscf (at 7% O_2)	hourly average <10%; maximum continuous 3-minute average <30%	30 ppmv hourly average (at 7% O_2) or shall be reduced by 90% by weight	100 ppmv hourly average (at 7% O_2)	30 ppmv hourly average (at 7% O_2) or shall be reduced by 70% by weight
New Jersey	0.02 gr/dscf (at 12% CO_2)	--	--	--	--
Connecticut	0.02 gr/dscf (at 12% CO_2)	--	--	--	--
Illinois (Facility with capacity >6000 lb/hr)	0.05 gr/scf (at 12% CO_2)	30%	--	--	--
Illinois (Facility with capacity >2000 lb/hr, <6000 lb/hr)	0.08 gr/scf (at 12% CO_2)	30%	--	500 ppm at 50% excess air	--
Illinois (Facility with capacity <2000 lb/hr)	0.1-0.20 gr/scf (at 12% CO_2)	30%	--	--	--

[a]References 15-19.

Table 5-2. The values listed were extracted from data submitted by State agencies to Radian Corporation for this study.

The State of New York has drafted operating guidelines for hospital waste combustion. These guidelines require stack emission limitations for particulate matter, carbon monoxide, hydrochloric acid, and visible air contaminants. Also, continuous monitoring and recording of temperature in the secondary chamber are required to show an exit temperature of at least $1600^{o}F$.

New York State generally requires emission tests for priority pollutant plus 10 toxic air contaminants (including dioxins). In addition, the State requires demonstration of compliance with acceptable ambient air quality levels for toxic air contaminants (or acceptable risk assessments for carcinogens) under its Air Guide policy (see Table 5-2).[11,12]

In the State of California each local air quality district can establish its own emission limit requirements. Presently, guidelines on emission limits MSW and hazardous waste facilities are serving as guidelines for hospital waste incineration. However, California is in the process of developing new restrictions that pertain directly to hospital waste incineration.

5.3 FOREIGN REGULATIONS

In Canada, air pollution regulations are established by each provincial government. Table 5-3 lists emission limits established in Alberta, Canada and technical requirements established in European countries. This study did not include the investigation per se of foreign procedures or regulations. However, the data presented in Table 5-3 were extracted from References 13 and 14.

TABLE 5-2. ACCEPTABLE ANNUAL AMBIENT CONCENTRATIONS REPORTED FOR SELECTED POLLUTANTS[a]

Metal/Compound	Pennsylvania	New York
Arsenic and Compounds	0.23×10^{-3}	0.67
Cadmium and Compounds	0.56×10^{-3}	2.0
Hexavalent Chromium and Compounds	0.83×10^{-4}	0.167
Lead and Compounds	0.50	1.5[b]
Mercury and Compounds	0.08	0.167
Nickel and Compounds	0.33×10^{-2}	3.3
2,3,7,8-TCDD[c]	0.30×10^{-7}	-[d]

[a]References 20 and 21; all concentrations in ug/m^3.

[b]Federal standard for lead; not yet officially adopted by New York State, but currently being applied to determine compliance status.

[c]Tetrachlorinated dibenzo-p-dioxin equivalents

[d]Emission sources of chlorinated dibenzofurans and dibenzodioxins are reviewed on a case-by-case basis by the Department of Health (DOH). The NY State DOH has determined that basing an acceptable ambient level on TCDDs does not adequately represent public health risks for the dioxin compounds.

TABLE 5-3. FOREIGN EMISSION REGULATIONS FOR HOSPITAL WASTE[a]

Pollutant	Alberta, Canada	European[a]
Particulate matter	0.20 kg/1000 kg of gaseous effluent[b]	200 mg/Nm^3 dry at 7% CO_2 maximum
	0.60 kg/1000 kg of gaseous effluent[c]	--
HCl	100 ppm at 50% excess air	300 mg/Nm^3 dry at 7% CO_2 maximum
CO	--	500 mg/Nm^3 dry at 7% CO_2 maximum
SO_2	--	200 mg/Nm^3 dry at 7% CO_2 maximum
HF	--	5 mg/Nm^3 dry at 7% CO_2 maximum
Opacity	--	Not to exceed 30%

[a]References 22 and 23.

[b]For incinerators with a capacity of greater than 227 kg/h.

[c]For incinerators with a capacity of less than 227 kg/h.

5.4 REFERENCES

1. EPA Guide for Infectious Waste Management. Office of Solid Waste and Emergency Response. EPA-530/SW-86-014 Washington, DC. May, 1986.

2. Reference 1.

3. Reference 1, p. VI.

4. Referece 1, p. 1-3.

5. Vogg H., Metzger M., Stieglitz E., "Recent Findings on the Formation and Decomposition of PCDD/PCDF in Solid Municipal Waste Incineration" presented at International Solid Waste and Public Cleansing Association specialized seminar on Emissions of Halogenated Organics form Municipal Solid Waste Incineration, January 22, 1987, Copenhagen, Denmark.

6. Reference 1, p. 1-3.

7. Pettit, C. L., "Infectious Waste State Programs Survey." Waste Age, April 1987, pp. 115-128.

8. Reference 7.

9. Reference 5.

10. Lauber, J.D., "Controlled Commercial/Regional Incineration of Biomedical Wastes." Presented at the Incineration of Low Level Radioactive and Mixed Wastes, 1987 Conference, St. Charles, Illinois, April 21-24, 1987.

11. Reference 10.

12. New York State Air-Guide-1. N.Y.S. Department of Environmental Conservation 1985-86 Edition, July, 1986 printing.

13. Powell, F.C., "Air Polutant Emission from the Incineration of Hospital Wastes, The Alberts Experience." J. Air Pollution Control Association, Vol. 37, No. 7, July 1987.

14. Faurholdt, B., "European Experience with Incineration of Hazardous and Pathological Wastes." Presented at the 80th Annual Meeting of the Air Pollution Control Association, New York, New York, June 21-26, 1987.

15. BAT and Chapter 127 Plan Approval Criteria Hospital/Infectious Waste Incinerators, Draft. Pennsylvania Department of Environmental Resource Bureau of Air Quality Control. Harrisburg, P.A. June 9, 1987.

16. Regulation of Medical Care Waste - Incineration Memorandum from Mr. Hovey (Originiator: W. Sonntag). New York State Department of Environmental Conservation. Albany, NY, January 1, 1987.

17. Reference 10, p. 14.

18. Environmental Register No. 230: Proceedings of Illinois Pollution Control Board, December 18, 1980.

19. U.S. Environmental Protection Agency, Federal Register 39:20792, 1974.

20. Reference 15.

21. Reference 12, p. 27 to 31.

22. Reference 13, p. 837 to 838.

23. Reference 14, p. 0-4.

6.0 HOSPITAL WASTE INCINERATOR MODEL PLANTS

One of the objectives of this study was to develop input parameters for modeling hospital incinerator units. The parameters developed in this study will be used as inputs to EPA's Human Exposure Model (HEM). Results of the HEM analysis will then be used to provide a preliminary estimate of chronic exposure to emissions from hospital waste incinerators. This objective was accomplished by developing input data for model incinerators which are felt to be representative of the general population instead of using actual hospital incinerator sites and stack parameters. This approach was taken because of the difficulty involved in characterizing the capacity and location of all hospital incinerators on a national level.

The approach used was to analyze a segment of the population for which detailed information could be obtained regarding unit capacity, stack parameters, and operation. In this case, a recent database of hospital incinerators in the State of New York was located during the study and used as a population segment. Through analysis of the distribution of incinerator capacities in the New York population, model plants were identified. The appropriate stack parameters (height, diameter, gas velocity, and temperature) were then determined by further evaluation of this data set. Finally the emissions factors of Section 3.0 were applied to to these model plants to estimate the short term and long term emissions rates.

This section contains a brief discussion of the relationship between hospital populations and incinerator populations. Next, the model incinerator capacities and stack parameters are determined. Finally, the corresponding emissions rates for pollutants of concern are presented for the model plants.

6.1 POPULATION CHARACTERISTICS

As discussed in Section 1.1, there are currently over 6,000 hospitals in the United States (US) and it is estimated that over 90 percent of these

facilities operate incinerator equipment of some kind, if only a small retort-type unit. The population of controlled air incinerators is smaller but still substantial. The development of a national inventory of hospital incinerators was not feasible for this study. Instead, an analysis of a subset of the population for which the necessary information was available was performed. A recent New York (NY) State database was located during the study which contained information gained through an in-state survey of incinerator units.[1] This database contained unit size, location, annual operation, and stack parameters for 433 incinerators located in NY.

To estimate the "representativeness" of the NY hospital population relative to the US population, the distribution of hospital sizes was examined. The distribution of hospital sizes according to bed number is presented for both NY and the US in Figure 6-1.[2] Both these distributions have similar shapes for hospital sizes between 0 and 500 beds. There is a greater proportion of hospitals above the 500 bed size in NY than in the US population. This is probably due to the fact that NY has several densely populated areas. Therefore, a model incinerator capacity which corresponds to hospitals with greater than 500 beds is needed since there are several densely populated areas in the U.S. and the potential impact of these incinerator units on the associated populations will likely be of interest to EPA.

No information was found during this study which relates hospital size to the use of incinerator or to incinerator capacity. Therefore, a correlation between hospital size and incinerator capacity could not be developed. A study of the population distribution of incinerator units within the NY incinerator database was therefore undertaken. Figure 6-2 presents the results of this investigation. As shown, 59.6 percent of the population are units with design feed capacities of less than 200 lb/hr. Assuming that there is some correlation between hospital size and incinerator capacity this would indicate that an even greater majority of the national population of incinerators have capacities in this range. A model incinerator should therefore be chosen from within the less than 200 lb/hr capacity range.

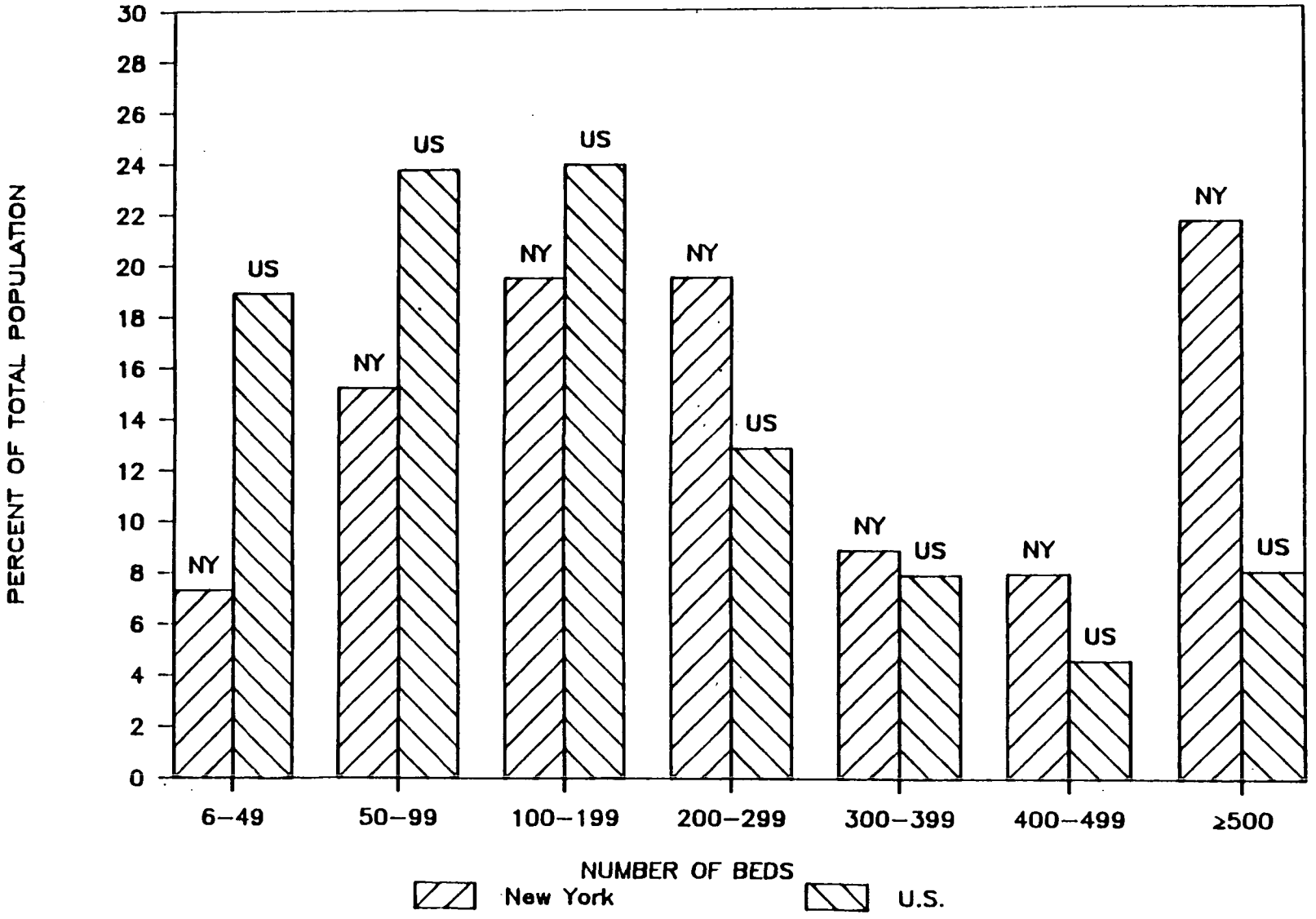

Figure 6-1. Distribution of hospital sizes according to bed number.

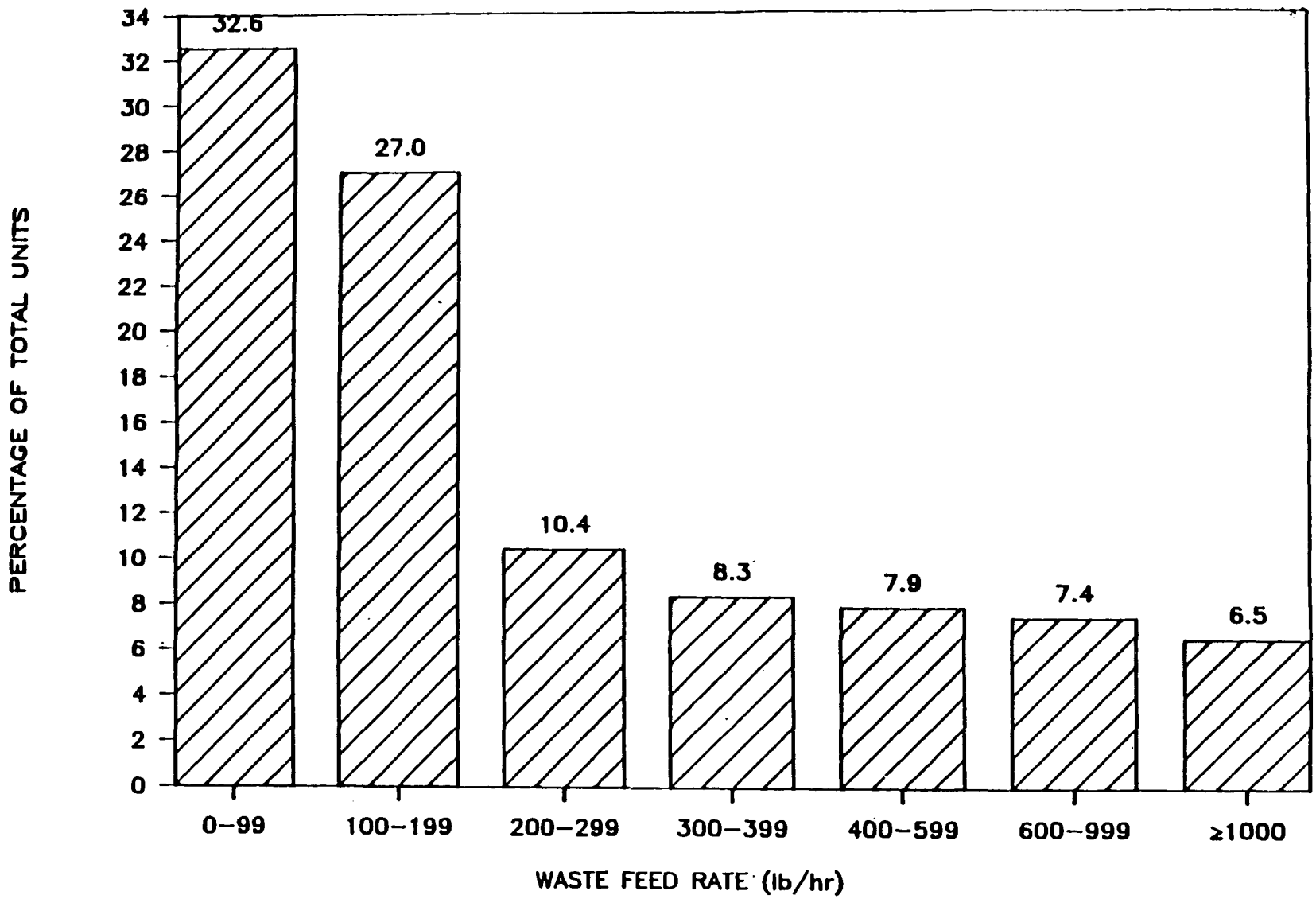

Figure 6-2. Distribution of incinerator units in N.Y. database according to selected waste feed rate ranges.

A further breakdown of the NY incinerator population by unit capacity is shown in Figure 6-3. As can be seen, the population is bimodal in this capacity range with peaks for units between 50 and 74 lb/hr and 100 and 124 lb/hr. A detailed analysis of these two size ranges reveals that the majority of units in each of the ranges are 50 and 100 lb/hr, respectively. Since a 100 lb/hr feed rate is closer to the median of this population segment than the 50 lb/hr feed rate, a model incinerator of 100 lb/hr capacity was chosen to represent the small incinerator population.

A study of the capacity distribution for the incinerators in the NY database was also undertaken. Figure 6-4 presents the results of this investigation. As can be seen, incinerator units which burn 1,000 lb/hr or greater make up 33.5 percent of the incineration capacity. Units which burn 600 lb/hr or greater make up 52 percent of the incineration capacity. A model unit size of 1,000 lb/hr was chosen to represent this half of the incineration population. The 1,000 lb/hr model size was chosen because it represents the median point within the population of units with feed rates of 600 lb/hr or above (see Figure 6-2) and is an order of magnitude greater than the 100 lb/hr model incinerator capacity.

6.1.1 Model Incinerator Stack Parameters

The stack parameters required as inputs to the HEM include stack height, diameter, and exit gas temperature and velocity. The NY incinerator database was used to determine values for each of these stack parameters. The approach taken was to evaluate a given stack parameter as a function of the previously presented incinerator capacity ranges of Figure 6-2. From this analysis, the variation of a given parameter was evaluated as a function of unit capacity. If the given stack parameter appeared to be a function of unit capacity, then a value based on units in a similar capacity range to the model was chosen. If the parameter of interest was not a function of unit size, then a mean value based on the entire population of units was used.

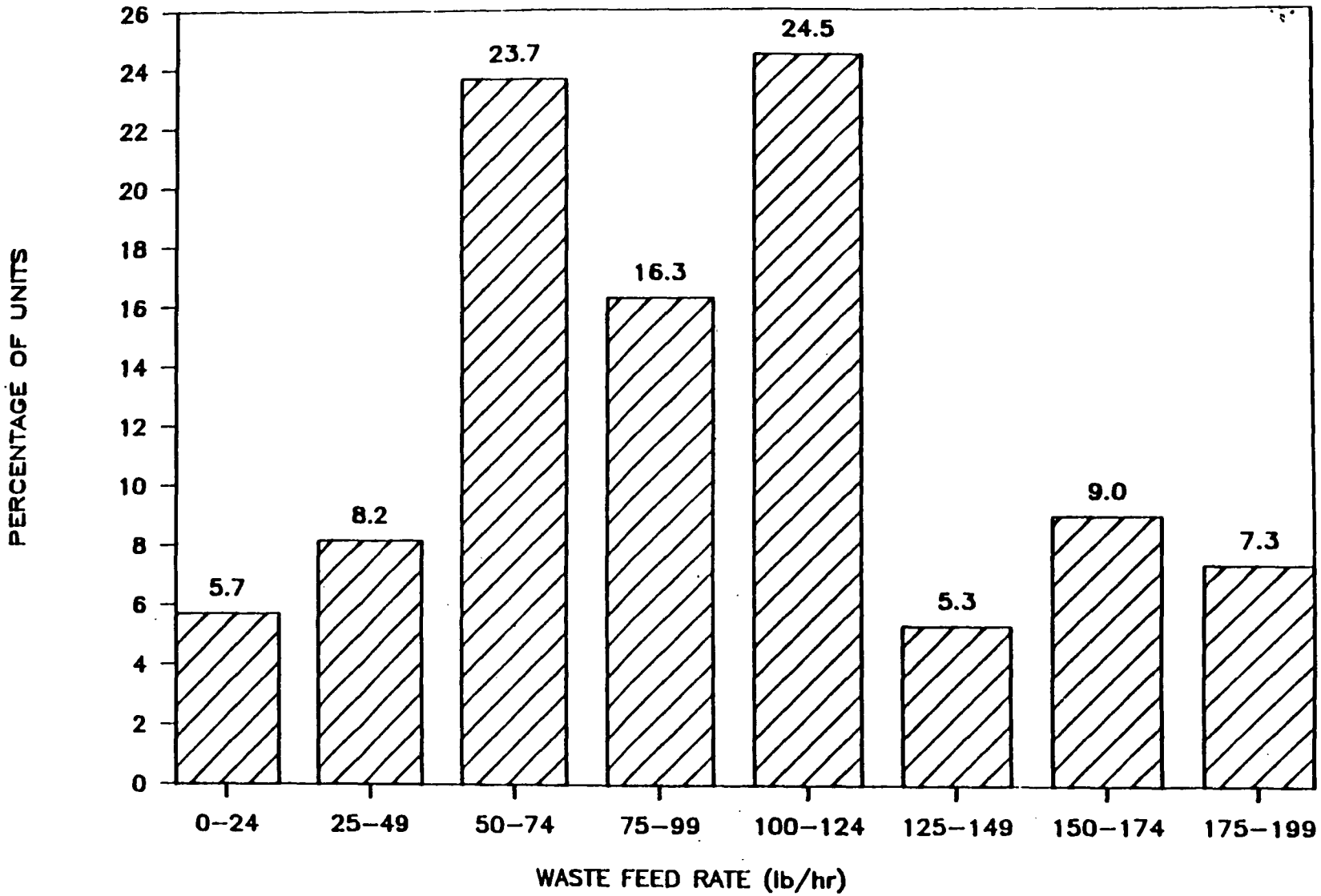

Figure 6-3. Distribution of incinerator units in N.Y. database with waste feed rates less than 200 lb/hr according to selected feed rate ranges.

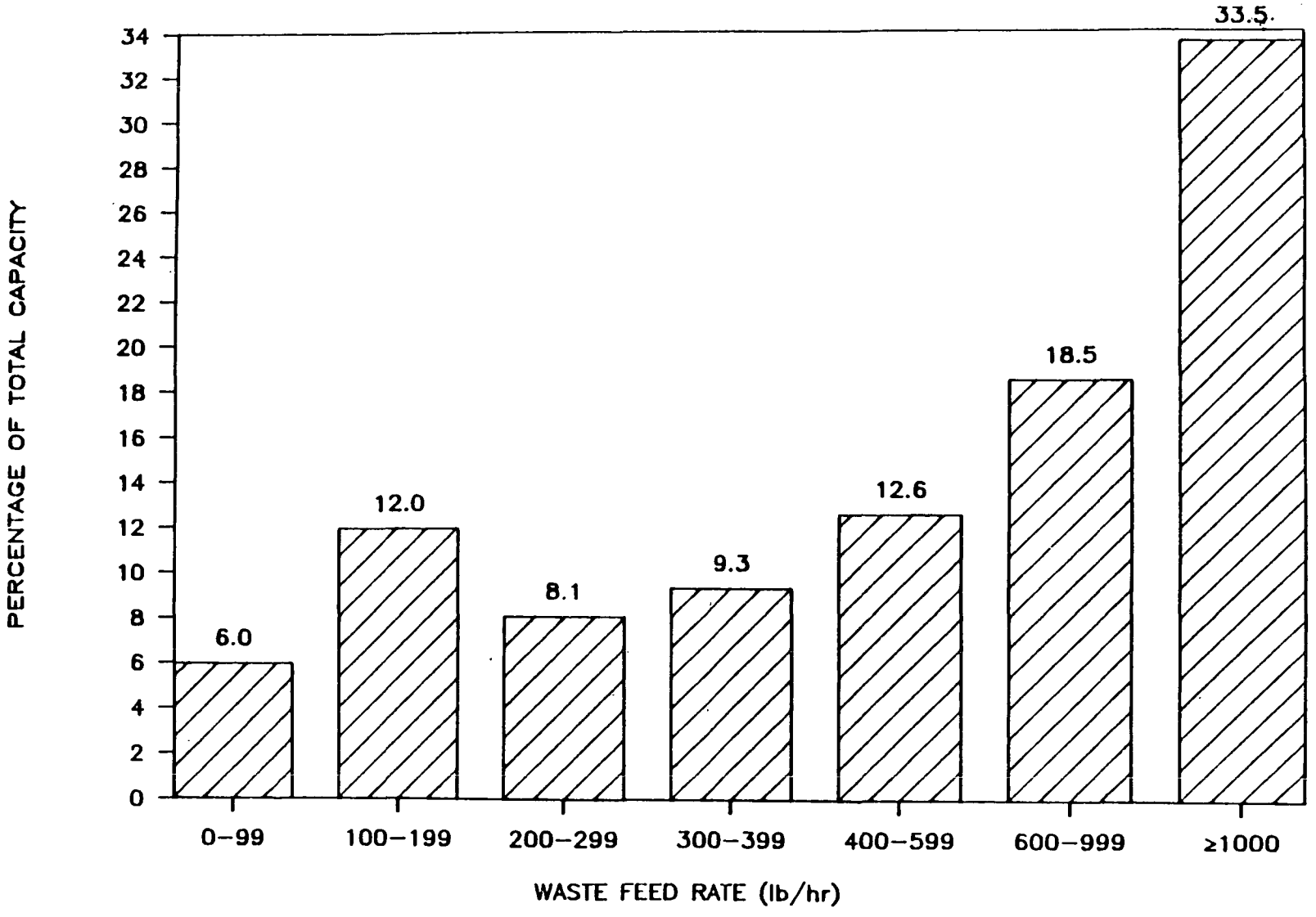

Figure 6-4. Capacity distribution of incinerator units in N.Y. database according to selected feed rate ranges.

Stack Height. The average, high, and low stack height values for a given feed rate range are shown as a function of feed rate ranges in Figure 6-5. The data shown are for incinerators with feed rates ranging from 1 to 2,700 lb/hr. As can be seen, stack heights vary greatly within a given capacity range. In fact, within a given capacity range, low stack height values of 8 feet were observed within the database. Although this height appears to be unrealistic, no reasons were identified which could be used to discount its use. One possible explanation is that this is the height of the stack above the nearest adjacent building and not above the base of the incinerator. Its inclusion as part of an average value for HEM modeling purposes should not be a concern, however, because of its conservative effect on the stack height estimates. A lower stack height should correspond to higher exposure levels for the population and therefore a conservative estimate of the associated risk.

The results presented in Figure 6-5 show little variation in the average stack height across the range of unit capacities. The highest of the average stack heights is 87 feet and the lowest is 66 feet. An average stack height of 78 feet is therefore recommended as the HEM input value regardless of unit size.

Stack Gas Temperature. The average, high, and low exhaust gas temperature values within a given feed rate range are shown as a function of feed rate ranges in Figure 6-6. As can be seen, the low in all cases is 400^{o}F. Analysis of the NY database indicated several vent streams with exit gas temperatures of less than 400^{o}F. Because it was known that outlet temperatures for units which have heat recovery equipment are limited to approximately 400^{o}F by the stack gas dew point, units with exit gas temperatures which were below 400^{o}F were excluded from analysis. A high value of 2,220^{o}F is shown. Little variation is seen in the average exhaust gas temperatures over the entire capacity range. For the entire population, the high value of the average temperatures is 1,237^{o}F and the low value is 1,081^{o}F. The average stack gas temperature for the entire database is 1,144^{o}F. This temperature is recommended for both the 100 and 1,000 lb/hr model incinerators. Because heat recovery is known to be employed on larger

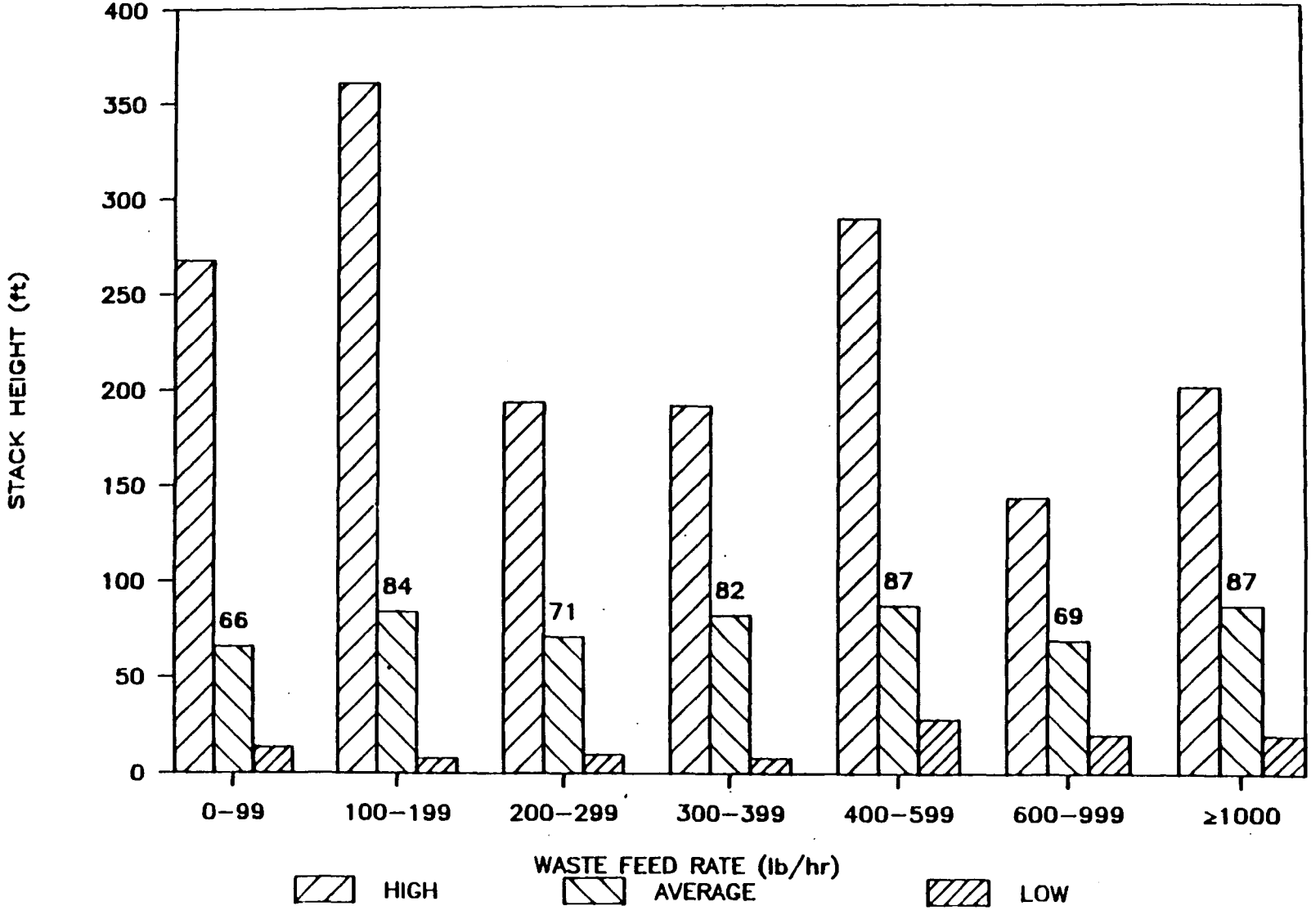

Figure 6-5. Average, high and low stack heights according to selected feed rate ranges.

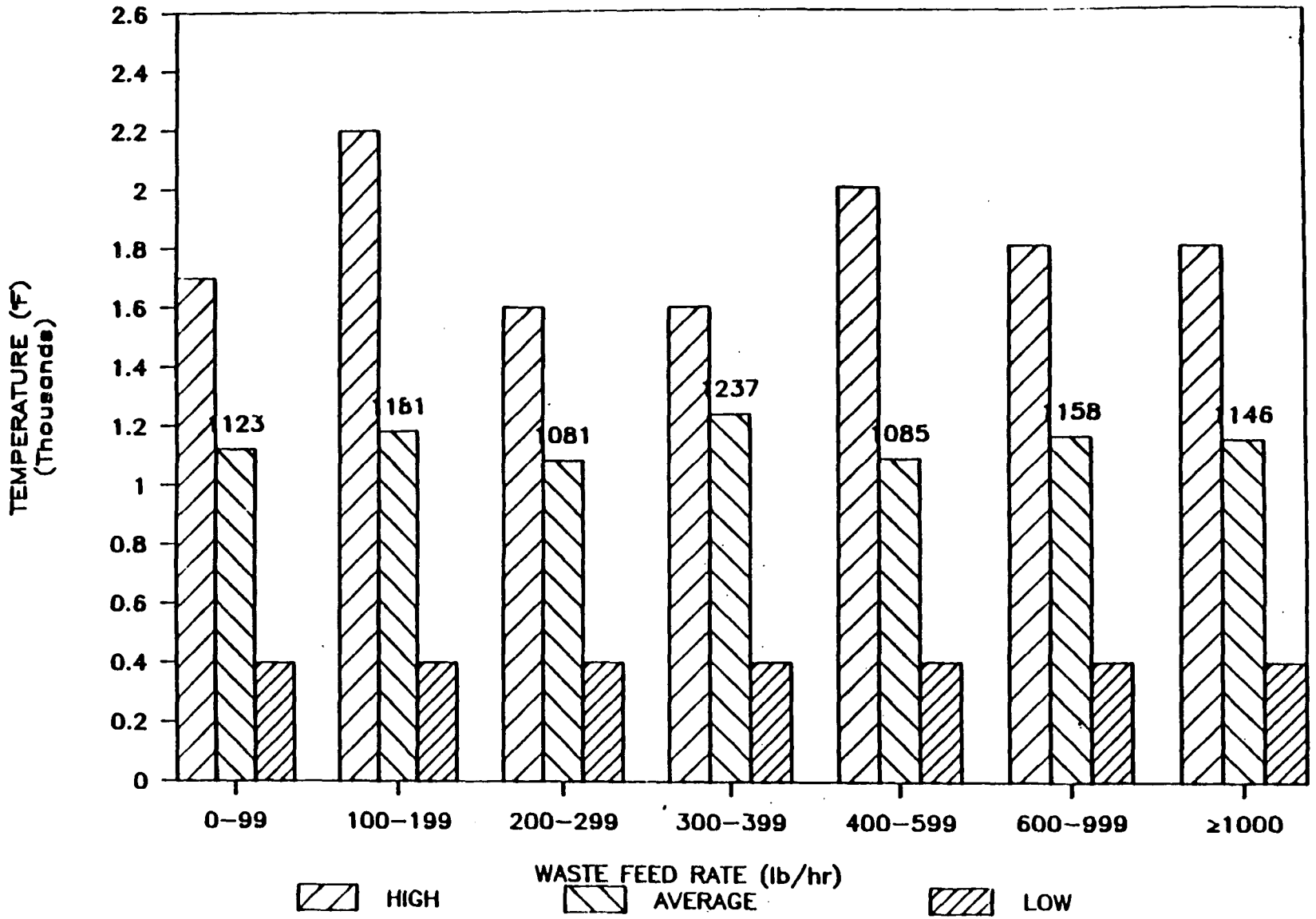

Figure 6-6. Average, high and low stack gas exit temperature according to selected feed rate ranges.

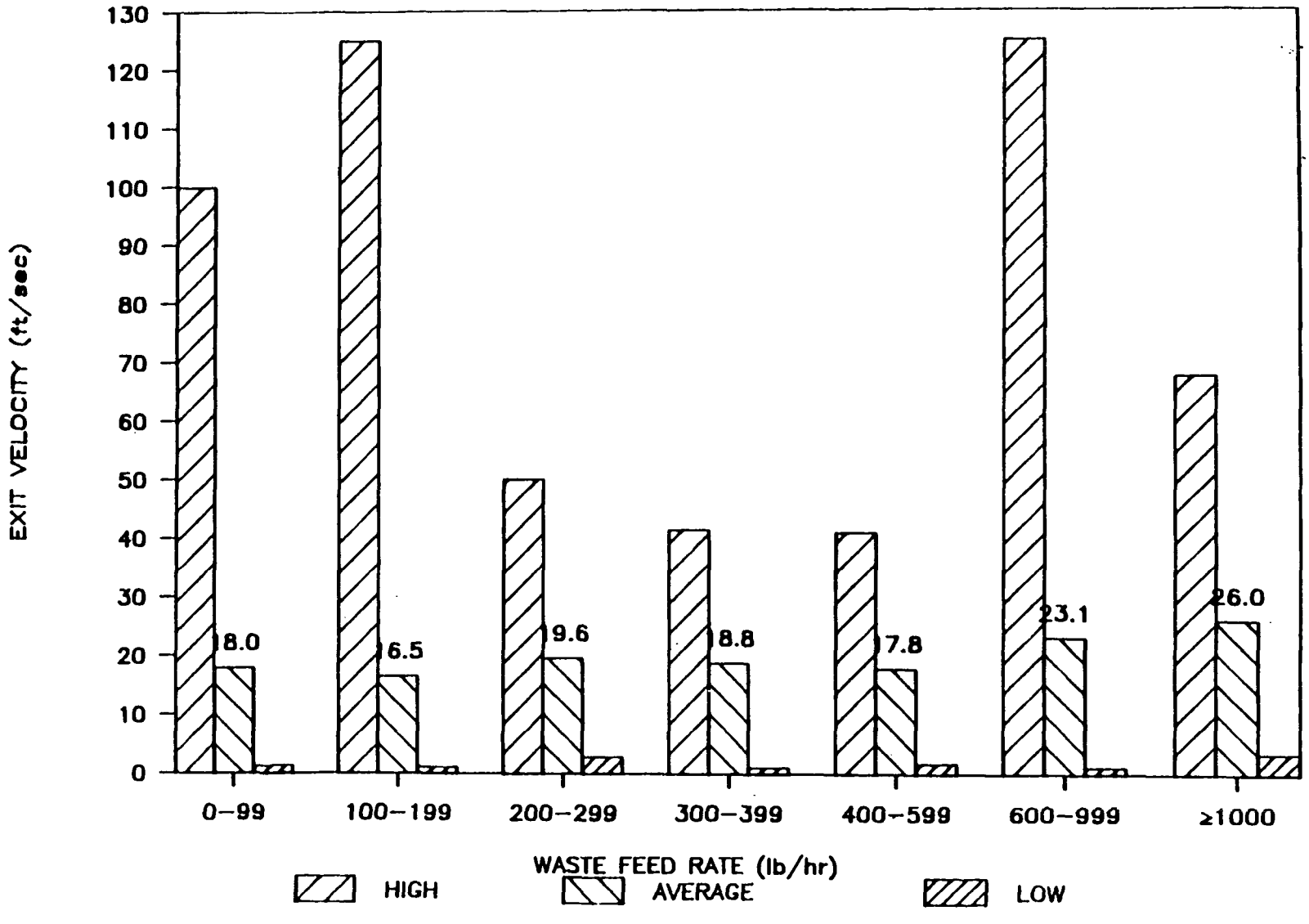

Figure 6-7. Average, high and low stack gas exit velocities according to selected feed rate ranges.

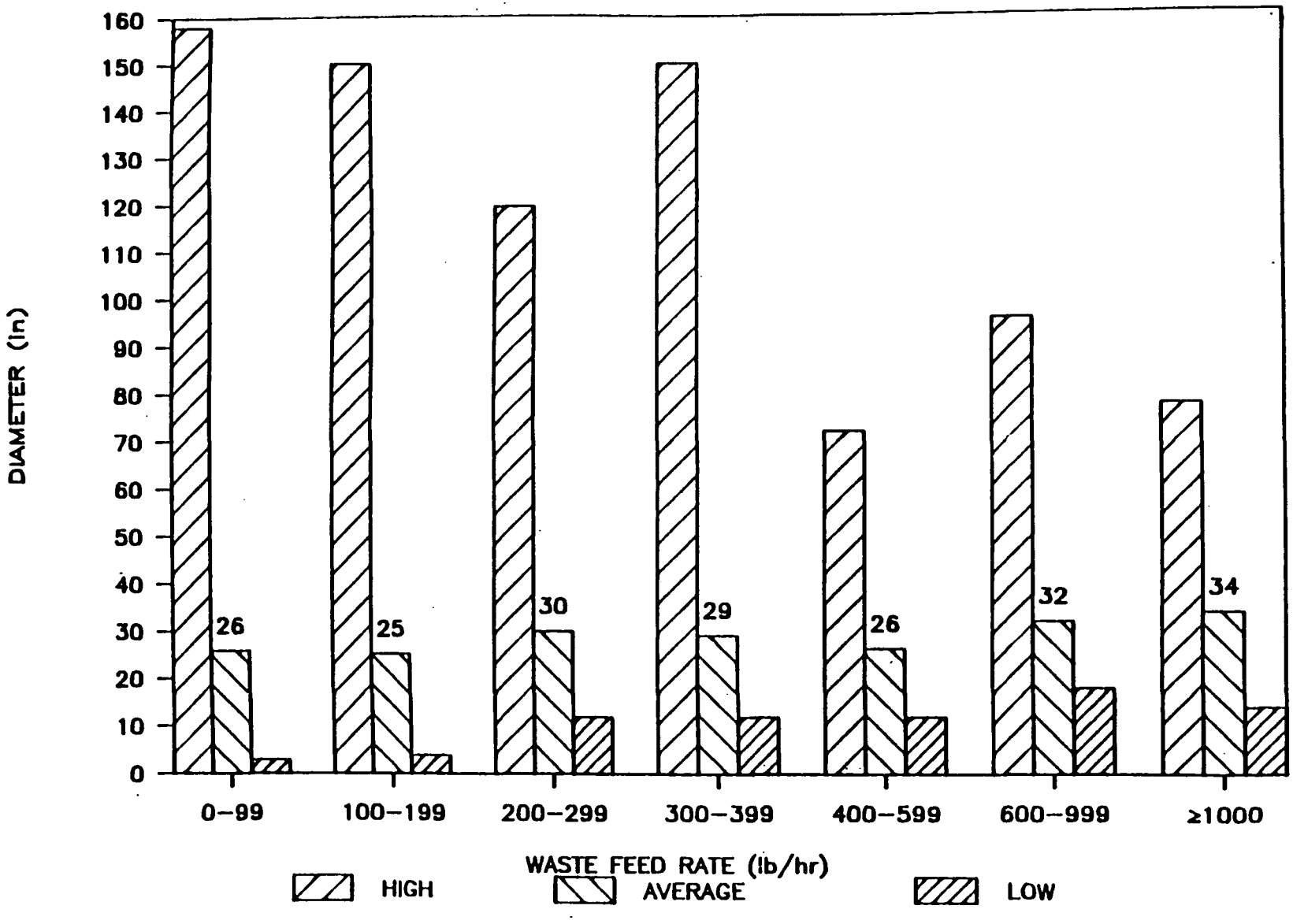

Figure 6-8. Average, high and low stack diameters according to selected feed rate ranges.

units, an additional 1,000 lb/hr model unit with an exit stack gas temperature of 450°F is recommended to reflect this situation. An exit gas temperature of 450°F is chosen because it provides a comfortable margin above the 400°F acid dew point. This temperature also corresponds to a known unit located at the University of Michigan.[3]

Stack Gas Exit Velocity. The average, high, and low stack gas exit velocities for a given feed rate range are shown as a function of feed rate ranges in Figure 6-7. Once again, the variation within a given capacity range is quite large. In general, the average stack velocities shown also increase with the capacity of the unit. This is understandable in view of the increasing volumetric flow rate of stack gases with increasing incinerator capacity and the need to maintain adequate draft and a slight negative pressure in the primary chambers of most incineraors. Therefore, the average stack gas velocity that applies to the selected model incinerator will be used. Exit gas velocities of 16.4 and 32.1 ft/sec are recommended for the 100 and 1,000 lb/hr model incinerators, respectively. The exit gas velocity for the 1,000 lb/hr heat recovery model is assumed to be the same as the non-heat recovery unit.

One might expect to see a decrease in the exit gas velocity for the model incinerator equipped with heat recovery. This is assumed not to be the case because of the need to maintain adequate draft and a slight negative pressure in the primary combustion chamber. Instead, stack diameter is reduced to maintain adequate velocity and, hence, draft.

Stack Diameter. The average, high, and low stack diameter values for a given feed rate range are shown as a function of feed rate ranges in Figure 6-8. As was the case for the other stack parameters, the stack diameters vary greatly within a given size range.

If the same approach used to determine the velocities is used to determine the stack diameter, diameters of 25 and 34 inches for the 100 and 1,000 lb/hr models are determined, respectively. Unfortunately, these diameters are not realistic when the volumetric flow rate associated with the two models are considered; the volumetric flow for a 1,000 lb/hr unit is expected to be 10 times greater than the volumetric flow from a 100 lb/hr

TABLE 6-1. SUMMARY OF MODEL INCINERATOR STACK PARAMETERS

	100 lb/hr Model Incinerator With No Heat Recovery	1,000 lb/hr Model Incinerator With No Heat Recovery	1,000 lb/hr Model Incinerator With Heat Recovery	1,500 lb/hr Model Univ. of Michigan Incinerator With Heat Recovery
Stack Heights				
(ft)	78	78	78	227
(m)	(24)	(24)	(24)	(69)
Exit Gas Temperature				
(^{o}F)	1,144	1,144	450	450
(^{o}K)	(891)	(891)	(506)	(506)
Exit Gas Velocity				
(ft/sec)	17.1	24.5	24.5	35
(m/s)	(5)	(7)	(7)	(11)
Stack Diameter				
(in)	25	66	37	24
(m)	(0.0635)	(1.676)	(0.940)	(0.610)

unit. Instead, the diameter for the 100 lb/hr model was chosen as a base point. The diameter for the 1,000 lb/hr unit was then determined by assuming a gas flow rate 10 times greater than the velocities previously determined. The resultant diameter for the 1,000 lb/hr model unit is 66 inches. For the case of the 1,000 lb/hr heat recovery model, the diameter was again adjusted for temperature while holding the velocity constant. The resultant diameter using this procedure is 37 inches.

The results of the stack parameter analysis of the NY database are summarized in Table 6-1. In conclusion, model incinerators of 100 and 1,000 lb/hr, with two cases for the 1,000 lb/hr model, are recommended. The recommended stack height, stack exit gas temperature, and velocity values for each of these models are shown in the table. For comparison purposes, the stack parameters used in modeling a 1,500 lb/hr controlled air incinerator operated by the University of Michigan (UM) hospitals are also presented in this table. This unit was equipped with a waste heat firetube boiler. Most of the UM parameters are within the general range of the recommended model incinerator stack parameters; the exception to this rule is stack height where the UM parameter is well above the recommended model values. Based on the NY database, manufacturer literature, and site visits conducted during this study, the UM stack height appears unusually high. One possible explanation is that the UM incinerator was located on the top of the hospital, as is sometimes done, and that the total height above the ground was used as the stack height.

6.1.2 Model Incinerator Operating Parameters

The operating parameters required as inputs to the HEM include the annual operating hours and hourly and yearly emissions rates. In order to determine values for each of these operating parameters, the NY incinerator database was used to determine the annual operating hours associated with each of the model incinerators. Next the hourly emissions rates were determined for each of the models by combining the emissions factor of Section 3.0 with the model capacities previously developed. Finally the

yearly emissions rates for each of the models was determined by applying the annual operating hours to the hourly emissions rates.

Annual Operating Hours. The average annual operating hours for a given feed rate range are shown as a function of feed rate ranges in Figure 6-9. As can be seen, the number of annual operating hours increases with increasing unit capacity. Smaller units (less than 200 lb/hr), which operate approximately 1,000 hrs/year, can be characterized as operating five days a week for about 4 hours each day. Larger units (greater than 600 lb/hr), which operate approximately 2,350 hrs/year, can be characterized as operating five days a week for 8 to 10 hrs each day. Therefore, annual operating operating hours of 1,000 and 2,350 are recommended for the 100 and 1,000 lb/hr model sizes, respectively.

Hourly Emissions Rates. The emissions factors previously developed in Section 3.0 are shown in Table 6-2 along with the corresponding hourly and yearly emissions rates for each of the model incinerators. High and low emissions rates are given for each of the compounds for which data exist. For compounds where only one datum point exists, only one rate in shown.

Different particulate matter (PM) emissions rates were used for the two model capacities because, as previously stated, for units of less than 400 lb/hr capacity a larger variation in PM emissions was seen over those of larger units. The high and low emission rates corresponding to this breakpoint are shown. A controlled PM emissions rate is also shown. This rate is based on the baghouse data from the St. Agnes emission test. It should be noted, that the yearly emissions rates are based on annual operation of 1,000 and 2,350 hrs/year for the 100 and 1,000 lb/hr model incinerators, respectively.

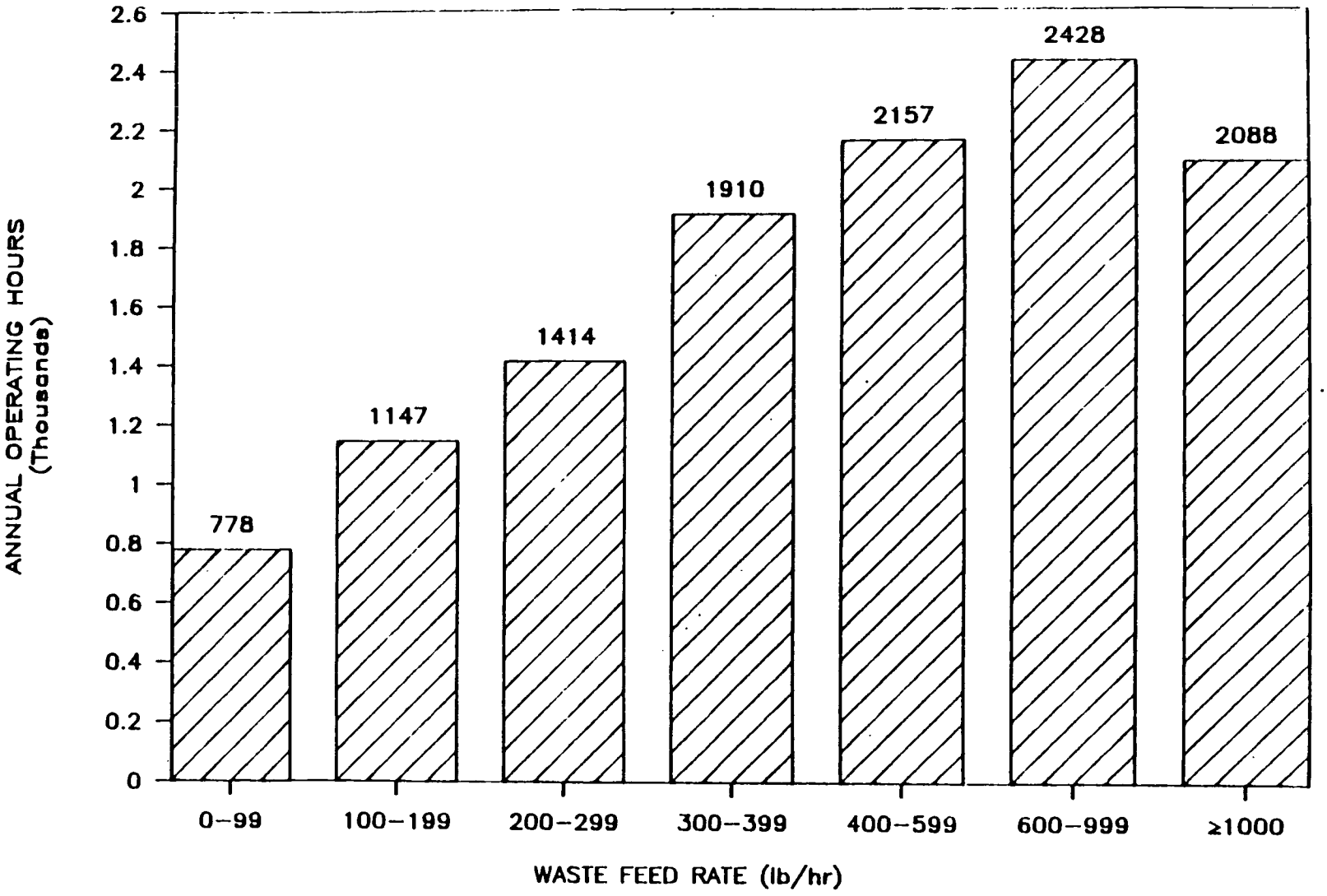

Figure 6-9. Annual operating hours according to selected feed rate changes.

TABLE 6-2. SUMMARY OF EMISSIONS FACTORS AND RATES FOR HOSPITAL INCINERATOR MODEL SIZES

Group/Compound	Emissions Factor (kg/Mg feed)	Hourly Emissions Rates (kg)		Yearly Emissions Rates (kg)	
		100 lb/hr Model	1,000 lb/hr Model	100 lb/hr[a] Model	1,000 lb/hr[b] Model
Acid Gases					
Hydrochloric Acid					
High	49.700	2.2564	22.5638	2,256.38	53,024.93
Low	3.300	0.1498	1.4982	149.82	3,520.77
Sulfur Dioxide					
High	1.505	0.0683	0.6833	68.33	1,605.68
Low	0.735	0.0334	0.3337	33.37	784.17
Nitrogen Oxides					
High	3.910	0.1775	1.7751	177.51	4,171.58
Low	2.320	0.1053	1.0533	105.33	2,475.21
Particulate Matter					
Uncontrolled (100 lb/hr)					
High	13.460	0.6111		611.08	
Low	0.845	0.0384		38.36	
Uncontrolled (1,000 lb/hr)					
High	2.725		1.2372		2,907.30
Low	0.685		0.3110		730.83
Controlled (all sizes)					
High	0.025	0.0011	0.0114	1.14	26.67
Low	0.005	0.0002	0.0023	0.23	5.33
Trace Metals (Uncontrolled)					
Arsenic					
High	1.07×10^{-4}	4.86×10^{-6}	4.86×10^{-5}	4.86×10^{-3}	2.14×10^{-1}
Low	3.55×10^{-5}	1.61×10^{-6}	1.61×10^{-5}	1.61×10^{-3}	3.79×10^{-2}
Cadmium					
High	1.40×10^{-3}	1.54×10^{-4}	1.54×10^{-3}	1.54×10^{-1}	3.63
Low	1.24×10^{-3}	5.63×10^{-5}	5.63×10^{-4}	5.63×10^{-2}	1.32
Chromium					
High	3.04×10^{-4}	1.38×10^{-5}	1.38×10^{-4}	1.38×10^{-2}	3.24×10^{-1}
Low	5.10×10^{-5}	2.32×10^{-6}	2.32×10^{-5}	2.32×10^{-3}	5.44×10^{-2}
Iron					
High	9.15×10^{-3}	4.15×10^{-4}	4.15×10^{-3}	4.15×10^{-1}	9.76
Low	1.99×10^{-3}	9.03×10^{-5}	9.03×10^{-4}	9.03×10^{-2}	2.12
Manganese					
High	5.70×10^{-4}	2.59×10^{-5}	2.59×10^{-4}	2.59×10^{-2}	6.08×10^{-1}
Low	7.90×10^{-5}	3.59×10^{-6}	3.59×10^{-5}	3.59×10^{-3}	8.43×10^{-2}
Nickel					
High	2.50×10^{-4}	1.14×10^{-5}	1.14×10^{-4}	1.14×10^{-2}	2.67×10^{-1}
Low	5.40×10^{-5}	2.45×10^{-6}	2.45×10^{-5}	2.45×10^{-3}	5.76×10^{-2}

TABLE 6-2. SUMMARY OF EMISSIONS FACTORS AND RATES FOR HOSPITAL INCINERATOR MODEL SIZES (CONTINUED)

Group/Compound	Emissions Factor (kg/Mg feed)	Hourly Emissions Rates (kg)		Yearly Emissions Rates (kg)	
		100 lb/hr Model	1,000 lb/hr Model	100 lb/hr[a] Model	1,000 lb/hr[b] Model
Lead					
High	2.80×10^{-2}	1.27×10^{-3}	1.27×10^{-2}	1.2700	29.8
Low	1.52×10^{-2}	6.90×10^{-4}	6.90×10^{-3}	6.90×10^{-1}	16.2
Dioxins					
(Tetra)TCDD					
High	5.35×10^{-7}	2.43×10^{-8}	2.43×10^{-7}	2.43×10^{-5}	5.71×10^{-4}
Low	2.00×10^{-8}	9.08×10^{-10}	9.08×10^{-9}	9.08×10^{-7}	2.13×10^{-5}
(Penta)PCDD					
High	3.80×10^{-7}	1.73×10^{-8}	1.73×10^{-7}	1.73×10^{-5}	4.05×10^{-4}
Low	5.50×10^{-8}	2.50×10^{-9}	2.50×10^{-8}	2.50×10^{-6}	5.87×10^{-5}
(Hexa)HxCDD					
High	7.60×10^{-7}	3.45×10^{-8}	3.45×10^{-7}	3.45×10^{-5}	8.11×10^{-4}
Low	1.35×10^{-7}	6.13×10^{-9}	6.13×10^{-8}	6.13×10^{-6}	1.44×10^{-4}
(Hepta)HpCDD					
High	1.92×10^{-6}	8.69×10^{-8}	8.69×10^{-7}	8.69×10^{-5}	2.04×10^{-3}
Low	1.60×10^{-7}	7.26×10^{-9}	7.26×10^{-8}	7.26×10^{-6}	1.71×10^{-4}
(Octa)DCDD					
High	2.74×10^{-6}	1.24×10^{-7}	1.24×10^{-6}	1.24×10^{-4}	2.92×10^{-3}
Low	1.70×10^{-7}	7.72×10^{-9}	7.72×10^{-8}	7.72×10^{-6}	1.81×10^{-4}
Total PCDD					
High	6.26×10^{-6}	2.84×10^{-7}	2.84×10^{-6}	2.84×10^{-4}	6.68×10^{-3}
Low	7.15×10^{-7}	3.25×10^{-8}	3.25×10^{-7}	3.25×10^{-5}	7.63×10^{-4}
Furans					
(Tetra)TCDF					
High	1.04×10^{-6}	4.70×10^{-8}	4.70×10^{-7}	4.70×10^{-5}	1.10×10^{-3}
Low	2.50×10^{-7}	1.14×10^{-8}	1.14×10^{-7}	1.14×10^{-5}	2.67×10^{-4}
(Penta)PCDF					
High	1.90×10^{-6}	8.60×10^{-8}	8.60×10^{-7}	8.60×10^{-5}	2.02×10^{-3}
Low	4.50×10^{-7}	2.04×10^{-8}	2.04×10^{-7}	2.04×10^{-5}	4.80×10^{-4}
(Hexa)HxCDF					
High	2.82×10^{-6}	1.28×10^{-7}	1.28×10^{-6}	1.28×10^{-4}	3.00×10^{-3}
Low	4.10×10^{-7}	1.86×10^{-8}	1.86×10^{-7}	1.86×10^{-5}	4.37×10^{-4}
(Hepta)HpCDF					
High	3.23×10^{-6}	1.47×10^{-7}	1.47×10^{-6}	1.47×10^{-4}	3.45×10^{-3}
Low	2.75×10^{-7}	1.25×10^{-8}	1.25×10^{-7}	1.25×10^{-5}	2.93×10^{-4}
(Octa)DCDF					
High	2.18×10^{-6}	9.87×10^{-8}	9.87×10^{-7}	9.87×10^{-5}	2.32×10^{-3}
Low	1.05×10^{-7}	4.77×10^{-9}	4.77×10^{-8}	4.77×10^{-6}	1.12×10^{-4}
Total PCDF					
High	1.09×10^{-5}	4.96×10^{-7}	4.96×10^{-6}	4.96×10^{-4}	1.17×10^{-2}
Low	1.63×10^{-6}	7.38×10^{-8}	7.38×10^{-7}	7.38×10^{-5}	1.73×10^{-3}

TABLE 6-2. SUMMARY OF EMISSIONS FACTORS AND RATES FOR HOSPITAL INCINERATOR MODEL SIZES (CONTINUED)

Group/Compound	Emissions Factor (kg/Mg feed)	Hourly Emissions Rates (kg)		Yearly Emissions Rates (kg)	
		100 lb/hr Model	1,000 lb/hr Model	100 lb/hr[a] Model	1,000 lb/hr[b] Model
Low Molecular Organics					
Ethane	0.0015	0.0001	0.0007	0.07	1.60
Ethylene	0.0100	0.0005	0.0045	0.45	10.67
Propane	0.0120	0.0005	0.0054	0.54	12.80
Propylene	0.0110	0.0050	0.0050	0.50	11.74
Trichlorotrifluoroethylene	4.13×10^{-5}	1.87×10^{-6}	1.87×10^{-5}	1.87×10^{-3}	4.40×10^{-2}
Tetrachloromethane	4.96×10^{-5}	2.25×10^{-7}	2.25×10^{-6}	2.25×10^{-4}	5.29×10^{-2}
Trichloroethylene	1.20×10^{-5}	5.43×10^{-7}	5.43×10^{-6}	5.43×10^{-4}	1.27×10^{-2}
Tetrachloroethylene	1.25×10^{-5}	5.65×10^{-7}	5.65×10^{-6}	5.65×10^{-4}	1.33×10^{-2}
Carbon Monoxide					
High	0.85	0.0384	0.3836	38.36	901.53
Low	0.66	0.0300	0.2996	29.26	704.15

[a]Based on 1,000 hours of yearly operation.

[b]Based on 2,350 hours of yearly operation.

6.2 REFERENCES

1. Private communication between T. Moody, Radian Corporation and Howe, Gordon, and Sontag, New York State Department of Environment Conservation, June 9, 1987.

2. Summary Report, Hospital Statistics, American Hospital Association, 1986 Edition.

3. Doucet, L. G., and Maiuka, P. C., Hospital Incinerator Emissions, Risk and Permitting - A case Study. Presented at the 80th Annual Meeting of APCA, New York, New York, June 21-26, 1987.

APPENDIX A

APPENDIX A

STATE REGULATIONS PERTAINING TO INFECTIOUS WASTE MANAGEMENT[1]

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Alabama	1975 Code of Alabama, Section 22-21-20. Alabama State Board of Health Rules and Regulations for Nursing Homes and Hospitals.	All infectious waste generated by nursing homes and hospitals must be incinerated on site.	Bureau of Licensure and Certification State Health Department Room 652 State Office Building Montgomery, Alabama 36130-1701 (205) 261-5105
	No regulations.	Policy is to recommend treatment of infectious waste prior to disposal.	Alabama Department of Environmental Management Land Division 1751 Federal Drive Montgomery, Alabama 36130 (205) 271-7700
Alaska	Laws of Alaska, Title 44, Chapter 46; Title 46, Chapter 3.	All infectious waste generated by medical and veterinary facilities must be incinerated prior to final disposal. The state has statutory authority to regulate infectious waste, but has not yet promulgated regulations.	Air and Solid Waste Management Department of Environmental Conservation Pouch O Juneau, Alaska 99811 (907) 465-2666
Arizona	Arizona Revised Statutes, Title 36, Article 2, General Hospitals. Regulation R9-10-220, Environmental Services, Subsection E.	All infectious waste must be either (1) autoclaved and disposed of in an approved sanitary landfill, or (2) incinerated in an approved incinerator. Variances are given for disposal of untreated waste when there is insufficient treatment capacity.	Bureau of Health Care Institution Licensure Arizona Department of Health Services 1740 West Adams Street Phoenix, Arizona 85007 (602) 255-1115
Arkansas	Act 414 of 1961, as amended by Act 444 of 1965 and Act 454 of 1965. Rules and Regulations for Hospitals and Related Institutions in Arkansas.	All infectious waste generated by hospitals and related institutions must be incinerated or disposed of by other approved methods. Revisions are expected in 1986.	Department of Health Division of Health Facilities Services 4815 W. Markham Street Little Rock, Arkansas 72205-3867 (501) 661-2201

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	The Solid Waste Management Act (237) of 1971. Arkansas Hazardous Waste Management Act of 1979 (Act 406 of 1979).	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Solid Waste Management Division Department of Pollution control and Ecology P.O. Box 9583 8001 National Drive Little Rock, Arkansas 72219 (501) 562-7444
California	California Health and Safety Code Chapter 6.5, Article 2, Section 25117.5 California Administrative Code, Title 22. Division 4, Chapter 30: Minimum Standards for Management of Hazardous and Extremely Hazardous Waste; Infectious Waste Regulations, effective November 16, 1985.*	Infectious waste must be incinerated, sterilized or treated by other approved methods.	California Department of Health Services Hazardous Materials Management Section 714/744 P Street Sacramento, California 95814 (916) 324-1798
Colorado	Colorado Revised Statutes, 1973, as amended; Title 25, Article 15, Parts 1, 2, and 3: Hazardous Waste Management Act.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Waste Management Division Colorado Department of Health 4210 E. 11th Avenue Denver, Colorado 80220 (303) 320-8333 Ext. 4364
	Chapter 4, Regulations Governing General Hospitals.	Pathological waste must be incinerated. Off-site disposal in approved sites is possible.	Division of Health Facilities Regulations Colorado Department of Health 4210 E. 11th Avenue Denver, Colorado 80220 (303) 320-8333 Ext. 6306
Connecticut	Connecticut General Statutes of 1979, Public Act 79-605. Code 22A-4483 and 22A-115.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Hazardous Waste Management Department of Environmental Protection State Office Building 165 Capitol Avenue Hartford, Connecticut 06106 (203) 566-4869 or 566-5712
Delaware	Delaware Code, Title 7, Chapter 60: Solid Waste Act. Delaware Solid Waste Disposal Regulations, August 1974.	Infectious waste disposal is approved on a case-by-case basis. None has been allowed to go to landfills untreated since the approval process was initiated. Revised regulations have been proposed.	Waste Management Section Department of Natural Resources and Environmental Control 89 King Highway P.O. Box 1401 Dover, Delaware 19903 (302) 736 4781

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
District of Columbia	District of Columbia Hazardous Waste Management Act of 1977, D.C. Law 2-64.	The District has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Department of Consumer and Regulatory Affairs and Environmental Control Division 5010 Overlook Avenue, SW Washington, DC 20032 (202) 767-8414
Florida	Florida Resource Recovery and Management Act (Florida Statutes Annotated, Title 27, Public Health, Chapter 403, Part IV, Enacted by the Laws of 1974, Chapter 342, as amended). Florida Resource Recovery and Management Regulations: Rules of the Department of Environmental Regulation, Chapter 17-7.04.*	Infectious waste must be incinerated or treated by an approved treatment method before being placed in a landfill.	Solid Waste Management Program Department of Environmental Regulation Twin Towers Office Building, 6th Floor 2600 Blair Stone Road Tallahassee, Florida 32301 (904) 488-0300 and Department of Health and Rehabilitative Services 1317 Winewood Boulevard Tallahassee, Florida 32301 (904) 488-2905
Georgia	Code of Georgia, Annotated, Title 43, Chapter 43-16: Solid Waste Management Act of 1972, as amended. Georgia Department of Natural Resources Rules and Regulations for Solid Waste Management, Chapter 391-3-4, 1972, as amended through 1974.	Infectious waste is considered a special waste. Policy is to require incineration or autoclaving before land disposal.	Land Protection Branch Environmental Protection Division Department of Natural Resources Room 724 270 Washington Street, SW Atlanta, Georgia 30334 (404) 656-2833
Hawaii	Hawaii Environmental Laws and Regulations, Vol. I, Title 19, Chapter 342, Part V, as amended by Chapter 230, Laws of 1974. Title 11, Department of Health, Chapter 58, Solid Waste Management Control Regulations, November 1981.	All infectious waste must be treated or otherwise rendered safe before disposal. Double bagging is considered a means of rendering an untreated waste safe.	Air and Solid Waste Permit Section Department of Health Amelco Building, 3rd Floor 645 Halekau Wila Street Honolulu, Hawaii 96313
Idaho	Idaho Code, Title 39, Chapter 1. Idaho Solid Waste Management Regulations, Title I, Chapter 6.	All solid waste must be managed to prevent health hazards, public nuisances, and pollution of the environment during treatment, storage and disposal. Policy is to recommend that infectious waste be double bagged prior to disposal.	Hazardous Materials Bureau Department of Health and Welfare State House Boise, Idaho 83720 (208) 334-4107

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Illinois	Illinois Revised Act 101-105, January 1985. State of Illinois Rules and Regulations 35, Subtitle G, Subpart F, Sections 700.601-700.605.	All infectious hospital waste must be rendered innocuous by sterilization or incineration before disposal.	Division of Land Pollution Control Environmental Protection Agency 2200 Churchill Road Springfield, Illinois 62706 (217) 782-6762 or 782-6760
Indiana	Indiana Code, Title 13, Article 7, Environmental Management Act.*	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. Regulations are being drafted.	Division of Land Pollution Control State Board of Health 1330 West Michigan Street Room A304 Indianapolis, Indiana 46206 (317) 243-9100
	Refuse Disposal Act: Recodified as Indiana Solid Waste Disposal Law IC-36-9-30. Rule 330 IAC 4.	Written approval must be obtained before disposal of infectious waste in a sanitary landfill. A 5-year permit system was established in April, 1987.*	
Iowa	Iowa Code 1985, Section 455B.304. 900--100.3(2) Iowa Administrative Code (IAC)	Land disposal of infectious waste is prohibited unless a special waste authorization is granted that requires autoclaving or formalin treatment before land disposal.	Air and Waste Permit Branch Program Operations Division Iowa Department of Water, Air and Waste Management Henry A. Wallace Building 900 East Grand Street Des Moines, Iowa 50319 (515) 281-8692
Kansas	Kansas Statutes Annotated, Chapter 65, Article 34, as amended. Kansas Administrative Regulations, Title 28. Public Health, Article 29, Regulation 27, Effective May 1984.	Infectious waste must be incinerated, treated before land disposal, or ground to the sewer. Untreated infectious waste may be sent to a hazardous waste land disposal facility or to a sanitary landfill with authorization from the Department.	Solid Waste Management Section Department of Health and Environment Forbes Field, Building 321 Topeka, Kansas 66620 (913) 862-9360, Ext. 309
Kentucky	Kentucky Revised Statutes, 224.005(227)(a).	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Division of Waste Management Cabinet of Natural Resources and Environmental Protection 18 Reilly Road Frankfort, Kentucky 40601 (502) 564-6716

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	Certificate of Need and Licensure Law, as revised, (originally effective January 1, 1973). 902 Kentucky Administrative Regulations, 20:009, Hospital Facility Regulation.	Hospitals must have an incinerator capable of destroying infectious waste. Hospitals which satisfy the treatment, packaging, and transportation requirements can secure waivers to incinerate the waste in city facilities. Revised regs effective 6/4/85 require that sharp waste (needless, glass, etc.) be separated from other infectious waste. Sharp waste is to be packaged in rigid containers for either incineration or disposal in approved landfills.	Division for Licensing and Regulation Department of Human Resources 275 E. Main Street Frankfort, Kentucky 40601 (502) 564-2800
Louisiana	Louisiana Revised Statutes, Act 449, 30: 1133, Environmental Affairs Act.*	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. Policy is to allow disposal of treated infectious waste in selected sanitary landfills. Revisions are expected.	Hazardous Waste Division Department of Natural Resources P.O. Box 44066 Baton Rouge, Louisiana 70804 (504) 342-1216
Maine	Title 38 of Main Revised Statutes Annotated.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Bureau of Oil and Hazardous Waste Materials Department of Environmental Protection State House, Station 17 Augusta, Maine 04333 (207) 289-2651
Maryland	Annotated Maryland Code. Health Environment Article, Sections 9-210(g) and 9-229, effective July 1, 1984. Amended Guidelines for the Disposal of Infectious Waste, effective July 1, 1984.	Infectious waste cannot be disposed of in a landfill. Incineration is the preferred method of treatment.	Air Management Administration Department of Health and Mental Hygiene 201 West Preston Street, 2nd Floor Baltimore, Maryland 21201 (301) 225-5260

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Massachusetts	Massachusetts General Laws, Chapter 111, Subsections 3 and 51-56, and Chapter 111D. 105 CMR 130.354 and 130.355. Hazardous Infectious Waste Disposal Regulations; and 105 CMR 180.275, Regulation for Disposal of Infectious Materials from Independent Laboratories. Massachusetts General Laws, Chapter 21-C.*	Infectious waste must be incinerated or treated before disposal.	Massachusetts Department of Public Health 150 Tremont Street Boston, Massachusetts 02111 (617) 727-2700
	Massachusetts General Laws, Chapter 21-C.*	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Division of Solid and Hazardous Waste 1 Winter Street Boston, Massachusetts 02108 (617) 292-5582
Michigan		As of December 28, 1985, Michigan deleted its list of infectious wastes from the regulations.	Office of Hazardous Waste Management Michigan Department of Natural Resources P.O. Box 30038 Lansing, Michigan 48909 (517) 373-1220
Minnesota	Minnesota Statutes Annotated, Chapters 115A and 116, enacted by Laws of 1980, as amended. Minnesota Code of Agency Rules, Title 6, Part 4, as amended SW1-12 and SW6-2viii.	Land disposal of infectious waste is prohibited.	Division of Solid and Hazardous Waste Minnesota Pollution Control 1935 West County Road B-2 Roseville, Minnesota 55113 (612) 296-7373
Mississippi	No laws or regulations pertaining to infectious waste management.		Division of Solid/Hazardous Waste Management Bureau of Pollution Control Department of Natural Resources P.O. Box 10385 Jackson, Mississippi 39209 (601) 961-5171
Missouri	Missouri Hospital Licensing law, Chapter 197 of Missouri Revised Statutes, Rules and Regulations for Hospitals.	Infectious waste generated by hospitals must be either incinerated or autoclaved before being sent to a landfill permitted to accept the waste. Waste is required to be treated on site. The state expects to revise regulations.	Missouri Department of Health Bureau of Hospital Licensing P.O. Box 570 Jefferson City, Missouri 65102 (314) 751-2713

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	Missouri Hazardous Waste Management Law, Chapter 260 of Revised Statutes of Missouri, 1'95, as amended.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Waste Management Program Department of Natural Resources P.O. Box 176 Jefferson City, Missouri 65102 (314) 751-3241
	Missouri Solid Waste Management Law, Chapter 260.200 of Revised Statutes of Missouri, 1975. Missouri Solid Waste Management Rules and Regulations, 10CSR80, Chapters 1-5.	Sterilized infectious waste may be disposed of in any permitted solid waste landfill.	
Montana	Montana Solid Waste Management Act of 1976. Administrative Rules of Montana, Title 16, Chapter 14, Subchapter 5, Solid Waste Management/Refuse Disposal.	Policy is to recommend treatment of infectious waste before land disposal.	Solid and Hazardous Waste Management Bureau Department of Health and Environmental Sciences Cogswell Building, Room B201 Helena, Montana 59620 (406) 444-2821
	Montana Hazardous Waste Act of 1981.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	
Nebraska	Nebraska Environmental Protection Act, Section 81-1501 through 81-1540.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Land Quality Division Department of Environmental Control State House Station P.O. Box 94877 Lincoln, Nebraska 68509 (402) 471-2186
Nevada	Nevada Revised Statutes, Chapter 459, Hazardous Waste Disposal and Solid Waste Disposal. Regulations Governing Solid Waste Management, Effective 1977.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. Infectious waste generated by hospitals may be placed in a land disposal facility only under approval of the Department.	Division of Environmental Protection Department of Conservation and Natural Resources Capital Complex Carson City, Nevada 89710 (702) 885-4670

APPENDIX A (CONTINUED)

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
New Hampshire	New Hampshire Revised Statutes Annotated 151, 1979. Health Facilities Rules and Regulations, effective February 1984. General Requirements for all Facilities, HEP-801.	Infectious waste generated by health care facilities must be incinerated.	Bureau of Health Facilities Administration Division of Public Health Department of Health and Welfare 6 Hazen Drive Concord, New Hampshire 03301 (603) 271-4592
New Jersey	New Jersey Statues Annotated, Title 13: Conservation and Development, Chapter 1E-1. New Jersey Administrative Code, Title 7, Chapter 26, as amended. New regulations dealing with hazardous wastes expected.*	Infectious waste must be rendered noninfectious in accordance with the standards of the New Jersey Department of Health.	Division of Waste Management Department of Environmental Protection 33 East Hanover Street Trenton, New Jersey 08625 (609) 292-9877
	New Jersey Health Care Facilities Planning Act. New Jersey Administrative Code 8:43-B-3.6.*	All infectious waste generated by hospitals must be treated before land disposal. Infectious waste that is not autoclaved or incinerated can be double-bagged for land disposal by a method approved by the Department of Environmental Protection.	New Jersey Department of Health Division of Health Facilities Evaluation CN 370 Trenton, New Jersey 08625 (609) 292-7834
New Mexico	Hazardous Waste Act, Section 74-4-3, as amended through 1981.	No specific regulations on infectious waste. Incineration or sterilization of infectious waste followed by land disposal is recommended.	Solid and Hazardous Waste Management Programs Health and Environment Department P.O. Box 968 Santa Fe, New Mexico 87504-0968 (505) 827-5271 or 827-0020
New York	Environmental Conservation Law, Article 27. Title 6 NCRR part 364. Collection and Transport of Industrial, Commercial, and Certain Other Wastes.*	Anyone transporting a hospital waste off-site (including infectious waste) must have a waste transporter's permit.	Division of Solid and Hazardous Waste Department of Environmental Conservation 50 Wolf Road, Room 417 Albany, New York 12233 (518) 457-3254
	Parts 219 and 222: General Regulation of Refuse and Waste Incineration.*	These regulations limit emissions of particulate matter and smoke.	New York State Department of Environmental Conservation 50 Wolf Road Albany, New York 12233 (518) 457-5618

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
	10 NYCRR 405.3(b)(5): Handling of Potentially Infections Waste.[a]	The various categories of potentially infections waste and acceptable methods of disposal for each are presented. All waste must be autoclaved or incinerated prior to disposal.	New York State Department of Health Office of Health Services Management Nelson A. Rockefeller Empire State Plaza Corning Tower, Room 1821 Albany, New York 12237 (518) 474-2121
North Carolina	North Carolina Solid and Hazardous Waste Act, as revised, July 1983. 10 NCAC 10G, Solid Waste Management, July 1, 1985.	Infectious waste must be treated by an approved method prior to disposal in a landfill.	Solid and Hazardous Waste Management Branch Division of Health Services Department of Human Resources P.O. Box 2091 Raleigh, North Carolina 27602 (919) 733-2178
North Dakota	No governing statute or regulations.	Policy is to require autoclaving or incineration of all infectious waste generated by hospitals and nursing homes. No untreated infectious waste may be disposed of in a landfill. Every hospital and nursing home must have access to a double-chambered, approved incinerator in order to be licensed.	Division of Health Facilities Department of Health State Capitol Building Bismark, North Dakota 58505 (701) 224-2352
Ohio	Ohio Revised Code, Title 37, Chapter 34, as amended. Ohio Administrative Code, Regulations 3745-27 and 3745-37, effective July 29, 1976.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Division of Solid and Hazardous Waste Management Ohio Environmental Protection Agency 361 East Broad Street Columbus, Ohio 43215 (614) 466-7220
Oklahoma	Oklahoma Statues, Title 63, 1981, Section 1-2001 et seq., Oklahoma Controlled Industrial Waste Disposal Act.[a]	The state has statutory authority to regulate infections waste as a hazardous waste, but has not yet promulgated regulations. Current policy is based on CDC guidelines. Infectious waste regulations are being drafted.	Institutional Services, Medical Facilities Department of Health P.O. 53551 1000 N.E. 10th Street, 4th Floor Oklahoma City, Oklahoma 73152 (405) 271-6811
Oregon	Oregon Revised Statutes, Chapter 459, as amended. Oregon Administrative Rules, Chapter 340, Division 61.	Land disposal of infectious waste is controlled through the permitting process for land disposal facilities.	Hazardous and Solid Waste Division Department of Environmental Quality P.O. Box 1760 Portland, Oregon 97207 (503) 229-6266

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Pennsylvania	Pennsylvania Statutes, 62 PS 901-1059, Public Welfare Code. Pennsylvania Code, Title 28, Chapter 147.74, Pennsylvania State Health Department Regulations: Disposal of Bacterial and Pathological Wastes that are Generated in Hospitals and Medical Care Facilities.*	Current policy is to allow off-site sterilization of infectious waste. New regulations are being drafted.	Bureau of Waste Management Department of Environmental Resources Fulton Building, 8th Floor P.O. Box 2063 Harrisburg, Pennsylvania 17120 (717) 787-6239
	25 Pa. Code 127.12(a)(5)*	Best Available Technology requirements for hospital/ infections waste incinerator facilities include stack emission limitations, ambient impact analyses, operating, testing and monitoring requirements. These regulations are in draft review, effective June 9, 1987.	Bureau of Air Quality Control Department of Environmental Resources Fulton Building, 18th Floor P.O. Box 2063 Harrisburg, Pennsylvania 17120 (717) 787-4324
Rhode Island	Rhode Island Hazardous Waste Management Act of 1978. Hazardous Waste Rules and Regulations for Hazardous Waste Generation, Transportation, Treatment, Storage and Disposal - Effective July 18, 1984.	Infectious waste is regulated as a hazardous waste.	Division of Air Hazardous Materials Department of Environmental Management 204 Cannon Building 75 Davis Street Providence, Rhode Island 02908 (401) 277-2797
South Carolina	Code of Laws of South Carolina, 1976, Sections 44-56-10 through 44-56-140, Hazardous Wastes.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations. The state recommends that infectious hospital waste be incinerated or otherwise treated before land disposal.	Bureau of Solid and Hazardous Waste South Carolina Department of Health and Environmental Control 2600 Bull Street Columbia, South Carolina 29201 (803) 758-5681
South Dakota	South Dakota Codified Laws, Chapter 34A-6-2, Solid Waste Disposal Act.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Office of Air Quality and Solid Waste Department of Water and Natural Resources Joe Foss Building 523 East Capitol Avenue Pierre, South Dakota 57501 (605) 773-3153

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Tennessee	Tennessee Hazardous Waste Management Act of 1977, as amended. Tennessee Solid Waste Disposal Act, as amended.*	The state is initiating rulemaking action.	Division of Solid Waste Management Tennessee Department of Public Health and Environment Customs House, 4th Floor 601 Broadway Street Nashville, Tennessee 37219-5403 (615) 741-3424
	Tennessee Code Annotated, 6811-201 through 217 Minimum Standards and Regulations for Hospitals, 1974.*	All infectious waste generated by hospitals must be incinerated in closed incinerators on elevated platforms.	Hospital Licensing Board 283 Plus Park Nashville, Tennessee 37210 (615) 367-6200
Texas	Revised Civil Statutes of the State of Texas Annotated, Article 4477-7 Texas Solid Waste Disposal Act; and Article 4477-1, Texas Sanitation and Health Protection Law, as amended. Texas Administrative Code 325.136(b)(1), Texas Department of Health, Municipal Solid Waste Management Regulations, effective July 1983, as amended.*	Infectious waste is regulated as a special waste. Incineration is the preferred method of treatment. Untreated waste may be double bagged and disposed of in a Type I municipal landfill.	Bureau of Solid Waste Management Texas Department of Health 1100 West 49th Street, T601A Austin, Texas 78756 - 3199 (512) 458-7271
Utah	Utah Code Annotated, Title 26, Chapter 14, Utah Solid and Hazardous Waste Act, Effective June, 1981.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Bureau of Solid and Hazardous Waste Department of Health P.O. Box 45500 Salt Lake City, Utah 84145-0501 (801) 533-4145
Vermont	Vermont Statutes Annotated, Title 10, Chapter 159. Hazardous Waste Management Regulations, as amended September 13, 1984, Section 6602(2)(a)(14).	Infectious waste is regulated as a hazardous waste.	Hazardous and Solid Waste Management Division Department of Water Resources and Environmental Engineering Agency of Environmental Conservation State Office Building Montpelier, Vermont 05602 (802) 828-3395
Virginia	Code of Virginia, Title 32.1, Chapter 6, Article 3. Virginia Regulations Governing Disposal of Solid Waste, April, 1971.	Infectious wastes are not as regulated as hazardous wastes. Waste generators must have special permission to dispose of nonmunicipal waste. Rules do not preclude land disposal of untreated infectious waste.	Division of Solid and Hazardous Waste Management Department of Health Monroe Building, 11th Floor 101 North 14th Street Richmond, Virginia 23219 (804) 225-2667

State	Statutory Authority and Regulation Citation	Summary of Requirements	State Agency
Washington	Revised Code of Washington, Hazardous Waste Disposal Chapter 70.105.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Hazardous Waste Section Department of Ecology Mail Stop PV-11 Olympia, Washington 98504-8711 (206) 459-6322
	Revised Code of Washington, Hospital Licensing and Regulation Statute, Chapter 70.41. Washington Administrative Code, 248-180-170, Hospital Rules and Regulations.	Infectious waste generated by hospitals must be incinerated or disposed of by other approved methods. Approved methods include autoclaving, retorting, or double bagging before land disposal.	Department of Social and Health Services Facility Licensing Certification Section of the Health Services Division Mail Stop ET-31 Olympia, Washington (206) 753-7039
West Virginia	Code of West Virginia, Chapter 20, Article 5E, Effective July 7, 1981.*	Infectious waste must be autoclaved and/or incinerated before land disposal. Infectious waste regulations are being revised.	State Health Department 1800 Washington Street, East Charleston, West Virginia 25305 (304) 348-2970
Wisconsin	Wisconsin Statutes Annotated, Chapter 144, as amended.	The state has statutory authority to regulate infectious waste as a hazardous waste, but has not yet promulgated regulations.	Bureau of Solid Waste Management Department of Natural Resources P.O. Box 7921 Madison, Wisconsin 53707 (608) 266-2111
	Chapter NR 181, and guidance summary "Handling and Disposal of Pathological Waste."	Policy is to recommended incineration of infectious waste. Infectious waste which as been autoclaved or sterilized may be bagged and disposed of in an engineered landfill.	
Wyoming	No regulations pertaining to infectious waste management.		Solid Waste Management Program State of Wyoming Department of Environmental Quality Herschler Building 122 West 25th Street Cheyenne, Wyoming 82002 (307) 777-7752 Department of Health and Social Services Division of Health and Medical Services 4th Floor Hathaway Building Cheyenne, Wyoming 82002 (307) 777-7121

*Denotes regulations as of June, 1987.