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UNIFIED FACILITIES CRITERIA (UFC)

SOLID WASTE INCINERATION

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UNIFIED FACILITIES CRITERIA (UFC)

SOLID WASTE INCINERATION

U.S. ARMY CORPS OF ENGINEERS (Preparing Activity)

NAVAL FACILITIES ENGINEERING COMMAND

AIR FORCE CIVIL ENGINEER SUPPORT AGENCY

Record of Changes (changes are indicated by **1**\ ... /**1**/)

Change No.	Date	Location

This UFC supersedes TI 814-21, dated 3 August 1998. The format of this UFC does not conform to UFC 1-300-01; however, the format will be adjusted to conform at the next revision. The body of this UFC is the previous TI 814-21, dated 3 August 1998.

FOREWORD

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The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration, and modernization criteria, and applies to the Military Departments, the Defense Agencies, and the DoD Field Activities in accordance with USD(AT&L) Memorandum dated 29 May 2002. UFC will be used for all DoD projects and work for other customers where appropriate. All construction outside of the United States is also governed by Status of forces Agreements (SOFA), Host Nation Funded Construction Agreements (HNFA), and in some instances, Bilateral Infrastructure Agreements (BIA.) Therefore, the acquisition team must ensure compliance with the more stringent of the UFC, the SOFA, the HNFA, and the BIA, as applicable.

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TI 814-21
3 August 1998

US Army Corps
of Engineers®

Technical Instructions

SOLID WASTE INCINERATION

Headquarters
U.S. Army Corps of Engineers
Engineering Division
Directorate of Military Programs
Washington, DC 20314-1000

TECHNICAL INSTRUCTIONS

Solid Waste Incineration

Approved for public release; distribution is unlimited.

Record of Changes (changes indicated by \1\..../1/)
No. Date Location

This Technical Instruction supersedes EI 11C302, dated 1 October 1997.
(EI 11C302 text is included in this Technical Instruction and may carry EI 11C302 identification.)

FOREWORD

These technical instructions (TI) provide design and construction criteria and apply to all U.S. Army Corps of Engineers (USACE) commands having military construction responsibilities. TI will be used for all Army projects and for projects executed for other military services or work for other customers where appropriate.

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FOR THE DIRECTOR OF MILITARY PROGRAMS:

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EI 11C302

Engineering Instructions
No. 11C302

1 October 1997

INCINERATORS

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CHAPTER 1

INTRODUCTION

1-1. PURPOSE. This manual provides guidance for the planning and concept design of municipal waste incineration plants.

1-2. SCOPE.

a. Planning. This manual introduces issues which must be considered to determine the cost effectiveness of municipal waste incineration as a complement to a comprehensive solid waste program.

b. Design. This manual introduces the designer to the basics of incineration, incineration technologies, pollution control, and overall incinerator plant design requirements.

c. Limitations. While this manual covers basic considerations which must be met to comply with current Federal regulations, the reader is cautioned that state and local requirements may have a significant affect upon the life cycle cost of an incineration project. In addition, regulations affecting incinerators have been fluctuating for several years as the effects of certain pollutants, combined with the ability to achieve emission reduction levels continue to be studied.

CHAPTER 2

PROJECT PLANNING

2-1. PROJECT MANAGEMENT. Project management's role in waste management planning activities is critical when incineration is being considered as an alternative, as municipal waste combustor projects bring together and focus the concerns of multiple agencies within federal, state, and local governments as few projects can.

2-2. ENVIRONMENTAL AND TECHNICAL COORDINATION. Incineration projects require close coordination between the environmental regulations and the technical requirements of the project. Assumptions used in environmental assessments must be coincidental with the technology used and ultimately the performance of the equipment which becomes integral to the plant.

2-3. DESIGN TEAM. The design team will by necessity consist of more individual technical disciplines than traditional facility design. Environmental engineers and biologists will need to rely on emission, discharge, and other technical data provided by the plant/equipment designers, just as the plant/equipment designers will need to have performance parameters which, for environmental assessment needs, may exceed nominal regulatory limits.

2-4. FEDERAL REGULATIONS. Under 40 CFR, the following regulations must be considered:

Subchapter C - Air Programs

Part 50, National Primary and Secondary Ambient Air Quality Standards
Part 51, Requirements for Preparation, Adoption and Submittal of Implementation Plans
Part 52, Approval and Promulgation of Implementation Plans Part 60, Subpart Ca, Emissions Guidelines and Compliance Times for Municipal Waste Combustors
Part 60, Subpart E, Standards of Performance for Incinerators
Part 60, Subpart Ea, Standards of Performance for Municipal Waste Combustors
Part 60, Subpart Eb, Standards of Performance for Municipal Waste Combustors for Which Construction is Commenced After September 20, 1994.

Subchapter D - Water Programs

Part 122, EPA Administered Permit Programs: The National Pollutant Discharge Elimination System
Part 125, Criteria And Standards For The National Pollutant Discharge Elimination System

Resource Conservation Recovery Act (RCRA)

Subchapter I - Solid Wastes
Part 240, Guidelines For The Thermal Processing Of Solid Wastes
Part 241, Guidelines For The Land Disposal Of Solid Wastes
Part 246, Source Separation For Materials Recovery Guidelines
Part 260, Hazardous Waste Management System: General

Part 261, Identification And Listing Of Hazardous Waste
Part 262, Standards Applicable To Generators Of Hazardous Waste

2-5. RESOURCE RECOVERY MANAGEMENT MODEL. The number of issues and coordination requirements for a municipal waste combustion project makes the use of previously developed management models appropriate. EPA publication SW-768 (September 1979), Resource Recovery Management Model is recommended as a guide to ensure that all aspects of the project are addressed in an appropriate sequence. While available technologies and regulatory requirements have changed since the publication of SW-768, the information presented for planning purposes is still valid. Excerpts from the introduction contained in the management model, as well as activity index lists for two phases of planning, identified as initial feasibility screening and feasibility analysis are included in appendix A.

2-6. TECHNOLOGY EFFECTS ON FEASIBILITY. As new technologies advance our ability to reduce pollutants, the complexity of waste incinerator systems increases, and the economic factors which must be considered to make accurate determinations of feasibility become complex as well. Capital and O&M (operations and maintenance) costs need to be closely examined. Uncertainties as to how residual wastes such as bottom ash and fly ash must be disposed of, and/or treated will have significant affects upon the ultimate cost of disposal, and may in fact alter completely the outcome of an alternative disposal study.

2-7. EXISTING SOLID WASTE PROGRAM SURVEY.

a. The existing solid waste program must be analyzed in detail to determine what the ultimate composition of the waste stream to be incinerated would be. The program should be analyzed for the following:

(1) Clean Green Programs (separate collection of yard wastes).

(2) Source Separation (recycling programs for aluminum, tin, cardboard, office paper, newspaper, glass, etc.).

(3) Source Separation for Hazardous Materials (separation of batteries, used oil containers, solvents, paint, etc.).

(4) Collection and Transportation Systems.

(5) Remaining Waste Stream.

b. Each waste stream, whether it be composted, recycled, land-filled on site, long hauled, or presently incinerated must be accurately quantified.

c. Weights and moisture content are critical, as are identification of unique types and quantities of waste. The results of this analysis will be used to determine waste holding capacities at the incinerator plant as well as equipment train sizing.

d. Variations in waste quantities should be considered in the context of leveling the throughput at the plant. Increasing temporary storage capacities and/or altering the present waste collection schedules are potential solutions.

e. In the case where short term large variations in the waste stream quantity and characteristics exist, consideration should be given to temporarily bypassing a portion of the waste stream rather than sizing the plant for the infrequent capacity requirements. Such situations may be the case where periodic training activities bring additional personnel and subsequently higher waste production rates.

f. Costs associated with each aspect of the solid waste program need to be determined. The value, or “cost to recycle” of a particular product is to a large degree dependent upon what the ultimate disposal cost of that product would be if it were not recycled.

2-8. DOCUMENTATION.

a. All aspects of the solid waste program survey need to be well documented. From early planning stages, through permitting, design, construction, and final commissioning can take years. Proper documentation is required such that changes in the waste stream may be detected by comparison of the historic data with the present situation.

b. Regulatory requirements under which the design is conducted must be documented, as well as any agreements made between regulatory agencies and the owner/design agent.

c. The fundamental data upon which decisions were made, and the rationale used in making those decisions must be available in the future. As regulations and technologies change, the ability to compensate for, and react to those changes efficiently is very often dependent upon having a well defined starting point. All problems and corresponding solutions, no matter how trivial they may seem at the time should become a matter of record.

CHAPTER 3

BASICS OF INCINERATION

3-1. DEFINITION AND DESCRIPTION OF INCINERATION PROCESS.

a. Definition. Incineration is a controlled combustion process for reducing solid, liquid, or gaseous combustible wastes primarily to carbon dioxide, water vapor, other gases, and a relatively small, noncombustible residue that can be further processed or land-filled in an environmentally acceptable manner.

b. Description. The incineration of solid waste involves a sequence of steps in the primary process, which includes drying, volatilization, combustion of fixed carbon, and burnout of char of the solids, which is followed by a secondary process, the combustion of the vapors, gases, and particulates driven off during the primary process.

3-2. CLASSIFICATION AND CHARACTERIZATION OF WASTE.

a. Waste Classification. Four types of waste have been identified in this manual. The Basic properties and descriptions of these four types are presented in Table 3-1.

b. Waste Characterization. Detailed combustion characteristics are needed for the calculation of heat balances for the incinerator. For design purposes, the most important characteristics are the higher heating value, moisture content, and percent of inert material in the waste.

(1) Maintaining minimum moisture is important as the energy required to dry the waste reduces the energy available to volatize vapors and provide the necessary gas temperatures to complete the destruction of the unburned gases, vapors, and particulates.

(2) Plastic wastes typically have a high specific-heating value (i.e., Btu/lb). The composite-waste Btu content is therefore sensitive to the percent of plastics and other dry, high-Btu material (e.g., cardboard, paper, etc.) in the incinerator feedstock. Tables 3-2 and 3-3 provide combustion data on some materials in domestic and commercial wastes. Table 3-4 shows the nominal composition of discards in municipal waste (household waste).

(3) The percentages of components in the waste which is to be combusted must be determined on the basis of a waste characterization analysis appendix B contains thermodynamic data and examples of combustion analysis.

3-3. HEATING VALUE OF WASTES AND FUELS.

a. Heating Value. The heating value for combustible materials may be presented in many ways. Table 3-3 lists the "as-fired" heating values generally assigned to different types of waste, some chemicals, and major constituents in municipal-type, and industrial-type, wastes. Table 3-5 lists the chemical analyses of some municipal, residential, and commercial wastes and indicates the higher heating values of the combined waste stream for as-received, moisture-free, and ash-free material. Table 3-6 lists the proximate analysis of 30 different components in municipal and commercial waste.

b. Effect of Moisture On Heating Value. Since moisture is in effect water, a nonburnable component in the waste, it is important that the water content be kept to a minimum. All water in the feed stock must be vaporized in the drying phase of combustion.

(1) Vaporization of water requires a nominal 1000 Btu/lb. Type-2 waste, containing 50% by weight water, requires approximately 12% of its heating value to dry the waste, and another 10% to raise the temperature of the water vapor to the required temperature for complete combustion.

(a) Where practical, the addition of moisture should be prevented by providing covers on disposal containers to keep out rain and snow .

(b) Alternative methods for the disposal of wet mess-hall food waste and landscape wastes will also help to improve the quality of the waste stream. Note the difference between the as-discarded and the dry-basis values for the items listed in table 3-6.

(2) Table 3-7 shows the ultimate analysis of these same constituents. Table 3-8 shows the ultimate analysis of some plastics commonly used in consumer products and containers and compares them with fuels used in power generation and space heating.

c. Effect of Preprocessing and of Source Separation/Collection for Recycle Programs on the Fuel Value.

(1) The practice of preprocessing waste to remove inert materials, many of which are recyclable, is increasing as more communities and states are requiring waste stream recycling . Materials separation plans are required by Federal regulations under 40 CFR Part 60 Subpart Eb, Standards of Performance for Municipal Waste Combustors for Which Construction is Commenced After September 20, 1994.

(2) Incinerator operators are finding this to be advantageous because it removes up to 20% of the waste that is nonburnable and which often creates ash-handling equipment difficulties.

(a) Processing the waste to produce an enhanced fuel product, called Refuse-Derived Fuel (RDF), raises the fuel heating value.

(b) If the waste is processed for both optimization of recyclable materials recovery (i.e., remove recyclable paper, cardboard, and plastic) and fuel beneficiation (i.e., remove glass, aluminum, steel and inerts), the heating value drops. The end product may now consist of only 43-55% of the original waste. Table 3-9 shows the effect of processing and materials recovery/recycle on the heating value of waste.

3-4. OXIDATION.

a. Basic Chemistry. Incineration is an oxidation process, where organic constituents react with oxygen and release heat during the process. Combustion may be defined as the rapid chemical combination of oxygen with the combustible elements of a fuel.

(1) The two major combustible chemical elements of significance are carbon and hydrogen. Chlorine and sulfur are usually of minor significance as sources of heat, but they (primarily chlorine) are usually the major constituents concerning corrosion and pollution.

(2) Carbon and hydrogen, when burned to completion with oxygen, unite according to equations 3.1 and 3.2.

$$C + O_2 = CO_2 + 14{,}100 \text{ Btu/lb of C} \qquad \text{(Eq. 3.1)}$$

$$2H_2 + O_2 = 2H_2O + 61{,}100 \text{ Btu/lb of } H_2. \qquad \text{(Eq. 3.2)}$$

2.66 lb of oxygen (or 11.5 lb of air) are required to oxidize one pound of carbon and produce 3.66 lb of carbon dioxide. Similarly, 8.0 lb of oxygen (or 34.6 lb of air) are required to oxidize one pound of hydrogen and produce 9.0 lb of water vapor.

b. Stoichiometry. The ratio of the actual amount of oxygen supplied in the oxidation process to the amount actually required is called the Stoichiometric Ratio (S.R.). In the examples given, the S.R.= 1.0. The heat released (i.e., 14,100 Btu/lb when carbon is oxidized, or 61,100 Btu/lb when hydrogen is oxidized) raises the respective products of combustion, plus other gases present, to high temperatures.

(1) The burning of compounds containing oxygen require less air since the compound already contains some oxygen that will be made available during the combustion process. A typical waste stream component like cellulose, a major constituent in paper products, is destroyed according to equation 3.3.

$$C_6H_{10}O_5+6O_2+(19.97N_2) = 6CO_2+5H_2O+(19.97N_2)+10{,}036 \text{ Btu/lb} \qquad \text{(Eq. 3.3)}$$

(2) Because oxygen is present in the "fuel," only 5.1 lb of air per pound of cellulose are required to completely oxidize the cellulose. The theoretical amount of combustion air will produce the highest temperature combustion product gas temperature (i.e., an adiabatic gas product temperature of $3{,}250^0$F).

c. Effect of Excess Air.

(1) Since air is the usual source of the oxygen, excess amounts of air will dilute the gases and reduce the temperature of the gases. When mass burning unprocessed municipal waste, approximately 7.5 lb of air (S.R.1.0) are required to burn 1 lb of waste. Any processing that improves the fuel quality (i.e., removal of non-combustibles and high-moisture-content materials) will increase the heating value of the remaining waste and the specific air demand (i.e., pounds of air per pound of material actually being burned).

(2) Figure 3-1 shows the relationship between calculated flame temperature, stoichiometric ratio, and moisture content in the waste.

d. Efficiency.

(1) The objectives of combustion in an incinerator are the complete destruction of the organic constituents to form harmless gases and the prevention of the release of any harmful material to the environment. Efficient conversion of the heat released into useful energy, though important, is secondary to safe and efficient destruction of the waste.

(2) The oxidation of the combustible elements requires a temperature high enough to ignite the constituents, mixing of the material with oxygen, or turbulence and sufficient time for complete combustion, (i.e., the three "Ts" of combustion). Proper attention to these three factors can produce destruction/conversion efficiencies of 99.9%-99.95% in well-operated incinerators.

e. Excess Air.

(1) High-efficiency destruction (oxidation) of any combustible material requires that more oxygen be present than what is required by the chemistry of the process. Since combustion is a chemical process, the rate of oxidation is contingent upon many factors that can make the reactions occur at a faster or slower rate. The percent of excess oxygen present and available to the reaction is one of these factors.

(a) In general, combustible gases and vapors require less excess oxygen to achieve high-efficiency oxidation than do solid fuels due to the ease of mixing and the nature of the compounds in the gases and vapors.

(b) Solid fuel materials, because of the more complex processes involved in their combustion, require more excess air and more time.

(2) Quantities of excess air have been determined empirically for different fuels and are given in table 3-10.

(3) Increasing the quantity of excess air beyond the percentages indicated does not benefit the combustion process and lowers the gas temperature thereby reducing the efficiency of the downstream heat-recovery process.

(a) The best combination of combustion efficiency and energy recovery when mass burning municipal waste in a large water-wall incinerator has been observed to occur with a system S.R. of 1.4 to 1.5.

(b) The secondary combustion chambers in modular and packaged incinerators achieve their highest destruction efficiency at S.R.s of 1.5 to 2.0.

3-5. MECHANISM OF COMBUSTION.

a. Primary Combustion Process. The thermal destruction of waste (or any other solid fuel with significant moisture content) is accomplished in four phases as described below:

(1) Phase One. The first phase is the drying phase that occurs in the initial heating of the heterogeneous material. Moisture is driven off as the material is heated past the vaporization temperature of water. Drying is usually complete by the time the material has reached 300^{o}F.

(2) Phase Two. The second phase is the volatilization of vapors and gases which occurs as the temperature of the waste continues to rise. Vapors and gases diffuse out as their respective volatilization temperatures are attained. Those vapors and gases having low flash points (i.e., the temperature at which a specific gas or vapor will ignite) may react with primary combustion air to burn at the surface of the bed of waste. If excess oxygen is not available, as in the case of starved-air incinerators, the low-temperature volatilization of vapors and gases may react to form other hydrocarbons and/or partially oxidized compounds (i.e., carbon monoxide, etc.). These compounds must be burned later in the secondary combustion process where there is sufficient oxygen for complete combustion. The higher flash point gases and vapors will most likely burn only after they have been swept up in the gas flow and subsequently ignite when they are exposed to their respective ignition temperatures. How well they are destroyed will depend upon their being subjected to their requisite "three T" conditions in the higher temperature zones of the furnace. The flash point for the gases and vapors driven off in this phase of the primary combustion process ranges from approximately 500 to 1,300^{o}F, which is usually several hundred degrees higher than their respective volatilization temperatures. Consequently, combustion of the gases and vapors occurs some distance above the bed in a zone where there is sufficient temperature and oxygen for them to be oxidized. If either or both conditions are not met, the partially oxidized vapors and gases will be carried through the system until the right conditions for completion of the oxidation process are met. Table 3-11 shows the ratios of air to weight of solids to burn different types of solid waste.

(3) Phase Three. The third phase in the burndown of solids is the in-place oxidation of the burnable solids left after the vapors and gases have been volatilized. The remaining, partially oxidized cellulose, lignins, and other hydrocarbon solids, when further heated, oxidize to form carbon dioxide and water vapor. This portion of the combustion process occurs in or on the bed in a fairly violent manner. In excess-air systems, the residues from this phase are incompletely burned carbon (char) and inert noncombustibles. Starved-air systems will also have some unburned hydrocarbons.

(4) Phase Four. The fourth phase in the process involves the final burndown of char and the consolidation and cooling of the inert residues, known as bottom ash (metals and ceramic oxides; primarily alumina, silica and calcia, plus lesser amounts of other oxides; see table 3-12). This material is the end product, which, after a short period of cooling on the hearth/grate, is dumped into the ash-receiving system. In small units, the ash may be dumped directly into a dry collection hopper. In large units, the grate continually dumps the ash into the ash quench pit where it is cooled by water.

b. Secondary Combustion.

(1) The final destruction process requires specific conditions. The secondary combustion zone (i.e., secondary combustion chamber in packaged and modular units and the high-temperature secondary combustion zone in large field-erected units) must provide the desired temperature, turbulence, and excess air required to achieve complete destruction of all the unburned gases, vapors, and particulates released from the primary combustion process.

(a) The complete destruction of high-flash-point, low-heat-content vapors and particulates requires more time and greater turbulence than does the complete destruction of the more easily burned materials.

(b) The secondary combustion zone or chamber in which this final combustion process occurs is therefore designed to provide a sufficient volume to achieve the high-temperature residence times required to complete the oxidation of these harder-to-burn materials.

(c) By maintaining the temperatures and oxygen partial pressure in the secondary combustion zones well above the requisite minimum conditions, the reactions involved in the complete destruction of the high-flash-point and/or the low-heat-of-combustion compounds is allowed to proceed at a rate fast enough to assure a high degree of destruction during the limited residence time in this zone or chamber.

(2) Common practice in the design of secondary combustion chambers for municipal waste incinerators is to provide a nominal minimum of 1 to 2.5-seconds gas residence time and nominal secondary gas temperatures in the range of 1,800 to 2,000^{o}F. Also, since the combustion of these volatiles will not be complete unless sufficient oxygen is available, additional air is introduced.

(a) For unprocessed municipal solid waste (MSW), the optimal percent excess air required to achieve high destruction efficiency and high-efficiency energy recovery in a large water-wall furnace is approximately 40-50% (i.e., a Stoichiometric Ratio of 1.4 to 1.5, which provides an atmosphere containing 6.6%-7.7% excess oxygen).

(b) The smaller modular and packaged units achieve their highest destruction efficiencies with 50-100% excess air, or greater (i.e., a stoichiometric ratio of 1.5 to 2.0). They pay for this higher dilution of exhaust gas by having lower efficiency energy recovery.

(c) Introduction of this amount of excess air has been found to be necessary in order to supply the necessary partial pressure of oxygen required to achieve the highest destruction efficiency practical for the conglomeration of materials in municipal waste.

c. Time for Primary Combustion Affected by the Method of Burning.

(1) The time required for complete burndown of municipal solid waste in the primary combustion chamber is a function of how the solid waste is fed into the system. The time required varies from six hours to a few minutes, depending upon the design of the furnace and the method used for feeding and supporting the waste while it is being burned.

(a) Mass Burn Systems. These systems are the dominant type used to burn solid waste. A mass burn system uses a hearth or a grate to support a large mass of raw or processed waste as it is progressively burned down. The burndown process typically requires a nominal four to six hours from the time the waste is introduced into the primary combustion chamber until the ash is discharged. Incinerators operating under oxygen-deficient conditions (starved-air primary-combustion mode) require longer burndown times than the furnaces operating in the oxygen-rich condition (excess-air primary-combustion mode).

(b) Injection-Fed, Dispersed-Bed System. This type of feed and method of distributing the waste as it is being burned is used in the fluidized-bed incinerator. Because the waste is diluted as it is rapidly distributed throughout the volume of the fluidized bed, much less time is required for complete destruction. The thermal destruction of waste in a fluidized-bed incinerator requires essentially the same sequence for progressive destruction of the material, but instead of occurring in discrete zones, all of the processes occur simultaneously in a single large bed. Air and small particles of waste are continuously injected at a high rate into the bed, and ample oxygen is always available to all parts of the bed. This allows each distinct piece of waste to undergo its drying, volatilization, oxidation of the gases and vapors, combustion of organic solids, and complete burndown of the char in all parts of the bed at the same time. Residence time for destruction of the small, (-2 inch), sized waste in the $1,500^0$F bed is of the order of minutes.

(c) Co-firing of Refuse-Derived Fuel (RDF). Co-feeding and co-firing of specially prepared refuse, RDF, with coal in a coal-fired boiler allows the waste to be destroyed at a rate comparable with that of burndown of the coal fed to the boiler furnace. This method of destruction of waste requires that the waste be sized, prepared, and fed into the furnace in a manner that assures that the 10-20% by weight of waste will burn down at a rate faster than that required for the 80-90% by weight of coal, for which the boiler was originally designed. Thus, a spreader stoker furnace burning 2-in. coal is co-fired with 0.75-1.5 in.-diameter pellets or cubes of RDF. Suspension-fired boiler furnaces firing pulverized coal are co-fired with fluff RDF.

d. Special Design Considerations.

(1) In the case of incinerators used to burn hazardous substances, a minimum residence time of 2 seconds at a minimum of $1,800^o$F is used in the design criteria for achieving the 99.99% destruction efficiency required by law for hazardous waste incinerators. Some states are also requiring this higher efficiency destruction on municipal waste incinerators in order to assure the destruction of dioxins.

(2) Toxic materials may be formed during primary combustion by the reaction of partially burned hydrocarbons with chlorine and must be destroyed in the secondary combustion process.

(3) Figure 3-2 shows the relationship of destruction efficiency of biphenyls and chlorobenzenes (autogenous ignition temperature of $1,319^0$F and $1,245^0$F, respectively), with time and temperature.

e. Mechanical Features Used to Achieve Process Control. The design of a mass burn furnace requires special provisions:

(1) Controlled introduction of air at the appropriate locations above and below the bed is required in order to accomplish the drying, volatilization, and combustion processes in the respective zones of the combustion chamber.

(2) Incinerators with primary combustion chambers operating in the starved-air mode require proportionately larger amounts of secondary air. This larger amount of air tends to cool the gases and requires that an auxiliary burner be provided to heat and maintain the gases at the required temperature. Typically, the less the amount of air delivered to the primary chamber (i.e., starved-air mode), the more air and the greater the auxiliary burner (either oil or natural gas fired) input to the secondary. This requires that the starved-air units (SAU) be provided with a larger volume secondary chamber than their comparable capacity excess-air unit (EAU). Table 3-13 lists the typical air distribution for primary and secondary combustion chambers/zones for modular and field-erected incinerators.

f. Chamber Geometry and Insulation. Well-designed units make provision for the necessary features (i.e., insulation, size and shape of the chambers, etc.) for attaining and maintaining the temperatures desired in the respective zones of the furnace. For this reason, a primary chamber designed to operate in the starved-air mode will use a different configuration and type of insulation than a unit designed for operation in the excess-air mode

g. Chamber Volume/Gas Residence Time.

(1) The combustion chamber must be sized to provide adequate residence time for complete destruction. The time required in the primary chamber is a function of the characteristics of the waste, the type of charging used, and the mode of operation (e.g., the starved-air mode requires more time than does the excess-air mode).

(a) Of principal interest to the furnace designer is the projected hourly throughput required, the average moisture in the waste, and the major constituents, including the percentage of inerts and highly combustible materials.

(b) Best performance is obtained by providing as uniform a feeding of the waste to the primary combustion chamber as possible. Similarly, allocation of space in the secondary chamber is a function of the volume of the total gas throughput and the need to provide the necessary 1.0 to 2.5 seconds of residence time, at temperature, before the gases are discharged to the downstream components.

h. Turbulence. Turbulence takes on two forms in the waste combustion process, slow agitation of the solid waste and turbulent mixing of gases and air in the gas combustion zones.

(1) Continuous and/or routine agitation of the solid waste during the drying and volatilization phases assures that material in the lower part of the bed will not be insulated from the heat and gases sweeping over the top of the bed. By providing some physical means (usually a patented grate system) for the continual turning of the waste, the drying process will proceed at a more uniform rate.

(2) Excessive and violent agitation of the bed by vigorous turning or by high-velocity flow of air up through the bed can be detrimental. Although drying may be more rapid and the waste is more frequently exposed to the radiated heat from the chamber walls, the lightweight ash and partially burned material on the surface could be excessively agitated.

(a) Vigorous agitation will result in excessive amounts of solids being carried up with the gases. Some of these solids (e.g., flakes of paper and partially burned lightweight material) will burn with the gases as they enter the secondary zone and end up as fly ash. However, some of this solid material will continue to burn long after it leaves the secondary zone simply because it takes much longer to oxidize the solid material than it does to oxidize the gases. Unless special equipment is provided, the burning material may cause fires in the bag house.

(b) Aside from the fire potential, the excess solid particulate creates problems by fouling the heat transfer surfaces and by producing additional loading to the gas cleanup system.

(c) Release of these unburned artifacts can also contribute to the adverse emissions from waste incinerators. The release of dibenzo-p-dioxins (dioxins) and dibenzofurans (furans) has been associated with this condition; it has been postulated that the airborne unburned carbon provides the sites for reaction of the chlorine gas released from the oxidized, chlorine-containing waste with other unburned hydrocarbons to form any number of chlorinated hydrocarbons, including small amounts of dioxin and furan.

i. Secondary Chamber Turbulence.

(1) High turbulence in the secondary combustion zone is necessary in order to assure proper mixing of the organic vapors and gases with the secondary combustion air. Complete mixing assures that the oxidation reaction proceeds to completion, since all of the carbon and hydrogen in the gases and vapors can come in contact and react with an adequate supply of air (oxygen) to convert these hydrocarbons into carbon dioxide and water vapor.

(2) Improper design and/or operation of the devices intended to provide proper turbulence in the solids and the gases will retard and impede the drying, volatilization, and oxidation processes critical to high-efficiency destruction of municipal solid waste. This results in low throughput, a high percent of unburned material in the ash, and serious emissions problems. Improper operation of a well-designed furnace by excessive loading or improper balance of the draft system can produce the same effect.

3-6. COMBUSTION PROCESS CONTROL.

a. Process Controlled by Design.

(1) The most recent combustion research indicates that the best correlation to complete destruction of individual compounds is the unique combination of the "3 Ts" required for that specific compound. Thus, a design for a municipal waste furnace that does not provide for either the careful control and monitoring of the envelope of three "Ts" required for the constituents in MSW nor the proper apportionment of air can only expect poor performance, excessive maintenance problems, and the release of unacceptable levels of pollutants to the environment.

(2) Fortunately, the reactions involved in the combustion process can be modified significantly by restricting/balancing the flow of air during the different stages/phases of the combustion process.

b. Effect of Air Control on the Primary Combustion Process.

(1) The four phases in the thermal destruction of waste by oxidation release chemical compounds generated from these reactions that can be altered by the conditions under which these compounds are formed. The amount of air available to the process will determine how far each different stage or phase can go through to completion, assuming all other conditions are met. Excess amounts of air has drawbacks as well.

(2) Drying Phase. Since this phase involves the driving off of absorbed and bound moisture in the waste, this phase of the combustion process does not produce energy, but it does produce products (water vapor and excess air) that can have a negative effect on subsequent phases of the total oxidation process. It is, therefore, advantageous to provide only the necessary heat and air required to remove as much moisture from the bed/fuel as is practical. The air-control system must inject only that amount of air needed to dry the waste, since this same air will be used downstream to provide oxygen to the other phases of the combustion process. Excessive amounts of air (i.e.,

more than is required for drying) will only upset the balance needed to control the subsequent phases.

(3) Volatilization Phase. Depending upon the availability of air, the chemical compounds released as the rising temperature reaches and exceeds the respective volatilization temperatures may or may not burn. Careful apportionment of air will determine how these reactions proceed. Typically, a primary combustion zone/chamber operating with a S.R. of 0.5 to 0.9 will provide less air through the bed and thus produces less agitation of the bed; as a result, fewer particulates are released from the bed. Also, the less the released gases and vapors are oxidized, the greater the amount of gases and vapors that will survive unburned through the primary combustion zone; as a result, a greater amount will be available as fuel in the secondary combustion zone. At lower gas temperatures, less NO_x is likely to form, and it will take longer to achieve the completion of this volatilization phase. The lower temperature and larger volume of unburned gases will require additional heat be supplied to the secondary combustion chamber in order to ensure that the requisite temperature for final destruction is attained and maintained. On the other hand, primary combustion zones/chambers operating with a S.R. of 0.95 to 1.1 will produce more particulate matter, because almost twice as much air is passing through and around the bed. In addition, the chamber will operate at higher temperatures since more of the gases and vapors will burn in and above the bed, resulting in higher levels of NO_x. It will also discharge smaller amounts of unburned gases and vapors to the secondary zone chamber, although they will be at a very high temperature and will therefore probably not require significant additional heat beyond that provided by the unburned gases and vapors as they are burned in the secondary combustion process. Even when operating with a primary combustion chamber S.R. of 1.0 to 1.1, the primary combustion gases will still contain significant amounts of CO and other partially burned combustible gases, vapors, and particulates. This fuel, when burned, will contribute enough heat to the secondary combustion process that usually there is no problem maintaining the gas temperature well above the minimum temperature of 1,600^{o}F for autogenous combustion of the gases and vapors. This is true even when additional air for secondary combustion is added to raise the S.R. to the desired 1.4 to 1.5.

(4) In-place Oxidation of Burnable Solids. This third phase of the primary combustion process produces the hottest zone of the bed. It is controlled by introducing only enough air to complete the burndown of the nonvolatile organic materials. Insufficient air in this stage will mean that these materials will go unburned, only be partially burned, and/or will require a longer time for burndown. If the burndown is not completed in this phase, it will occur concurrent with and compete for the air in the burndown of the char in the last stage. Any material not burned will mean that heat will not be generated and effectively lost to this stage of the process. Excess air during this stage will produce hotter combustion products because of the higher rate of combustion, which will also produce more NO_x. The higher agitation caused by greater air flow will produce more fly ash in the gases.

(5) Char Burndown. This phase normally requires only enough air to achieve final destruction of the carbonaceous material remaining after the burning of the hydrocarbon during the third stage. Insufficient combustion air at this stage will mean that the ash residues will contain excessive amounts of carbon. Thus, the primary combustion process will not have achieved maximum volume and weight reduction in the waste destruction process, and the ash residues will be biologically active since it contains organic material. Excessive air to this stage will achieve the desired destruction of the carbon, but it will also introduce more air into the primary chamber, which will counter the effect of trying to maintain the control of air introduced to the system in the other stages. Since this final stage requires the lowest percentage of the primary combustion air, the

effect of introducing moderate levels of excess air in this stage has the least effect on the total system.

c. Effect of Air Control On Secondary Combustion.

(1) Since this is the last of the two processes, the secondary combustion process is designed to provide the final destruction and "polishing" of the combustion gases to achieve as benign a discharge gas as possible. This requires that the amount of air and the points of introduction to the secondary combustion process be closely controlled.

(2) Large water-wall incinerator systems may achieve the highest destruction rates, produce the lowest CO concentrations (below 30-50 ppm), and have the highest combustion efficiency, with exit gas S.R.s of 1.4 to 1.5 and secondary gas temperature maintained above 1,600^{0}F for 1.0 to 2.0 s. (see figure 3-3).

(3) The smaller modular and packaged incinerator units achieve their best performance with exit gas S.R.s of 1.5-2.0 and exit gas temperature in the 1800-2000^{0}F range. To attain these temperatures with the higher air dilution, auxiliary burners must be used.

d. Effect of Air Control On Emissions.

(1) Control of the stoichiometry, temperature and time relationship in the secondary combustion process have been shown to be the primary factors in meeting emissions requirements.

(a) Analysis of operating waste to energy facilities in the United States and Canada have shown that the lowest levels of chlorinated hydrocarbons and benzopyrenes are achieved when the CO levels are below 50 ppm (see figure 3-3).

(b) The achievement of low NO_x is a function of what happens to the air as it passes through both the primary and secondary chamber. Since the kinetics of NO_x formation is a function of both temperature and the stoichiometric ratio of the gas (i.e., NO_x decomposes in substoichiometric gases), systems that use the starved-air mode of operation in the primary combustor have lower levels of NO_x than do excess-air systems, even though they operate their secondary combustion chambers under essentially the same temperature, time, and S.R. conditions. Figure 3-4 shows the equilibrium concentration of NO_x.

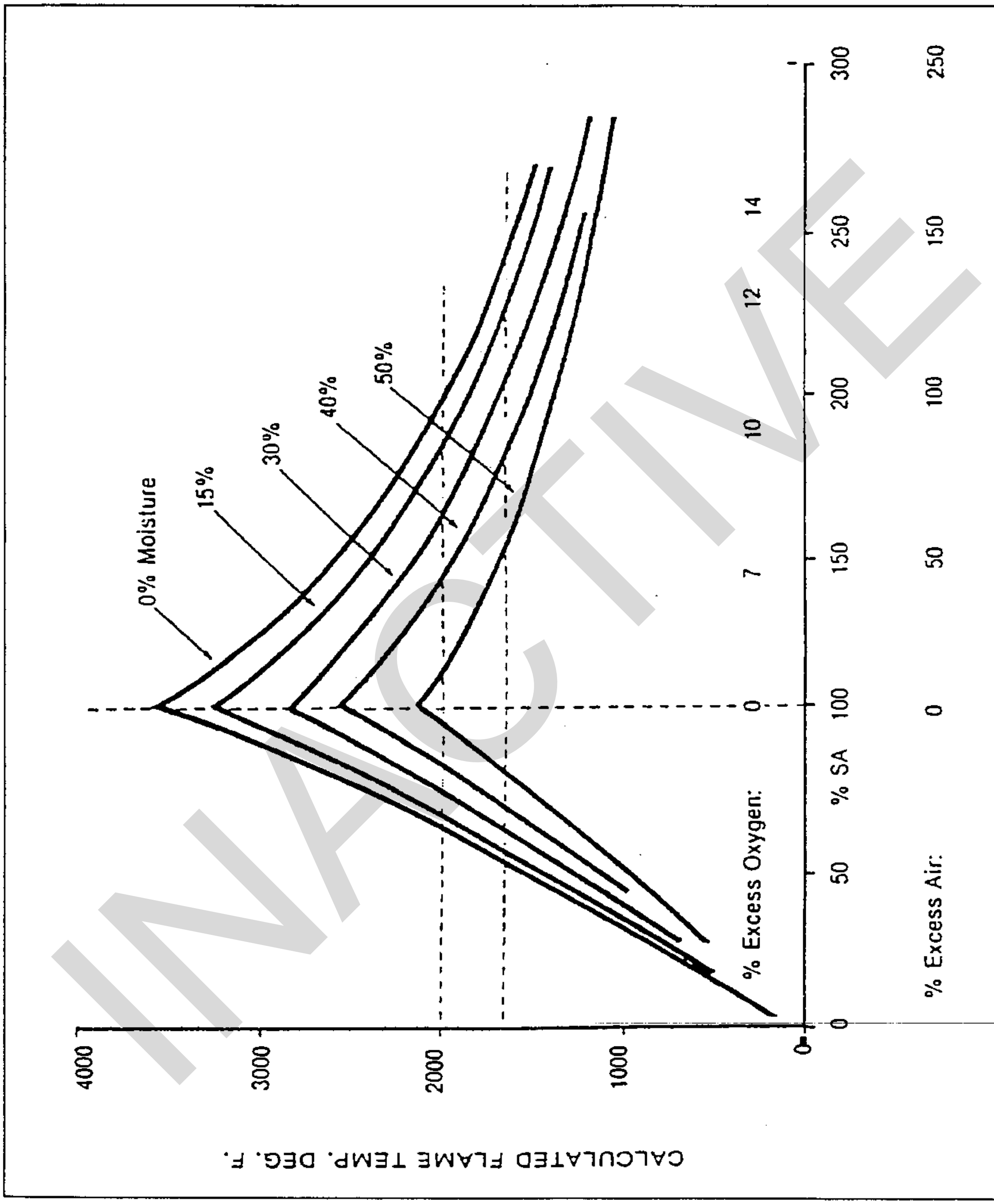

Figure 3-1. Theoretical temperature of the products of combustion

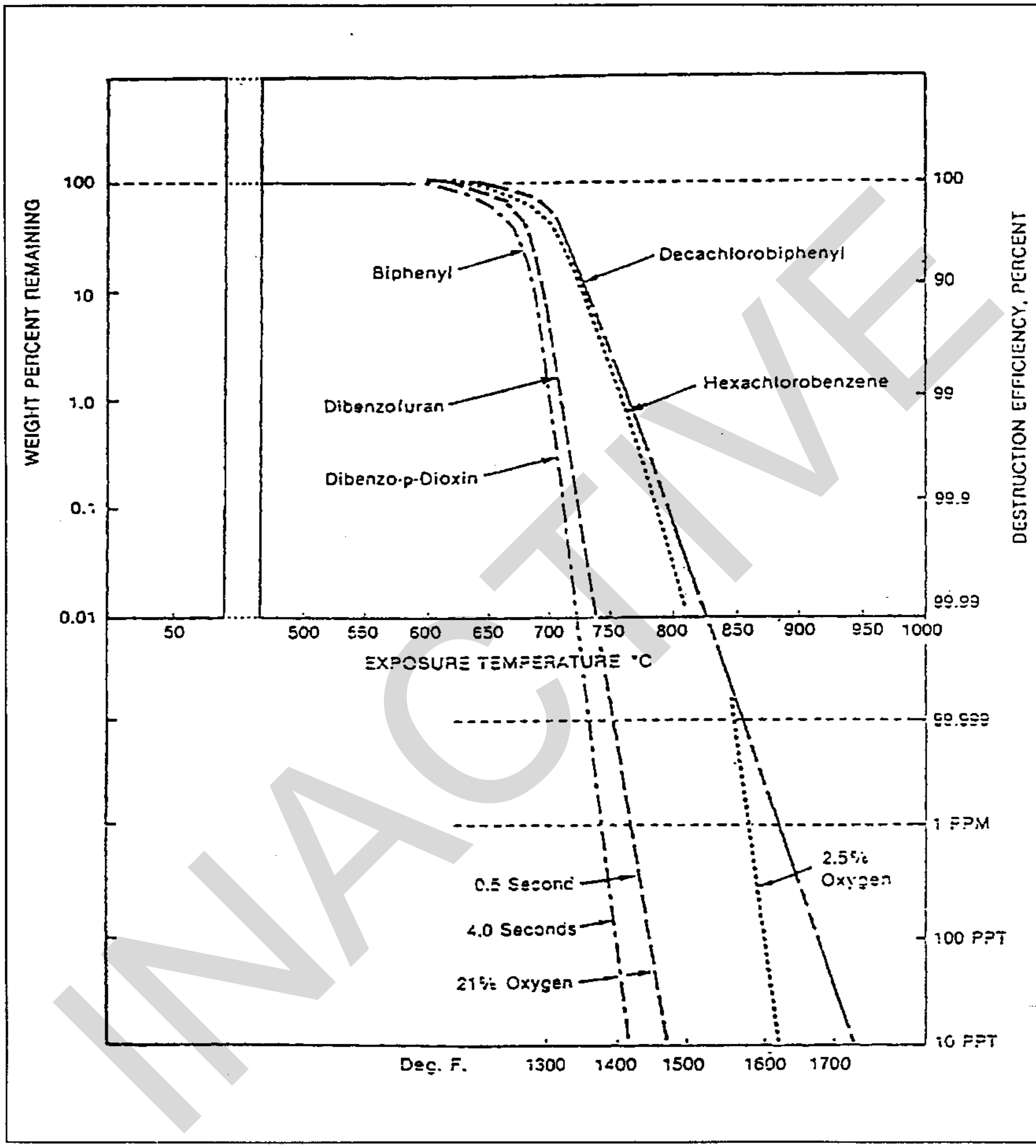

Figure 3-2. Relationship of destruction efficiency of biphenyls and
and chlorobenzenes with temperature

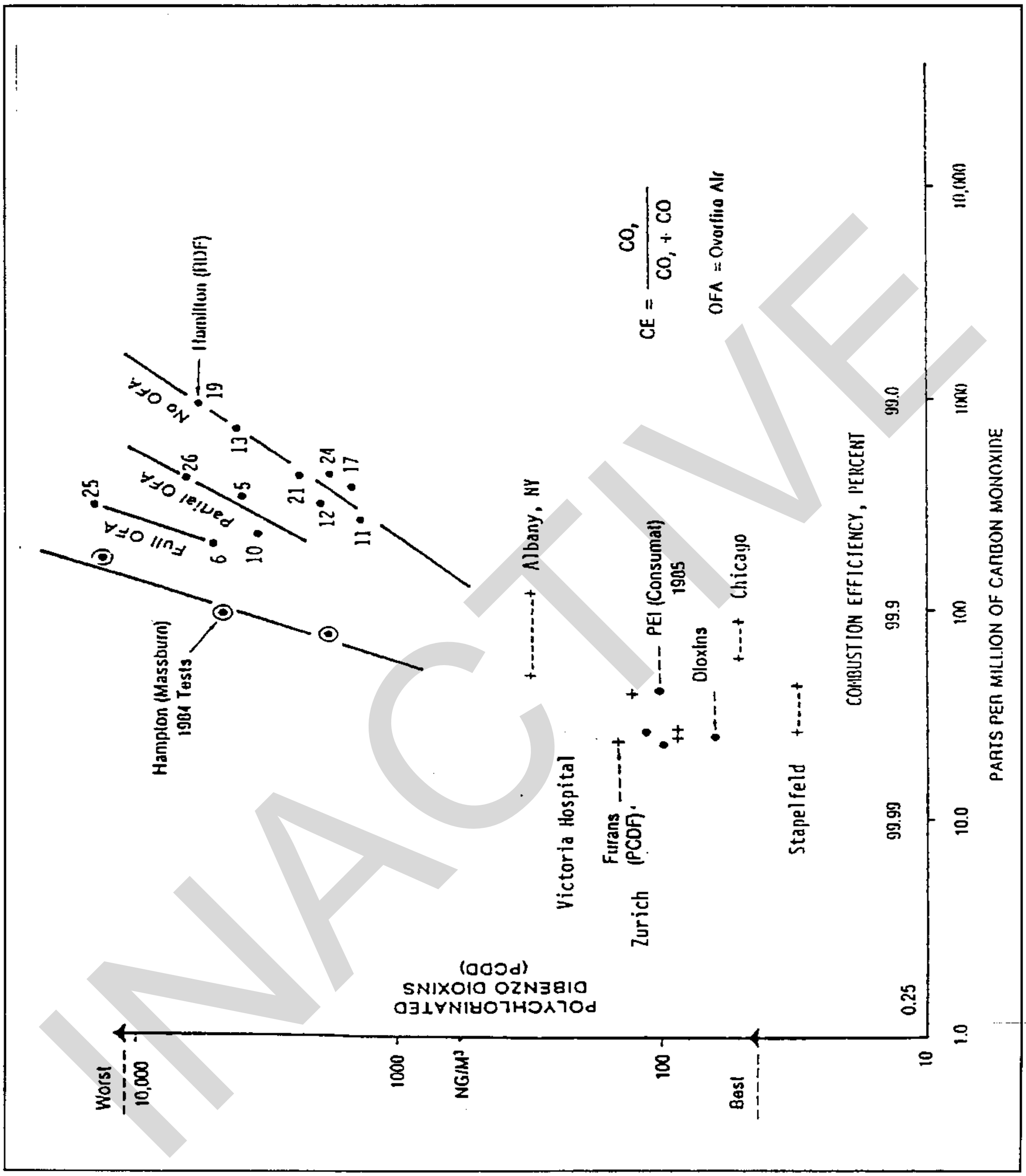

Figure 3-3. Logarithmic plot of PCCD versus carbon monoxide and combustion efficiency

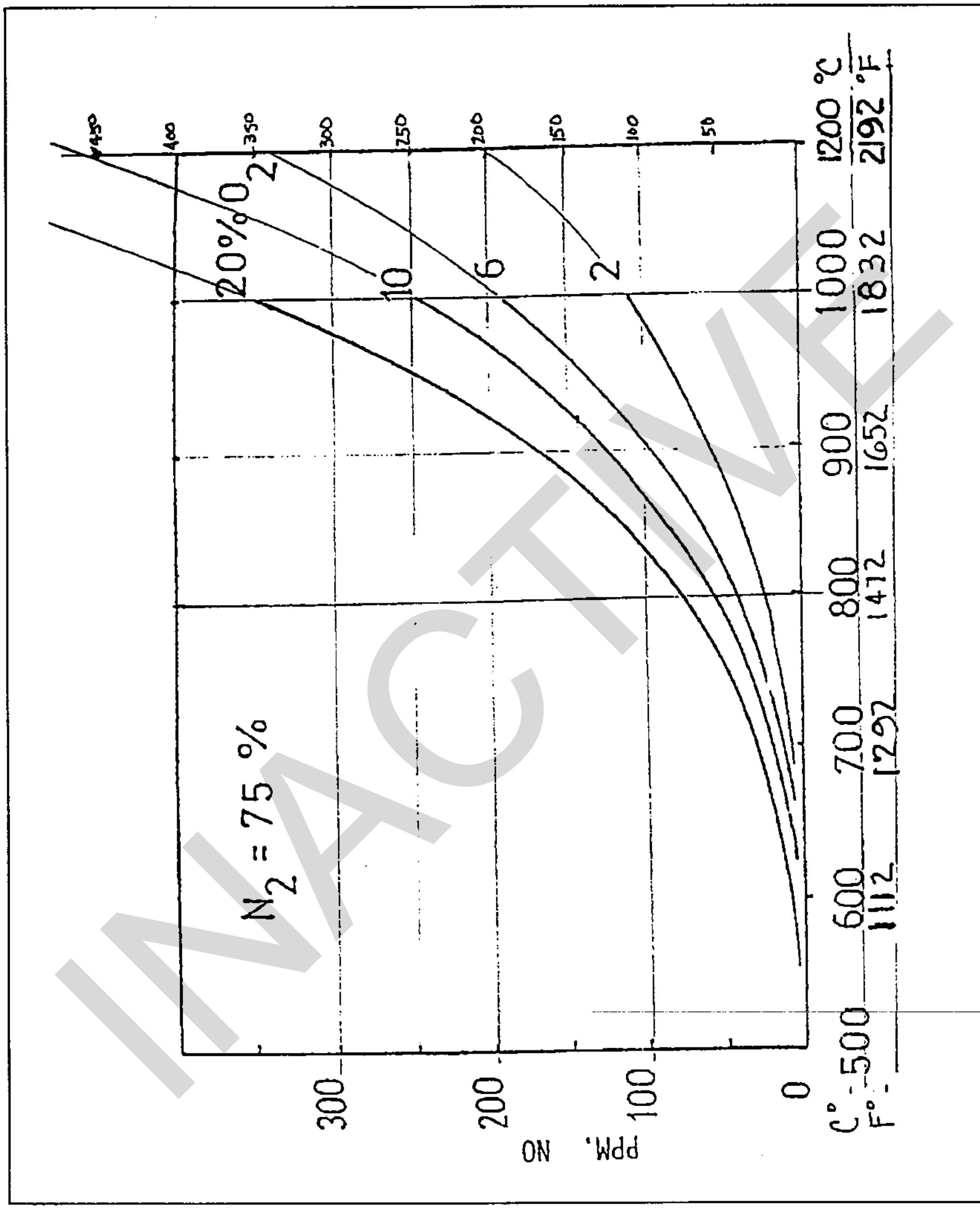

Figure 3-4. Equilibrium concentrations of NO_x

Table 3-1. Classification of Wastes to be Incinerated.

Classification of Wastes	Principal Components	Approximate Composition % by weight	Approximate Moisture Content %	Approximate Incombustible Solids, %	Approximate Heating Value As-Fired, Btu/lb	Btu of Aux. Fuel per lb of Waste to be Included in Combustion Calculations	Average Weight of Waste lb/cu. ft.*
Trash, Type 0	Highly combustible waste, paper, wood, cardboard, cartons, including up to 10% treated papers, plastic or rubber scraps; commercial and industrial sources	Trash, 100	10	5	8,500	0	8 to 10
Rubbish, Type 1	Combustible waste: paper, cartons, rags, wood scraps, combustible floor sweepings; domestic, commercial, and industrial sources	Rubbish, 80	25	10	6,500	0	8 to 10
Refuse, Type 2	Rubbish and garbage residential sources	Rubbish, 50 Garbage, 50	50	7	4,300	0	15 to 20
Garbage, Type 3	Food wastes, animal and vegetable	Garbage, 100	70	5	2,500	1,500	30 to 35
Animal solids and organic wastes, Type 4	Carcasses, organs, solid organic wastes, hospital, laboratory, abattoirs, animal pounds, and similar sources	Animal and human tissue, 100	85	5	1,000	3,000	45 to 55

*The weights given are general and based on materials usually expected in refuse collection. Wherever these densities are exceeded, consideration must be given to designs beyond minimum standards.

SOURCE: Incinerator Standards, Incinerator Institute of America (National Solid Wastes Management Association), Washington, D.C., Nov., 1968.

Table 3-2. Combustion Data for Paper, Wood, and Garbage.

Material	Sulfite Paper[a] %		Average Wood %		Douglas Fir %		Garbage[b] %	
Carbon, C	44.34		49.56		52.30		52.78	
Hydrogen, H	6.27		6.11		6.30		6.27	
Nitrogen, N			0.07		0.10			
Oxygen, O	48.39		43.83		40.50		39.95	
Ash	1.0		0.42		0.80		1.0	
Gross Btu/lb, dry	7,590		8,517		9,050		8,820	
Constituent (Based on 1 lb)	scfc	lb	scf	lb	scf	lb	scf	lb
Theoretical air								
40% sat at 60°F	67.58	5.16	77.30	5.90	84.16	6.43	85.12	6.50
Flue gas with theo. air	68.05	5.18	77.84	5.93	84.75	6.46	85.72	6.53
CO_2	13.99	1.62	15.64	1.81	16.51	1.91	16.66	1.93
N_2	53.40	3.94	61.10	4.51	66.53	4.91	67.23	4.97
H_2O formed	11.78	0.56	11.48	0.54	11.84	0.56	11.88	0.56
H_2O (air)	0.47	0.02	0.53	0.02	0.58	0.02	0.59	0.02
Total Flue Gas/lb fuel S.R.=1	79.65	6.15	88.77	6.90	95.46	7.42	96.37	7.49
Flue gas with % excess air as indicated								
0 (S.R.=1)	79.65	6.16	88.77	6.91	95.47	7.43	96.38	7.50
50	113.44	8.74	127.42	9.86	137.55	10.64	139.24	10.77
100	147.23	11.32	166.07	12.81	179.63	13.86	182.00	14.04
150	181.26	13.91	204.99	15.78	222.01	17.09	224.86	17.21
200	215.28	16.51	243.91	18.75	264.38	20.12	267.72	20.58
300	283.33	21.70	321.75	24.68	349.13	26.58	353.44	27.12

[a]constituents of sulfite paper, %

Cellulose	$C_6H_{10}O_5$	84
Hemicellulose	$C_6H_{10}O_5$	8
Lignin	$C_6H_{10}O_5$	6
Resin	$C_6H_{10}O_5$	2
Ash	SiO_2 & CaO	1

[b]Estimated

[c]Measured at 60 F and 14.7 psia.

Source: Air Pollution Engineering Manual, U.S. Environmental Protection Agency, AP-40, 1973

Table 3-3. Btu and other pertinent combustion values for selected materials.

Waste	Btu Value/lb as Fired	Weight in lb/ft³, Loose	Weight in lb/ft³	Content by weight in Percentage	
				Ash	Moisture
Type 0 waste	8,500	10		5	10
Type 1 waste	6,500	10		10	25
Type 2 waste	4,300	20		7	50
Type 3 waste	2,500	35		5	70
Type 4 waste	1,000	55		5	85
Kerosene	18,900		50	0.5	0
Benzene	18,210		55	0.5	0
Toluene	18,440		52	0.5	0
Hydrogen	61,000		0.0053	0	0
Acetic acid	6,280		65.8	0.5	0
Methyl alcohol	10,250		49.6	0	0
Ethyl alcohol	13,325		49.3	0	0
Turpentine	17,000		53.6	0	0
Naphtha	15,000		41.6	0	0
Newspaper	7,975	7		1.5	6
Brown paper	7,250	7		1.0	6
Magazines	5,250	35		22.5	5
Corrugated paper	7,040	7		5.0	5
Plastic coated paper	7,340	7		2.6	5
Coated milk cartons	11,330	5		1.0	3.5
Citrus rinds	1,700	40		0.75	75
Shoe leather	7,240	20		21.0	7.5
Butyl sole composition	10,900	25		30.0	1
Polyethylene	20,000	40-60	60	0	0
Polyurethane, foamed	13,000	2	2	0	0
Latex	10,000	15	45	0	0
Rubber waste	9,000-11,000	62-125		20-30	
Carbon	14,093		138	0	0
Wax paraffin	18,621		54-57	0	0
1/3 wax - 2/3 paper	11,500	7-10		3	1
Tar or asphalt	17,000	60		1	0
1/3 tar - 2/3 paper	11,000	10-20		2	1
Wood sawdust, pine	9,600	10-12		3	10
Wood sawdust	7,800-8,500	10-12		3	10
Wood bark, fir	9,500	12-20		3	10
Wood bark	8,000-9,000	12-20		3	10
Corn cobs	8,000	10-15		3	5
Rags, silk or wool	8,400-8,900	10-15		2	5
Rags, linen or cotton	7,200	10-15		2	5
Animal fats	17,000	50-70			0
Cotton seed hulls	8,600	25-30		2	10
Coffee grounds	10,000	25-30		2	20
Linoleum scrap	11,000	70-100		20-30	

The chart shows the various Btu values of materials commonly encountered in incinerator designs. The values given are approximate and may vary based on their exact characteristics or moisture content.

SOURCE: Incinerator Standards, Incinerator Institute of America (National Solid Waste Management Association), November, 1968.

Table 3-4. Nominal Composition of Discards in U.S Municipal Solid Waste.

	1986 Gross MSW Waste Stream 10^6 Tons	1986 Gross MSW Waste Stream Percent	Inerts/Ash Unit %	Inerts/Ash % MSW	Moisture Unit %	Moisture % MSW	As Discarded Heating Value Btu/lb
1. Paper and Paperboard	64.7	41.0		1.88		2.26	
Newspaper	12.7	8.0	1.5	0.12	6.0		7,974
Books and Magazines	4.8	3.0	20.0	0.60	4.1		5,254
Office Paper	6.1	3.9	7.0	0.27	5.5		
Commercial Printing	3.7	2.3	7.0	0.16	5.5		
Other Nonpackaging Paper	8.5	5.4	1.0	0.5	4.6		
Corrugated Containers	19.4	12.3	5.0	0.62	5.2		7,043
Other Paperboard	5.4	3.4	1.0	0.03	5.6		
Paper Packaging	4.2	2.7	1.0	0.03	5.8		
2. Aluminum	2.4	1.5		1.50		0	0
Beverage Cans	1.3	0.8	100	0.80			
Other Aluminum Packages	0.4	0.3	100	0.30			
Other Aluminum Products	0.7	0.4	100	0.40			
3. Other Non Ferrous Metal	0.3	0.2	100	0.20		0	0
4. Ferrous	11.0	7.0		7.00		0	0
Beverage Containers		0.1	100	0.10			
Food Cans	1.8	1.1	100	1.10			
Other Steel Packaging	0.9	0.6	100	1.10			
Other Steel Products	8.2	5.2	100	5.20			
5. Glass	12.9	8.2		8.2		0	0
Beverage Containers	5.5	3.5	100	3.50			
Other Glass Containers	6.3	4.0	100	4.0			
Other Glass Products	1.1	0.7	100	0.70			
6. Plastics	10.3	6.5		1.00	0.2	0.013	
Plastic Containers	2.9	1.8	19.0	0.34			15,000
Other Plastic Packaging	2.8	1.8	6.0	0.11			
Other Plastic Products	4.6	2.9	19.0	0.55			
7. Yard Wastes	28.3	17.9	33.0	5.91	55.0	9.80	4,900
8. Food Wastes	12.5	7.9	5.0	0.40	60.0	4.74	3,700
9. Wood Products/Materials	5.8	3.7	1.6	0.06	20.0	0.74	7,000
10. Clothes, Textiles, Rubber	5.0	3.2	14.5	0.46	10.0	0.32	6,000
11. Tires	1.8	1.1	16.0	0.18		0	11,300
12. Dirt/Inorganics/Misc.	2.8	1.8	100	0.02	10.0	0.18	0
Total	157.7	100.0		28.65		18.05	

Table 3-5. Chemical Analyses of Some Residential and Commercial Wastes.

	Portland, Oregon			Broward City, FL
Analyses	Residential	Commercial	Mixed	Mixed
Carbon	29.45%	40.17%	34.67%	40.94%
Hydrogen	6.72	6.48	6.60	5.77
Oxygen	28.44	31.33	29.86	21.64
Sulfur	1.33	2.45	1.86	0.09
Chlorine	0.19	0.31	0.25	0.41
Nitrogen	1.50	0.50	1.00	0.50
Moisture	26.34	11.24	18.98	24.58
Ash	6.09	7.53	6.79	6.07
Total	100.00%	100.00%	100.00%	100.00%
Higher Heating Value (HHV), Btu per Pound				
As Received	6,281	7,107	6,694	6,756
Dry	9,946	8,053	9,000	8,958
Moisture/ Ash Free	10,639	8,721	9,680	10,291

Table 3-6. Proximate Analysis of Waste Components in Household Discards (Percent by Weight).

Component	Moisture	Volatile Matter	Fixed Carbon	Ash	As Discarded kJ/kg	As Discarded Btu/lb	Dry Basis kJ/kg	Dry Basis Btu/lb
Newspaper	5.97	81.12	11.48	1.43	18,540	7,974	19,716	8,480
Brown Paper	5.83	83.92	9.24	1.01	16,870	7,256	17,916	7,706
Trade Magazine	4.11	66.39	7.03	22.47	12,216	5,254	12,741	5,480
Corrug. Paper Boxes	5.20	77.47	12.27	5.06	16,375	7,043	17,272	7,429
Mixed Paper	--	--	--	--	--	--	18,119	7,793
Plastic Film	--	--	--	--	--	--	32,192	13,846
Plastic, Other	--	--	--	--	--	--	21,039	9,049
Plastic Coated Paper	4.71	84.20	8.45	2.64	17,068	7,341	17,909	7,703
Waxed Milk Cartons	3.45	90.92	4.46	1.17	26,335	11,327	27,277	11,732
Paper Food Cartons	6.11	75.59	11.80	6.50	16,875	7,258	17,972	7,730
Junk Mail	4.56	73.32	9.03	13.09	14,155	6,088	14,829	6,378
Vegetable Food Wastes	78.29	17.10	3.55	1.06	4,173	1,795	19,228	8,270
Citrus Rinds and Seeds	78.70	16.55	4.01	0.74	3,969	1,707	18,635	8,015
Meat Scraps, Cooked	38.74	56.34	1.81	3.11	17,723	7,623	28,930	12,443
Fried Fats	0.00	97.64	2.36	0.00	38,283	16,466	38,283	16,466
Leather Shoe	7.46	57.12	14.26	21.16	16,840	7,243	18,195	7,826
Heel and Sole Composition	1.15	67.03	2.08	29.74	25,340	10,899	25,635	11,026
Rubber	1.2	83.98	4.94	9.88	--	--	26,342	11,330
Rags	10.0	84.34	3.46	2.20	--	--	17,791	7,652
Vacuum Cleaner Catch	5.47	55.68	8.51	30.34	14,847	6,386	15,708	6,756
Evergreen Trimmings	69.00	25.18	5.01	0.81	6,296	2,708	20,309	8,735
Balsam Spruce	74.35	20.70	4.13	0.82	5,689	2,447	22,183	9,541
Flower Garden Plants	53.94	35.64	8.08	2.34	8,596	3,697	18,663	8,027
Lawn Grass	75.24	18.64	4.50	1.62	4,785	2,058	19,325	8,312
Ripe Tree Leaves	9.97	66.92	19.29	3.82	18,563	7,984	20,620	8,869
Wood and Bark	20.0	67.89	11.31	0.80	--	--	20,025	8,613
Brush	40.0	--	--	5.0	--	--	18,368	7,900
Metallics	3.0	0.5	0.5	96.0	--	--	288	124
Glass and Ceramics	2.0	0.4	0.4	97.2	--	--	151	65
Ashes	10.0	2.68	24.12	63.2	--	--	9,700	4,172

Table 3-7. Ultimate Analysis of Waste Components (Dry Basis, Percent by Weight).

Component	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Newspaper	49.14	6.10	43.03	0.05	0.16	1.52
Brown Paper	44.90	6.08	47.84	0.00	0.11	1.07
Trade Magazine	32.91	4.95	38.55	0.07	0.09	23.43
Corrug. Paper Boxes	43.73	5.70	44.93	0.09	0.21	5.34
Mixed Paper	44.0	6.15	41.65	0.43	0.12	7.65
Plastic Film	67.21	9.72	15.82	0.46	0.07	6.72
Plastic, Other	47.70	6.04	24.06	1.93	0.55	19.72
Plastic Coated Paper	45.30	6.17	45.50	0.18	0.08	2.77
Waxed Milk Cartons	59.18	9.25	30.13	0.12	0.10	1.22
Paper Food Cartons	44.74	6.10	41.92	0.15	0.16	6.93
Junk Mail	37.87	5.41	42.74	0.17	0.09	13.72
Vegetable Food Wastes	49.06	6.62	37.55	1.68	0.20	4.89
Citrus Rinds and Seeds	47.96	5.68	41.67	1.11	0.12	3.46
Meat Scraps, Cooked	59.59	9.47	24.65	1.02	0.19	5.08
Fried Fats	73.14	11.54	14.82	0.43	0.07	0.00
Leather Shoe	42.01	5.32	22.83	5.98	1.00	22.86
Heel and Sole Composition	53.22	7.09	7.76	0.50	1.34	30.09
Rubber	77.65	10.35	--	--	2.0	10.0
Rags	55.00	6.60	31.20	4.62	0.13	2.45
Vacuum Cleaner Catch	35.69	4.73	20.08	6.26	1.15	32.09
Evergreen Trimmings	48.51	6.54	40.44	1.71	0.19	2.61
Balsam Spruce	53.30	6.66	35.17	1.49	0.20	3.18
Flower Garden Plants	46.65	6.61	40.18	1.21	0.26	5.09
Lawn Grass	46.18	5.96	36.43	4.46	0.24	6.55
Ripe Tree Leaves	52.15	6.11	30.34	6.99	0.16	4.25
Wood and Bark	50.46	5.97	42.37	0.15	0.05	1.60
Brush	42.52	5.90	41.20	2.0	0.05	8.33
Metallics	0.76	0.04	0.2	--	--	--
Glass and Ceramics	0.56	0.03	0.11	--	--	--
Ashes	0.28	0.5	0.8	--	0.5	70.2

Table 3-8. Ultimate Analysis of Some Commonly Used Plastics and Fuels (Percent by Weight).

Plastic Type	Moisture	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Chlorine	Ash	Btu/lb
Polyethylene Low Dens.	0.20	67.20	9.70	15.8	0.46	0.07	--	6.64	14,600
Polyethylene High Dens.	0.20	84.38	14.14	0.0	0.06	0.03	tr	1.19	20,034
Polystyrene	0.20	86.91	8.42	3.96	0.21	0.02	tr	0.45	18,096
Polyurethane	0.20	63.14	6.25	17.61	5.98	0.02	2.42	4.38	11,700
Polyvinyl Chloride	0.20	45.04	5.60	1.56	0.08	0.14	45.32	2.06	8,617
Polyethylene Terephtalale	0.20	62.50	4.14	33.10	0	0	0	0.50	9,263
Polypropelene		85.70	14.30						19,819
Natural Gas	tr	71.6	23.9	0	3.38	--	--	--	22,500
Kerosene		85.8	14.2	--	--	0.0058	--	tr	19,957
IL No. 6 Coal	12.0	63.8	3.5					16.0	11,160
No. 1 Fuel Oil		86.3	13.8	--	7.1	0.1		tr	19,810
Pine									

Table 3-9. Effect of Processing and Recycle Programs

	Raw MSW	RDF	RDF After Source Separation
% Original Material	100%	66-65%	43-55%
Heating Value (Btu/lb)	4,300-4,600	7,000-8,000	6,200-6,500

Table 3-10. Excess Air at Furnace Outlet

Fuels		Percent Excess Air
Gaseous	Natural Gas	5-10
	Refinery Gas	8-15
	Blast Furnace Gas	15-25
	Coke Oven Gas	5-10
Liquid	Oil	3-15
Solid	Coal (Pulverized)	15-30
	Coke	20-40
	Wood	25-50
	Bagasse	25-45
	MSW (Excess Air)	40-50
	MSW (Starved Air)	130-150

Table 3-11. Amounts of Air Needed for Combustion of Various Kinds of Waste.

Material	High Heat Value,[a] Btu per lb of MAF[b] Waste	Air Needed for Complete Combustion lb per lb of MAF Waste[c]
Paper	7,900	5.9
Wood	8,400	6.3
Leaves and Grass	8,600	6.5
Rags, wool	8,900	6.7
Rags, cotton	7,200	5.4
Garbage	7,300	5.5
Rubber	12,500	9.4
Suet	16,200	12.1

[a] Values are necessarily approximate, since the ultimate composition of the combustible part of the materials varies, depending upon sources. The heating value of the materials as it is received is obtained by multiplying the moisture-free and ash-free Btu value of the materials by 1-(% moisture + % ash)/100. For example, garbage with an MAF value of 7,300 and containing 35 percent ash or other noncombustible material will have an "as-fired" heating value of 4,380 Btu per lb.

[b] MAF means moisture-free and ash-free if ash refers to total noncombustible materials.

[c] These values are also approximate and are based on 0.75 lb of air per 1,000 Btu for complete combustion. For various percentages of excess air, multiply these values by (100 plus percent of excess air. For example, after adjusting for moisture and ash, MAF paper requires 11.8 lb of air for complete combustion (i.e., (5.9)(200/100) = 11.8 lb/lb).

SOURCE: Municipal Refuse Disposal, Institute for Solid Wastes, American Public Works Association, 1970, P. 174.

Table 3-12. Chemical Analysis of Waste-to-Energy Facility Ashes and Other Materials.

Major Compounds	Westchester[a] Total Ash	EPA Study[b] Bottom	EPA Study[b] Fly	Swedish Study[c] Bottom	Swedish Study[c] Fly	RDF[d] Ash	Portland Cement[e] Typ. I	Portland Cement[e] Typ. III
SiO_2	40.3-46.8	0.2-40	0.3-57	49.8-60	31.6-63.6	28-47	21.3	20.4
CaO	11.3-15.4	0.8-10	2-38	11.0-13.6	9.4-15.5	5-15	63.2	64.3
Al_2O_3	10.5-16.3	0.9-10	0.9-33.2	11.2-13.6	11.5-20.6	10-31	6.0	5.9
Fe_2O_3	8.0-19.2	0.1-19	0.1-12	5.3-7.0	2.0-5.7	2-5	2.7	3.1
Na_2O	3.1-4.2	1.3-4.4	1.3-6.7	4.8-6.9	2.9-5.7	4-7	---	---
TiO_2	1.5-2.1	0.5-1.8	T-7.0	0.7-1.0	0.5-2.1		---	---
MgO	2.4-4.2	.13-1.7	.33-3.5	2.1-3.2	2.0-4.6	4-7	2.9	2.0
K_2O	1.4-3.4	.11-1.6	1.3-8.0	1.7-2.7	2.6-7.2	0.1-0.9	---	---
P_2O_5	1.0-1.4	0.7-4.1	0.7-2.1	1.4-2.9	1.2-2.5		---	---
ZnO		.03-1.6	.38-19				---	---
PbO		.01-.53	.02-2.9				---	---
SO_3				0.2-0.8	0.4-1.7		1.8	2.3
Softn'g °F						1945-1987		
Fluid °F						2160-2179		

[a]Cundari, Incin. Ash Disposal Workshop Proceedings, Table 5 Laboratory Evaluation of expected Leachate Quality from a Resource Recovery Ashfill
[b]U.S. EPA
[c]Hjelmer
[d]Cal Recovery
[e]Concrete Institute

Table 3-13. Comparison of Under-Fired Air and Over-Fired Air Patterns in Different Types of Combustion Systems

Type of Unit	Primary Chamber Air		Secondary Chamber	Dilution Air
	Under-Fired	Over-Fired		
Modular Starved-Air	50% - 60%	nil	80 - 100%	100 - 200%
Modular Excess-Air	-60%	40 - 50%	60 - 100%	50 - 100%
Water-Wall	80 - 140%	-60%	minimal	minimal

NOTE: The percentage of stoichiometric air given above is based on a S.R. in the gases leaving the secondary chamber of 1.5-2.0.

CHAPTER 4

INCINERATOR TECHNOLOGIES

4-1. GENERAL DESCRIPTION.

a. Furnace type incinerators have the following classifications:

(1) Packaged Units - Packaged furnace-type units are generally the smallest and least sophisticated. The controls are minimal, and an automated ash-removal system may not be included. The unit comes completely shop-assembled. The primary combustion chamber has a fixed hearth that may be either a solid surface or a grate. The capacity for these incinerators is approximately 100-900 lb of waste/h (i.e., 1-10 tons/day).

(2) Modular Units - Modular, furnace-type units are larger than packaged units typically having capacities of 20-75 tons/day per combustion chamber. The primary combustion chamber, the secondary combustion chamber, the stack, the energy recovery heat exchanger, and the waste-charging system are totally fabricated in the shop as separate modules. These modules are shipped for final assembly and hookup in the field. Installation requires the construction of foundations, erection of support steel structures and enclosures, the assembly of the modules, and the final installation of the auxiliary systems (i.e., the instrumentation and control system, the ash-handling equipment, the hydraulic power system, etc.). Typically, a modular incinerator facility has two to four units in parallel.

(3) Field-Erected Units. These are usually the largest, most sophisticated, and most efficient incinerators. With typical single unit capacities greater that 75 tons/day, major components are too large to be shipped as modules. Basic parts are shop fabricated and shipped to the site. These large units are meant to run continuously and due to capacity are required by law to have elaborate pollution control systems. A unit with this capacity will have limited application to a military installation, especially if the base has an aggressive materials recovery and recycle program. The increased construction costs of a plant with a capacity exceeding 250-400 tons/day is offset by higher efficiency and lower maintenance costs per ton of waste destroyed. The furnace type incinerators denote stationary hearth system designs and include fixed solid-surface hearths, fixed grate hearths, rocking grates, reciprocating grates, traveling grates and sliding tiered solid hearths. Rotary hearths or fluidized-bed units are not included in the furnace type classification. Rotary-hearth units and the fluidized-bed units are described in sections 4-5 and 4-6 as technology systems that are unique and different from the more commonly used stationary-hearth-type furnace incinerator.

b. Mode of Operation.

(1) Irrespective of the size classification (packaged, modular, or field-erected), the mode of operation of the furnace used to destroy the waste (i.e., starved-air units [SAU] or excess-air units, [EAU]) is often used as the primary basis for characterizing an incinerator system.

(2) The size of the combustion chambers will be affected by the mode of operation. Most packaged and modular units operate in the starved-air mode because of the inherent simplicity of primary combustion chamber design, the inherently lower emission of particulates that has allowed

these systems to meet past particulate emissions requirements without the addition of a particulate control device, and the ability to easily adjust and maintain secondary combustor conditions. The large field-erected units always operate in the excess-air mode.

4-2. PACKAGED INCINERATOR.

a. Retort-Type Incinerators.

(1) Most small, packaged incinerators in the 100-1000 lb/h (i.e., 1.2 to 12 tons/day) capacity range are of the stationary hearth, retort-type. Gases are directed through a series of connected "U"-shaped combustion chambers that share common walls and a common base (in lieu of an "in-line" configuration). Figure 4-1 illustrates a typical "U"-shaped retort design.

(2) The "U"-shaped retort requires the gases to make right turns in both the horizontal and vertical directions. This return flow of the gases permits the use of a common hot wall between the various chambers. The compactness of a "U"-shaped retort incinerator saves space, yet it provides a gas flow path that is long enough to keep the gases at the temperatures for the time required to complete the oxidation process.

(a) Combustion air is introduced into each chamber at the rate required to achieve complete burndown for the mode of operation (i.e., starved-air or excess-air).

(b) Solid waste is batch-fed through a sliding door onto a vented grate hearth. Each batch pushes the previous batch along the hearth where it is ignited by the prior material. As the material burns, the ash falls through the grate into the ash chamber.

(c) Primary chamber air, usually at substoichiometric ratios (i.e., starved-air mode) to minimize fly ash, is introduced above and below the grate and controlled by dampers in the ducts supplying air to each zone. Each succeeding chamber has provisions for adding more air and has supplemental burner/heaters so that the desired temperature and stoichiometric ratios can be adjusted and controlled in each chamber.

(3) The small, packaged, single units have wide application for the controlled destruction of small quantities of municipal-type waste and are especially well suited for burning unique types of waste that must be processed separately from general wastes.

(4) They are designed to be operated 8-16 h/day so that ash removal and certain maintenance can be performed during the shutdown.

b. I n-line Retort Type Incinerator. The in-line packaged unit also has all chambers in one housing, but the gases make 90° turns in the vertical direction only. Thus, the secondary chamber is in-line, at the end of the primary chamber, rather than mounted alongside. The in-line unit is therefore longer and less compact than the standard "U"-shaped retort design. All other aspects of operation and performance are similar to the retort unit.

4-3. MODULAR INCINERATOR.

a. General Description.

(1) Modular incinerators are by far the most prevalent in terms of units built. Multiple, 20-75-tpd module units, combined to provide a total facility capacity of 50-300 tpd, have been widely used in small communities and have found wide application at military installations.

(2) Units designed for operation in the starved-air mode (SAU) have historically been most common because of their ability to achieve sufficiently clean burning of the waste (i.e., relatively low particulate emission without the need for separate air pollution control equipment. This resulted in making the modular SAU facility the least expensive facility to construct. New federal regulations however, have tightened particulate emissions limits, restricted acid gas emissions and subject the smaller capacity units to federal emissions regulations.

b. System Configuration. Generally, facilities size each unit to carry its share of the daily waste stream when one unit in the system is down for repair. Thus, a facility consisting of four primary combustion chambers would have each unit sized to handle one-third of the projected maximum daily throughput. The operating availability of a modular unit may be approximately 75-80%. The operator can anticipate that downtime for planned maintenance and repair will amount to about 10% of the annual operating time, and that forced downtime due to unexpected failures and malfunctions may account for another 10-15% of the time. If one secondary chamber services two primary combustion chambers, the ducts between the primary and secondary chambers are provided with isolation dampers. This allows continued operation of the unaffected primary and secondary chambers when one primary chamber must be shut down.

c. Typical Design. Figure 4-2 illustrates a typical design of a multiple combustion chamber arrangement of a modular incinerator. Units designed as either a SAU or an EAU incinerator use separate primary and secondary combustion chambers. The details of each design differ in order to accommodate differences in operating conditions. In either mode, measured amounts of waste are normally batch-fed through a fire door into the primary chamber by using essentially the same equipment. Beyond this point, their mechanical features vary.

d. Starved-Air Modular Incinerator.

(1) Primary Combustion Chamber. The SAU primary combustion chamber usually has a solid, stepped-floor, with three or four steps. The vertical riser of each step is connected to a ram that pushes waste from one level down to the next. The use of slow-moving rams and low flow of air into the bed result in only enough agitation of the waste to slowly tumble it down over each succeeding step as it progresses over the full length of the stepped hearth. Minimal agitation and mixing of the waste helps to minimize particulate generation and carry over in the gases and vapors leaving the primary chamber.

(a) Longer retention times (i.e. 4-6 s to transverse the length of the primary chamber) are required to achieve a reasonable burndown of the waste due to the low agitation, reduced rate of destruction associated with the low stoichiometry (S.R. of 0.6 to 0.9), and the subsequent lower temperature.

(b) A minimal flow of air is provided to the bed from overfire air ports along the walls and underfire air ports below the bed meter. The careful balance of airflow achieves the uniform substoichiometric conditions required for the partial oxidation of the waste in the front two-thirds of the furnace and the burndown of the combustible solids and char at the last third of the bed.

(c) The height of the furnace at the inlet is reduced in order to force the burning away from the charging door. The chamber increases to its full height where partial combustion and pyrolysis occur in order to accommodate the large flow of gases released.

(d) A large opening strategically located in the roof of the furnace discharges the partially oxidized vapors, gases, and particulates into the secondary combustion chamber. Some manufacturers attach two primaries to a common secondary chamber and manifold more than one secondary chamber to a heat-recovery boiler.

(2) Secondary Combustion Chamber. Irrespective of the configuration, the secondary combustion chamber is essentially a solid-walled, solid-floored, horizontal, refractory-lined cylinder.

(a) Length and diameter are determined by the volume of gas that leaves the primary chamber, the amount of gas generated by the secondary burner and the necessary retention times for completion of the required reactions. The size of the chamber is such that it takes from 1.5 to 2.5 s from the time the gases enter the chamber until they leave.

(b) The burner flame and secondary combustion air are introduced just above the secondary chamber gas inlet opening. Gases entering the chamber are injected in such a manner as to induce a swirling action to enhance the agitation needed to improve mixing and uniform combustion.

(c) Normally, the gases leaving the secondary chamber are vented to a heat-recovery boiler to produce steam or hot water. However, an alternate discharge path, via a "dump valve" in the secondary chamber discharge duct, is required to allow direct discharge to the atmosphere in the event of an upset condition (i.e., a case where the boiler is forced to shut down because of equipment failure). The hot gases generally cannot be sent to the gas-cleanup system if their temperature is above 500°F, so they must be "dumped" to the atmosphere. In such a case, the waste feeding operation is stopped, but the waste in the incinerator continues to burn.

e. Excess-Air Modular Incinerator.

(1) Primary Combustion Chamber. The primary combustion chamber of the EAU modular incinerator usually uses a porous grate that allows larger volumes of air to be introduced to the bottom of the bed and in a more uniform manner than that provided on the SAU.

(a) The grate is usually a manufacturer's patented design that provides unique means for introducing underfire air and for moving the waste along the length of the furnace. The plane of the floor is inclined, and the mechanism for moving the waste also imparts a slow tumbling action to the bed of waste as it is moved and burns along the length of the combustion chamber.

(b) Because of the larger amounts of air required (i.e., S.R.= 1.1 vs. S.R.= 0.6-0.9 for the SAU), and the consequent larger volume of combustion gases, the primary chamber volume for an EAU will be larger than a comparable-capacity SAU. The primary chamber length and the residence time for burndown will be shorter than those for an SAU. Overfire air inlets direct air to the full length of the bed. Exterior ducting and valving controls the amount of air directed to each stage (zone) of combustion.

(2) Secondary Combustion Chamber. The design of the secondary chamber for the modular EAU attempts to produce the same mixing, chamber temperatures, and retention times as for the SAU. However, since the EAU secondary chamber inlet gas temperature tends to be 400-500°F higher, less additional secondary combustion air is required (see table 3-12). The final combustion of unburned gases, vapors, and particulates (i.e., 25-50% of that discharged to the SAU secondary chamber) will require less time and less supplemental heat. Like the modular SAU, the EAU must have a hot gas "dump valve" to bypass the heat exchanger and/or flue gas treatment system when either system is not operating.

f. Controlled-Air Modular Incinerator. Some incinerator designs, referred to as "controlled-air" incinerators, use a modified single chamber and a grate system similar to that of the excess-air units. By careful control of underfire and overfire air, they achieve performance similar to a starved-air unit, even though they have the physical appearance of an excess-air unit..

4-4. FIELD-ERECTED INCINERATOR.

a. General Description. When the capacity of a waste incineration system exceeds the nominal 200-250-t/day capacity of modular incinerator systems, field-erected incinerators are usually used because of their higher operating efficiency and more dependable operation. Their design is comparable with the design used for coal-fired boilers; however, the design contains a number of significant, unique features required for the efficient destruction of municipal-type waste. Figure 4-1 illustrates a typical field-erected mass-burn incinerator.

b. System Configuration. Because of the large stream of waste serviced by these facilities, it is important the facility have redundant destruction capability so that outage of one furnace will not result in a large accumulation of waste.

(1) Field-erected furnaces with their integrated boilers also require time for maintenance and repair, as well as allowances for forced outages due to failure of any major component in the unit. If three units are used, it is common to size each unit to handle one-half of the facility's total capacity. Similarily, if four units are used, each is sized to handle one-third total capacity.

(2) In general, an 80% availability is projected for field-erected units.

c. Design Description for In-Line Grate Systems.

(1) Primary Combustion. The basic design uses an excess air grate of patented design, which may be a traveling grate, a rocking grate, a reciprocating grate, or some combination thereof.

(a) The grate meters waste delivered by the feeding system, which includes a crane and a long chute. The waste then flows by gravity down onto the grate.

(b) The grate then moves the bed of waste through the primary combustion section until the residues are dumped off the grate into a water--filled ash-quench system, where the ash is cooled and removed by conveyor.

(c) Air is metered to locations along the length of the grate system to control the rate of drying, volatization, and burndown of the nonvolatiles and char. The primary combustion air is supplied above and below the bed in excess of stoichiometric requirements in order to force the combustion process to progress in a prescribed manner.

(d) Typically, 40-60% of the combustion air is introduced under grate to provide grate cooling.

(e) The walls of the primary combustion chamber are lined with refractory insulation, which covers the water-wall boiler piping to a height that assures that the pipe will not be attacked by corrosive substoichiometric gases leaving the bed. The roof of the primary combustion chamber is contoured to force the hot combustion gases to sweep across the top of the bed of waste.

(f) Combustion of the solid waste in these large units is characterized by vigorous, turbulent burning from the high volume of air used with a consequent high rate of destruction. Burndown is usually completed in less than four hours.

(2) Secondary Combustion.

(a) Secondary combustion starts as the gases approach the roof of the primary combustion chamber. Secondary air is injected above the primary combustion overfire air ports; in addition, air is also injected at the bottom of the secondary combustion area (i.e., at the base of the vertical radiant boiler) and at one or two elevations along the length of the vertical waterwall boiler.

(b) Air is introduced at strategic positions and in sufficient quantities to impart the turbulence required to ensure complete combustion and maintain gas temperatures at prescribed levels.

(c) The mean gas temperature in the radiant boiler is approximately 1,600-1800°F with combustion gas hot spots as high as 3,000°F. With higher localized temperatures, larger units can generate significantly higher concentrations of NO_x than the modular SAUs and EAUs.

(d) Typically, the efficient field erected incinerators can yield 5,000-6,000 lb of low-pressure district heating steam, or 350-450 kWh of electricity, per ton of waste destroyed.

4-5. ROTARY KILN INCINERATOR.

a. General Description. The unique feature of the rotary kiln furnace/incinerator is that the primary chamber rotates in order to agitate the waste and expose it to combustion air and heat generated by a supplementary burner. Rotary kiln incinerators have found wide application where the material to be destroyed contains high moisture or is deficient in readily combustible constituents.

b. Packaged Rotary Kiln Incinerators. Packaged rotary kiln incinerators have been used extensively for the destruction of hospital waste and pathological wastes. Typically, they are used to destroy up to 500 lb/h of these difficult to burn materials.

(1) Primary Combustion. Packaged rotary kilns are very similar to retort-type furnaces, except that the primary combustion chambers are rotating, inclined, refractory-lined cylinders.

(a) Material to be destroyed is fed into the chamber through a sliding door via a ram in much the same manner used to feed the retort furnace. The stationary door frame has a sliding seal that prevents gas leakage between the door frame and the rotating kiln.

(b) Once inside the chamber, the material is slowly tumbled by the rotating action at a rate of 0.75 to 2.50 rpm. Material is destroyed as it moves along the length of the drum, which has a nominal length-to-diameter ratio of 2:1 to 5:1. Typically, the supplemental heat burner in the primary chamber provides much of the heat required to destroy the waste. Residence time in the chamber is changed by adjusting the angle (tilt of the horizontal axis) of the cylinder.

(2) Secondary Combustion. Residue ash tumbles off the kiln into the ash-collection pit in the secondary chamber. Combustion gases pass through the secondary chambers in the same manner as the fixed-hearth retort furnace.

(3) Capacity. Typical capacity for packaged rotary kilns is less than that for packaged retort furnaces of the same physical size.

c. Modular Rotary Kiln.

(1) The rotary kiln incinerator size of interest to military bases is often a two-package, large-scale, modularized version of the packaged incinerator. One package or module is the rotating cylinder primary combustion chamber and its associated charging system. The second package is the stationary secondary chamber unit described above. The modular rotary kilns may differ in configuration and provide greater capacity than packaged rotary kilns; however, they operate in the same manner at capacities up to 5000 lb/h. Seldom are these units operated in multiple-unit facilities. Figure 4-4 illustrates a typical modular rotary kiln unit with heat recovery.

(2) Large-scale, multiple-module, rotary kiln systems, using individual truck-trailer mounted modules for each subsystem, are used extensively for decontaminating soils and for destroying large batches of difficult to burn wastes. Throughput for such modular systems is usually less than 5,000 lb/h.

d. Field Erected Rotary Chamber Systems.

(1) Application. Large-scale rotary kilns have been used for the routine destruction of municipal-type wastes. Rotary kilns generate larger amounts of particulate when burning municipal.

(2) Field-Erected Incinerator Systems Incorporating Rotary Chambers. Several incinerator manufacturers use rotary chambers in place of moving grates in the primary combustion sections of their incinerators.

(a) Volund System. The Volund incinerator uses a refractory-lined rotary kiln in the final two stages of primary combustion. Two moving grates are used for the drying and initial volatilization /combustion stage. The partially burned material is then moved into the rotary kiln for completion of primary combustion and final burndown of the char. Gases, vapors, and particulates generated upstream of the kiln are partially burned in the kiln, and final destruction is completed in the secondary combustion chamber/boiler section. All other aspects of the incinerator and its operation are similar to other field-erected, furnace-type incinerators.

(b) O'Connor-Westinghouse System. This system uses an all-steel-pipe, inclined, rotary-cylinder, primary-combustion chamber. Water-filled pipes make up the rotating, inclined, horizontal, cylindrical chamber. The pipes are spaced and attached in a manner that allows primary combustion air to be introduced between the pipes and supplied to the bed of waste as it slowly tumbles with the rotation of the cylinder. All four stages of combustion progress to completion as the solid waste passes through the chamber. Residence time is determined by the speed of rotation. The water in the pipes is pumped from manifolds attached to rotary seals that are located some distance from the actual combustion of the waste. Thus, the seals are not subject to the high gas temperature environment of the pipes that make up the walls of the rotating cylindrical chamber.

(3) Unique Applications. Rotary kilns may be operated in either a starved-air mode or an excess-air mode. The mode of operation will dictate the materials of construction. Of concern is the corrosiveness of the products of partial combustion in the primary chamber. The refractory-lined kilns have been especially effective for the destruction of difficult to burn, high-moisture-content materials that require air-rich conditions and high agitation of the solids.

(a) In such applications, the primary source of heat is the auxiliary burner used to maintain the temperature in the rotating chamber at the desired 1,800 to 2,000°F.

(b) The chamber stoichiometry is maintained in the air-rich condition to ensure there is enough oxygen to destroy the waste. The partially burned gases leave the rotary kiln and enter into the stationary secondary combustion chamber. Additional air and a supplementary burner is required in the secondary chamber to maintain optimum temperature. The necessary temperature, residence time and outlet gas stoichiometry conditions are required to completely destroy unburned gases and particulates to the same extent as in conventional furnace units.

(c) Since these type units generate large amounts of particulates, even small packaged-unit installations may require some type of permit that will mandate the unit meet some set of emissions requirements.

4-6. FLUIDIZED-BED COMBUSTOR (FBC) INCINERATOR.

a. General Description. Figure 4-5 illustrates a typical bubbling-bed FBC unit. Combustion air enters the lower portion of the combustion chamber and passes through a grid that acts as a floor for the inert (usually sand) bed. The bed is levitated and kept in constant agitation by the flowing (vertical) air. Auxiliary fuel burners are used to heat air delivered to the bed to the temperature required for ignition of the waste fuel. The waste is shredded, sized, and air classified to eliminate the larger and/or heavier materials before being fed into the FBC unit via a pneumatic feed system.

b. Process Description. Once the bed reaches the fuel-ignition temperature, sized feedstock is fed into the bed. The "boiling/scrubbing" action of the sand/fuel mix keeps the feed material in constant contact with the combustion air. As combustion progresses, lighter fuel particles rise to the top of the bed and are consumed; heavier residue particles settle to the bottom and are routinely discharged. Since the bed temperature is typically 1,500°F, NO_x emissions are low and particulate emissions are high. Heat is recovered by hot water or steam pipes in the wall of the chamber and in the waste-heat recovery heat exchanger in the path of the discharge gases. Instead of an external scrubber, specially sized limestone is added to the bed to accomplish acid-gas control within the unit.

c. Waste Feed. One of the main advantages of using an FBC unit to burn waste (besides environmental emissions) is the insensitivity of the combustor portion to fuel quality. However, preparation of the fuel in order to feed it into the bed is a major impediment of FBC. Although beneficiation of the waste by removal of certain components is not required (with the possible exception of glass), bulk material still must be shredded, sized, and classified and thus is considered a form of refuse-derived fuel (RDF). The status of commercial FBC technology using RDF, though considered developmental for certain applications, does not have the satisfactory third-generation experience that would make it a proven technology.

4-7. CO-FIRING OF REFUSE-DERIVED FUEL IN A COAL-FIRED BOILER.

a. Application. The destruction of processed refuse by co-feeding with coal into a coal fired boiler is an option that has not been used at military installations in the past but has been well demonstrated in the civilian sector

b. Operation. Typically, the co-firing of carefully processed waste (up to 20% by heat content) with coal (80% by heat content) has no significant detrimental effect on the performance of the boiler, nor has it reduced the effectiveness of destruction of the waste. Waste processed to make Refuse-Derived Fuel (RDF) with a 6,000-8,000-Btu/lb fuel value displaces bituminous coal at a ratio of 1.5-2 tons of RDF for every ton of coal. When co-fired at 20% by heating value, 30-40 tons of RDF would be burned for every 80 tons of coal consumed. This would mean that a 100,000 lb/h steam boiler for a district heating plant that normally consumes 145 tons per day (tpd) of coal would then burn 120 tpd of coal and 45-65 tpd of RDF. This 45-60 tpd of RDF would be produced from 90-120 tpd of waste generated at the base, before recycling.

c. Economics. Typically, the cost for constructing a facility to produce RDF has been 20-40% of the cost for an incinerator. This option may be an effective solution if the base has a suitable size and type of coal-fired district heating boiler. The drawback to using this technology is that the RDF/waste stream would have to be matched to the minimum daily steam demand of the boiler, thus assuring that the daily waste stream could always be processed and burned.

4-8. MEDICAL WASTE INCINERATOR. Medical waste incinerators fall into the category of special applications of proven technology.

a. Technologies. Most incinerators used for the disposal of medical waste are of the packaged, fixed-hearth, multiple-chamber, retort type, although some hospitals have installed a single modular unit for the processing of all their waste. Most medical-waste-incineration operations are extremely small (i.e., several hundred pounds per day). Rotary kilns have been used on larger, regional facilities.

b. Operation. The very small units will typically be located in the same area as the regular hospital boilers. One of the existing boilers may be modified to recover the heat from the gases.

(1) Supplementary fuel burners are usually required to maintain the necessary temperatures in both the primary and secondary chambers. If the waste steam has large amounts of wet, Type 4 pathological waste, large quantities of auxiliary fuel will be needed to maintain the temperatures required for safe destruction.

(2) Some hospitals have co-fired fairly large percentages of relatively dry, noninfectious paper; plastic products; and paper-product type waste with their infectious waste to successfully accomplish the job with minimal extra fuel required. The smaller units are usually batch operated (i.e., waste being fed only when the previous load has been consumed). This only permits a certain number of loads to be burned per day; furthermore, if there is no provision for an automatic ash-removal system, the ash must be removed manually following an overnight burndown and cool-off.

c. Environmental Considerations. Current trends are that even the smallest incinerators (especially medical waste incinerators) will be subject to pollution control regulations.

(1) Air pollution control equipment that may be cost-effective on larger units may be prohibitively expensive on typical medical waste incinerators. Wet scrubbers have been found to be very effective and are probably the best pollution control device for these small units since they capture acid gas and particulates.

(2) High-pressure venturi scrubbers have been used effectively; however, require a great deal of energy in order to achieve high capture efficiency. If the gases can be cooled by an acid-gas condenser heat exchanger, a small fabric dust filter may be sufficient and is cost-effective.

(3) The bottom-ash residue must not contain any recognizable medical material (i.e., complete burnout). Therefore, sharps may have to be screened from the ash and disposed of separately as scrap metal. Because of the potential hazards and liability if the unit is poorly operated, operators will have to be properly trained and certified. A training course has been jointly established by the American Hospital Association and the American Society of Mechanical Engineers.

4-9. TECHNOLOGY SELECTION GUIDANCE.

a. Technology Selection. Modular starved-air units have been the most widely selected for the military services because their capacity includes units below 50 tpd (the size most used at military installations), without the need for additional air pollution control equipment. Other small-capacity systems, namely excess-air grate, fluidized-bed, and most rotary kiln incinerator designs, usually requiresome type of particulate emissions control. A number of states have enacted, or are enacting, increasingly stringent acid gas and particulate control legislation applicable to small units (down to 20 tpd have been regulated in New Jersey). It is expected that incinerator plants at military installations with unit sizes of 20 tpd or greater will most likely be modular unit plants operating in either the starved-air mode or the excess-air mode and equipped with state-of-the-art pollution control. Comparative economics will be the ultimate selection factor. For installations not located in states with highly stringent regulations, or for plants with unit sizes below the Federal regulatory threshold, the modular starved-air incinerator will probably continue to be the incinerator of choice. The military procurement guidelines for incinerators will be used to specify this incineration equipment. It may be modified if it is necessary to allow for excess-air units.

b. Special Needs. Two technologies are expected to have definite, but limited, applications. The rotary kiln is especially good for difficult-to-burn wastes, such as sludges or other very wet materials. The fluidized-bed combustor (FBC) should be used for very homogeneous wastes that may be hazardous because of acidity or possible toxic elements. FBC can also burn liquids and sludges as well as solids and can burn several fuels simultaneously. Further details on all of these types of incinerators may be found in the literature listed in the bibliography.

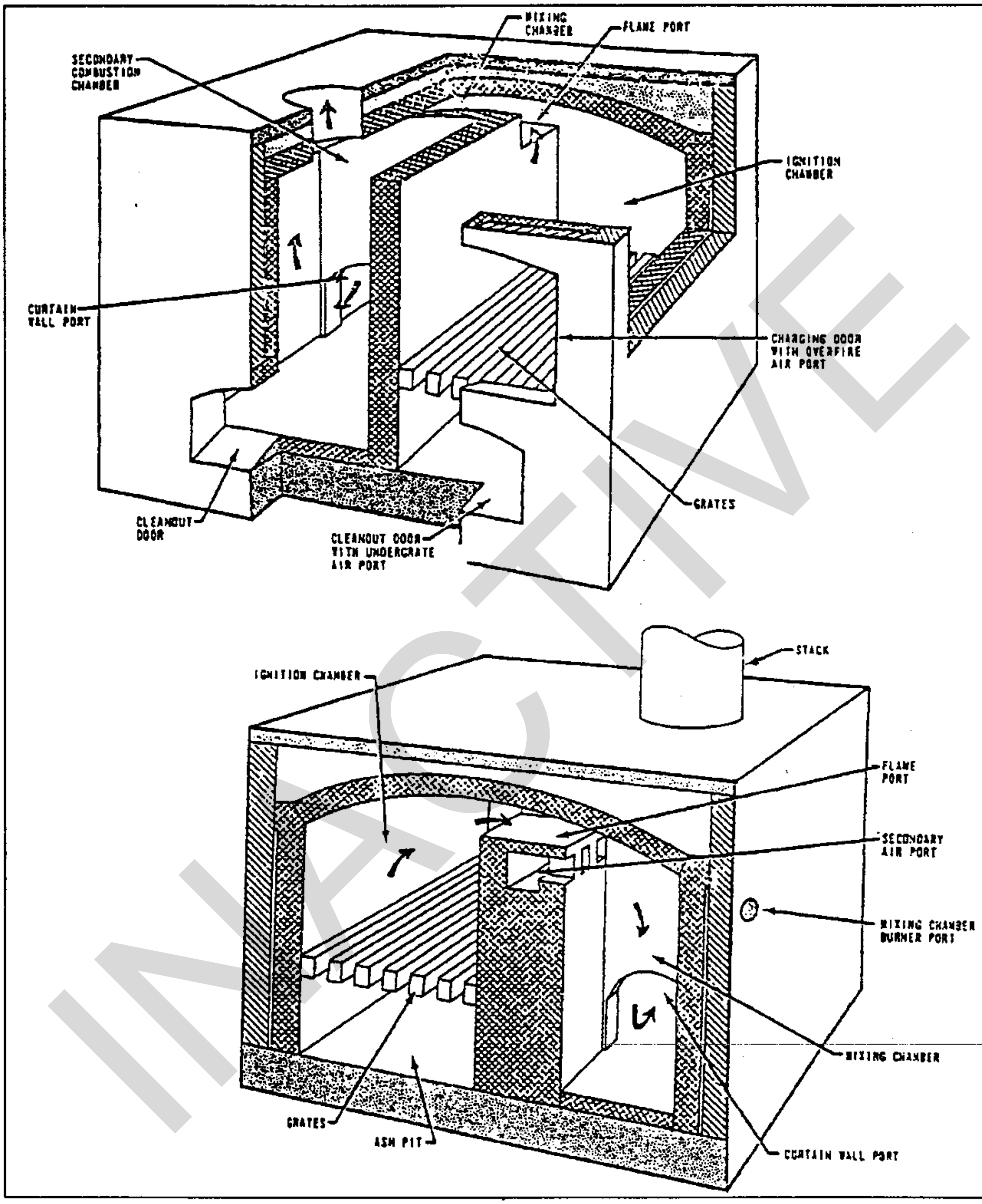

Figure 4-1. Typical retort unit

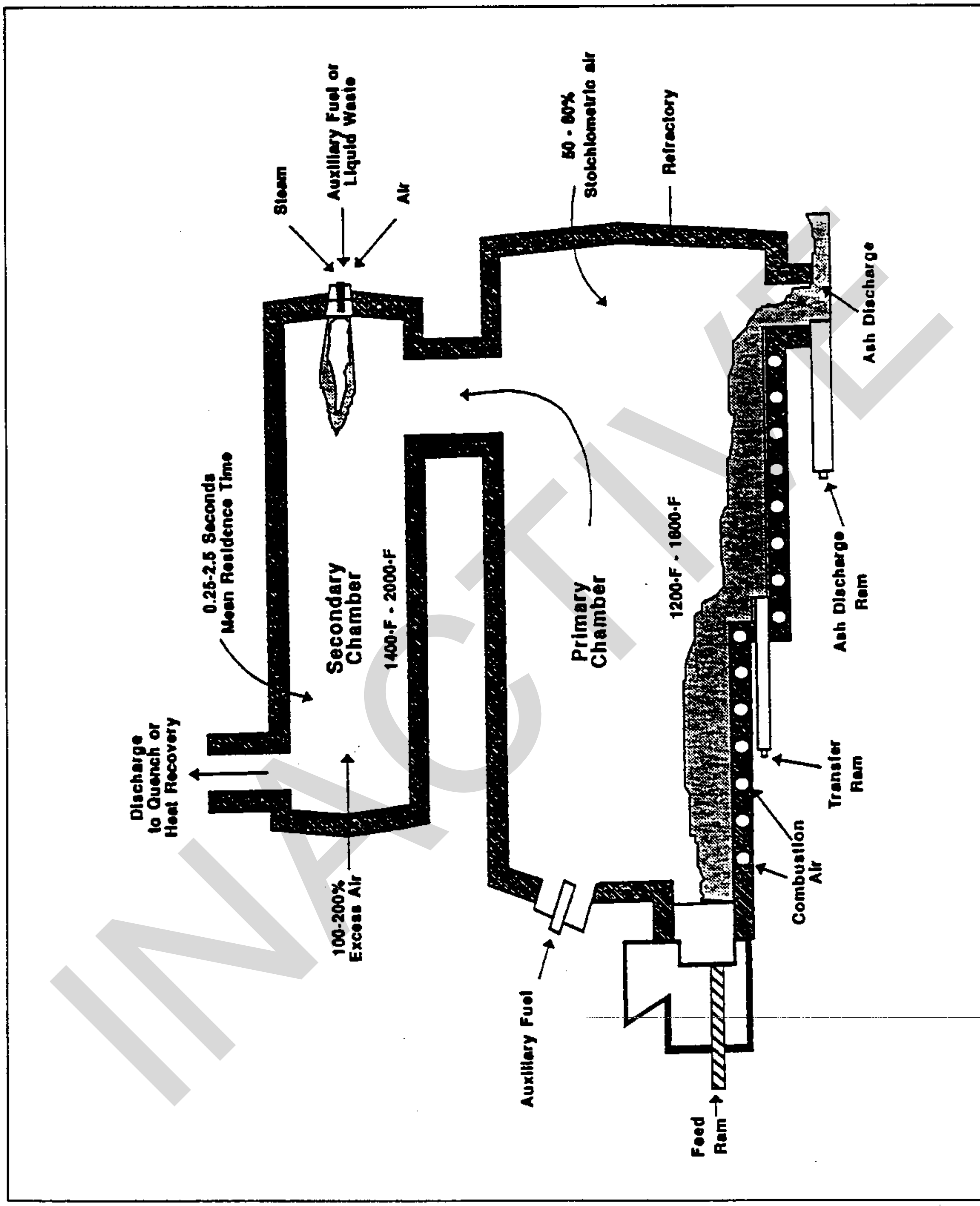

Figure 4-2. Typical modular incinerator configuration

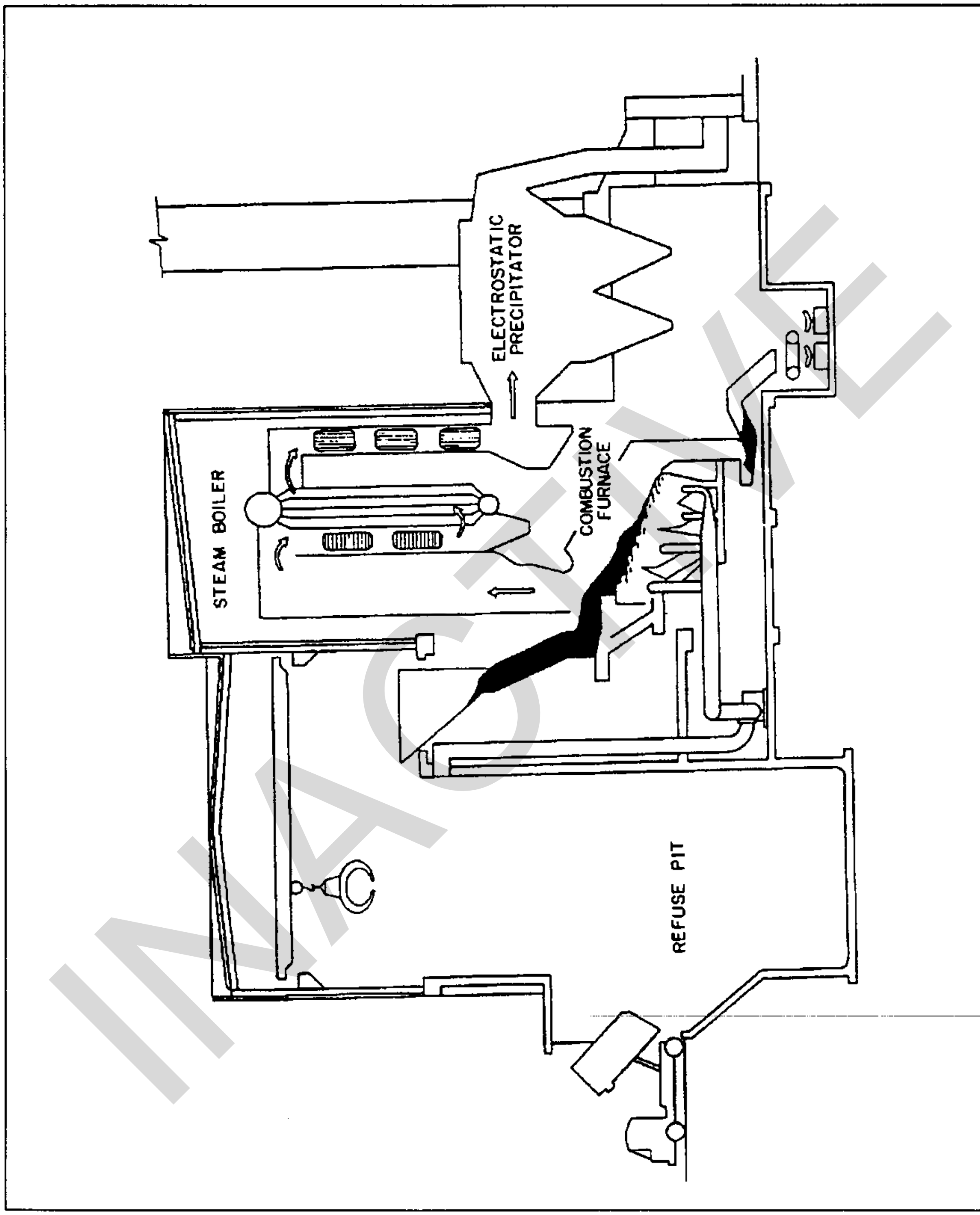

Figure 4-3. Typical field-erected, mass-burn incinerator

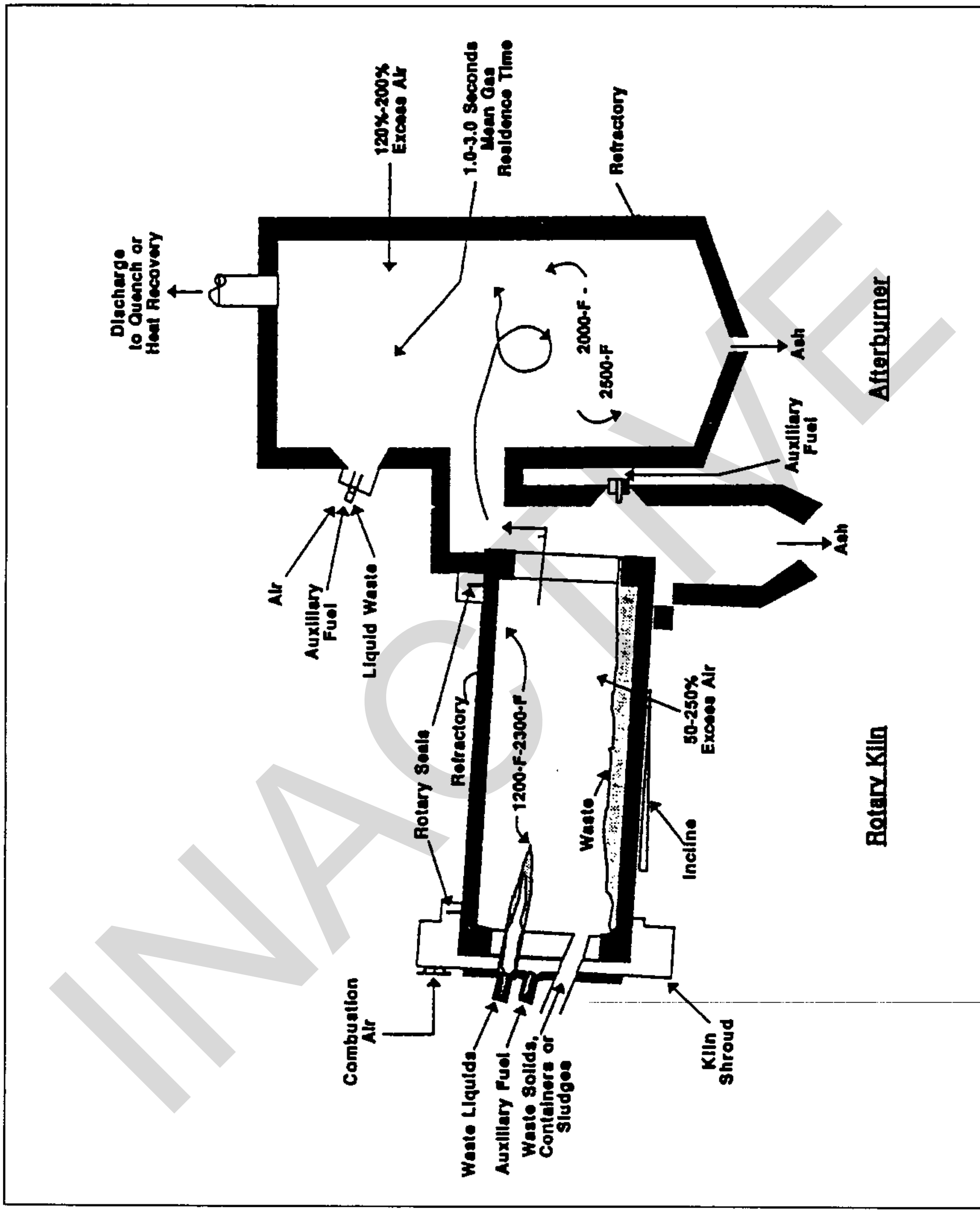

Figure 4-4. Typical rotary kiln incinerator

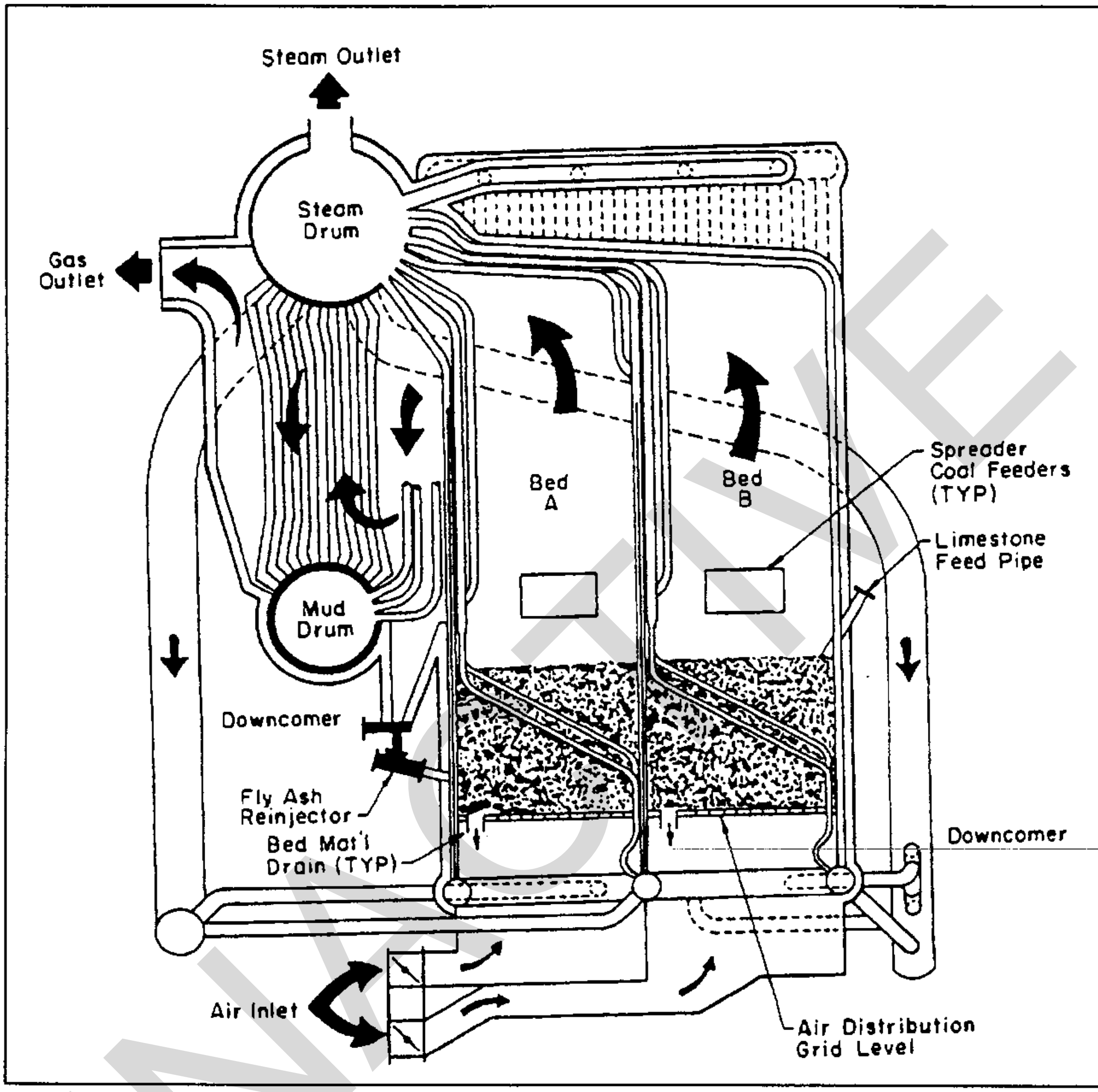

Figure 4-5. Typical bubbling-bed fluidized-bed combustor.

CHAPTER 5

POLLUTION CONTROL AND ENVIRONMENTAL PERMITTING

5-1. POLLUTION CONTROL CONSIDERATIONS. The major problem with the public's acceptance of waste incineration has been the issue of pollution. As a result of increased apprehension, the waste incineration industry has one of the most stringent sets of air emissions and residue disposal regulations of all industries.

a. Comparative Efficiencies. Figure 5-1 shows the comparative efficiencies of the various types of particulate removal technologies in use. As regulations become more stringent, designers are required to use more sophisticated systems for achieving 80-90% removal of acids formed, higher efficiency removal of particulates, and the associated removal of any chemicals that may adhere to the particulates.

b. Current Regulations.

(1) The most recent regulations use the Best Available Control Technology (BACT, see section 5-3) to establish the minimum performance limits.

(a) The most recent of these regulations is the revised Clean Air Act, 40CFR Parts 51, 52, and 60 dated July 1, 1996. The regulations continue to be revised, requiring the designer to keep up to date with the latest revisions and their application to the facility proposed.

(b) The current regulations apply to municipal waste combustors (MWC's) with a capacity greater than 250 tpd. Comparable regulations appropriate to smaller facilities will be issued, and the planning of any new facility for the incineration of municipal-type waste must provide for pollution control equipment.

(c) Additional considerations for required permits are discussed in appendix C.

(2) Many states also require continuous emission monitoring equipment for the pollutants of concern. It is imperative that the project planning effort determine all applicable federal, state and local regulations for the new facility.

5-2. POLLUTION CONTROL EQUIPMENT. The devices discussed in the following paragraphs are schematically illustrated in figure 5-2. Many of these devices are covered in their respective military design manuals and procurement guide specifications.

a. Cyclone.

(1) A particle separation cyclone is a common and inexpensive device for control of large particulates. It has a conical shape and imparts a swirling action to the gases to remove the particulates. The cleaned gas is extracted from the center of the vortex and the ash falls out of the bottom of the cone.

(2) High-efficiency cyclones improve the collection of particulates by using additional gas injected along the sides at high velocity or mechanical impellers to increase the velocity of the gases inside the cyclone.

(3) A multiclone is a housing containing many small cyclones that is used to improve the collection efficiency for the smaller particulates.

(4) Typically, high-efficiency cyclones and multiclones cannot meet state particulate control regulations; however, they may be used in conjunction with other pollution control equipment. Cyclones have been used to reduce the incidences of fires in bag houses. A refractory-lined cyclone may be used before the heat recovery boiler to reduce plugging and erosion and lower the required frequency of cleaning ash from the boiler.

b. Bag house.

(1) A bag house is a housing that contains multiple fabric filters. Depending upon the filter material selected, flow rate can vary from 3 - 50 scfm per square foot of filtration surface. Generally, the flue gases are maintained between 300°F and 500°F. Bags may be damaged or remaining carbon in the ash may ignite at temperatures exceeding 500°F. Below 300°F condensed acids attack the bags and other equipment. Table 5-1 shows a comparison of the intrinsic properties of various commercial bag materials.

(2) A bag house has a high collection efficiency and is especially good for smaller particulates.

(3) Bag houses are generally located upstream of the induced draft fan, operating under negative pressure. This minimizes the escape of unfiltered flue gases and fugitive emissions.

c. Electrostatic Precipitator.

(1) An electrostatic precipitator (ESP) uses an electrically-charged field between a series of plates and wires to attract and collect particulates. In general, fly ash from municipal waste is more difficult to collect and remove than fly ash from coal because its characteristics constantly change with the composition of waste. Some designs use a variable electrical field to compensate for changes in the ash characteristics. The collection efficiency decreases as the particle size decreases. While ESP's can attain 99% removal and an emission limit of 0.012 grains/dscf, they have problems doing so on a consistent basis.

d. Wet Scrubber.

(1) A wet scrubber is either one of the following two devices, or both devices working together:

(a) One such device is called a venturi and involves the gases going through a passageway that first narrows and then expands. An alkaline solution (frequently calcium-based) is injected into the venturi in order to atomize it, cause it to mix with the gas, and react with the acids in the gas.

(b) The other device is called a packed tower and is a chamber with baffles or other materials that cause the gas to flow through numerous small passages which constantly change direction.

(2) The gas normally flows up through the scrubber as the scrubber solution is sprayed down from the top. The solution mixes with the gas as both flow through the small passages. In most cases, the gas flows through a venturi then through a packed tower.

(3) This system will remove particulates as well as acid gases**.** The scrubber solution needs to be removed and replaced frequently, as it becomes contaminated with the particulates and salts from reaction with the acid. Before exiting to the atmosphere, the gases pass through a demister (usually chevron type) in order to remove the scrubber solution liquid entrained in the gas. If the demister does not function with a high degree of efficiency, the chemical mist in the gas will be detected as particulate and the incinerator will fail the environmental test.

(4) The used scrubber solution is a liquid and may have to be dewatered before disposal.

e. Dry Scrubber.

(1) A spray dry scrubber involves a tall reaction tower that sprays a fine mist of scrubber solution into the flue gas. The acid/scrubber solution reacts in the flue gas and produces a soluble salt which when dried becomes a fine particulate. The temperature of the ambient flue gas into which the scrubber solution is sprayed enhances the drying process and causes the reacted solution (salts) to dry into fine powder. The warm gases, with powder entrained, go into either an ESP or a bag house for removal of the ash particulate and dry salt powder.

(2) Units that utilize a bag house generally remove more pollutants than those utilizing an ESP because of the higher fine particle collection efficiency of the bag house and the additional acid gas reaction that occurs as the gases pass through the powder cake on the surface of the bags. All of the material to be discarded is a dry powder.

(3) This equipment is commonly used in large incinerator plants, but is prohibitively expensive for use in small plants. The spray dry scrubber followed by a bag house is generally regarded as the standard system against which all other systems must compete in regard to performance.

5-3. TYPICAL STACK EMISSIONS AND CONTROL STRATEGIES.

a. Particulate.

(1) Particulate is composed of fine ash (usually inert) and unburned carbon particles (smoke)**.** The amount of particulate in the gas is directly related to the velocity and turbulence of the gas in the combustion chambers.

(2) Reported values for particulate emissions from uncontrolled starved-air, staged-combustion incinerators vary from 0.012 to 0.212 grains/dscf at 12% CO_2. Starved-air incinerators have the ability to operate with particulate emission rates consistently below 0.08 grains/dscf at 12% CO_2 for IIA Waste Types O, 1, and 2 (see table 3-1). Other technologies have much higher uncontrolled levels.

(3) The 1996 federal regulations mandating low levels of specific species of emissions, will necessitate the use of particulate control devices for all incinerator technologies.

b. Acid Gases.

(1) Sulfur Dioxide. Based on the limited literature available, an average uncontrolled SO_2 emission rate of 45-87 ppm can be expected from municipal waste incinerators. In normal SO_2 scrubbing systems for solid fuel boiler systems, an actual operating removal efficiency of 90-95% can be assumed.

(2) Hydrogen Chloride.

(a) Under 40CFR Part 60, the scrubbing system must also control hydrogen chloride (HCl), acid gases, and NO_x. Control of NO_x will reduce the removal efficiency SO_2 to an anticipated 80%. Fortunately, most municipal-type waste has a low sulfur content and SO_2 emission levels of 50 ppm or less are readily achieved with a scrubber.

(b) Hydrogen chloride (HCl) is the primary form of acid gas produced in municipal waste incinerators. PVC plastics, paper, and putrescible garbage are the major contributors of chlorine in the refuse stream and are considered the primary source of HCl emissions at refuse-burning facilities.

(c) HCl emissions from burning IIA Type 2 waste (municipal) in starved-air or excess-air incinerators have ranged from 53-724 ppm before the exhaust gas is treated.

(d) HCl emission levels vary widely and reflect variations in feed stock. Plastics and paper have been found to be the major contributors, while food waste and untreated wood products are minor contributors of HCl. Typically, food waste and wood products make up only 8% of the source of chlorine. Because military waste streams have high paper content, an aggressive paper and plastic recycle program can drastically reduce the source of chlorine and reduce HCl emissions to the low end of the 50-725 ppm HCl range for an incinerator with a materials recovery facility.

(e) Because PVC plastics contain 40% chlorine, removal of all PVC plastics from the waste delivered to the incinerator may be a significant factor in helping achieve low HCl emissions.

(f) The recommended process for removal of HCl is a spray dry scrubber followed by a bag house (emission limits in the Federal Regulations were established on the basis that the limits could be achieved by a spray dryer/bag house system).

(g) In all systems, uncaptured acid vapors (e.g., H_2SO_4, H_2SO_3 or HCl) will condense on surfaces at temperatures below 275°F. Resultant corrosion on equipment and structures can be detrimental. If scrubbers are not used, the equipment and structures downstream must be kept at temperatures above 300°F or designed to withstand the acid attack.

c. Nitrogen Oxides.

(1) Oxides of nitrogen (NO_x) are compounds consisting of nitrogen and oxygen and are products of all combustion processes.

(a) Nitric oxide (NO) is the predominant form of NO_x produced during combustion withNO_2 produced in smaller quantities.

(b) NO_x emissions come from two separate sources during combustion. The first source is oxidation of nitrogen in the fuel (fuel NO_x); the second source is the high temperature oxidation of atmospheric nitrogen (thermal NO_x). The amount of NO_x generated is highly dependent upon the furnace heat release rates and residence time (see figure 3-4). NO_x emission rates increase with increasing furnace temperatures and excess air. The rate of thermal NO_2 generated at temperatures below 2900°F is substantially reduced by lowering the temperature. The primary combustion process in starved-air incinerators typically operates well below 2900°F with a S.R. below 1. As noted, these conditions combine to produce minimal thermal NO_x.

(c) Rates of NO_x formation are affected by nitrogen availability as well as temperature. Waste containing a high nitrogen-content, such as leaves and grass clippings, will increase the fuel NO_x.

(d) An uncontrolled NO_x emission rate between 258-327 ppm can be expected from most incinerators. The starved-air configuration which limits excess air during thermal decomposition of wastes in the primary chamber, typically produces emissions below or at the low end of this range. The federal limit on NO_x for incinerator unit sizes of 250 tpd or larger is 180 ppm.

(e) NO_x can be reduced by the injection of ammonia of urea. Injection is accomplished using either steam or compressed air. The relationship between NO_x removal efficiency and reagent utilization is known as the Normalized Stoichiometric Ratio, which is the actual molar ratio of reagant to inlet NO_x divided by the stoichiometric molar ratio of reagant to inlet NO_x. The efficiency of the reduction process is temperature dependent which usually requires multiple injection points, as the temperature at any given point in the system tends to vary in proportion to the heat content of the fuel source. By monitoring the temperature and injecting the reagant at the appropriate locations, the effectiveness of the NO_x reduction system can be maintained. Reduction levels as high as 65 percent can be obtained.

d. Carbon Monoxide.

Carbon monoxide (CO) is a product of incomplete oxidation of carbon compounds. The control of CO is by way of complete combustion. Federal Regulations 40CFR 60, Sect. 129 and 56FR 5488 set CO emission limits for all types of incinerators. Excerpts from the regulations are listed in table 5-2. Existing control systems and standard operating and maintenance practices are generally sufficient to regulate CO emissions. Maintenance on the natural gas burners and their temperature controllers, in the primary and secondary chambers, will assure that temperatures in these chambers are maintained above the 1130-1215°F ignition temperature of CO. Bag house and scrubber systems have no effect on CO emissions. High CO emissions reflect inefficiency in the combustion process, incomplete destruction of organic compounds, and loss of energy that should have been released in the combustion process. Also, there is a strong correlation between the presence of CO above 50 ppm and the presence of chlorinated hydrocarbons (especially dioxins), making close control of CO very important to minimize release of toxic chemical compounds.

e. Dioxins and Furans.

(1) Chlorinated dibenzo-dioxins (PCDD) and dibenzo-furans (PCDF) can be generated with small amounts of chlorine present.

(2) The formation of these complex chlorinated hydrocarbons can occur in the combustion process and during the combustion gas cool-down process. The quantity of PCDD and PCDF is a function of the combustion process efficiency (see figures 5-3).

(3) The secondary combustion process has a significant affect on the "polishing" of the combustion gas. The temperature must be maintained above 1500°F to assure rapid destruction of the PCDDs and PCDFs formed at lower temperatures in the primary combustion process (see figure 5-4).

(4) Measurable amounts of PCDD and PCDF are formed as secondary pollutants during the cool-down of gas and condensation of vapors. Therefore, it is important the chlorine be "locked" into stable compounds during the prior oxidation process or be scrubbed out of the gas stream by reaction with a chemical sorbent in the high-efficiency gas cleanup system.

(5) There are no current or proposed regulations governing the emissions of PCDD (commonly called dioxin) and PCDF (commonly called difurans) for incinerators with a unit capacity below 250 tpd. Federal regulation (40CFR 60.34) specifies a limit of 125 ng/dscm emission of dioxin/difuran from incinerator units with capacities between 250 tpd and 1,100 tpd. Any release greater than these levels from unregulated facilities (i.e., capacities below 250 tpd) would likely be unacceptable to anyone opposing an incinerator project.

(6) Baghouses will not have an appreciable effect on either PCDD or PCDF unless the exiting gas temperatures are below 350°F. Scrubber efficiency for the removal of PCDD and PCDF is on the order of 50%. Efficiency is affected by the ability of the mist eliminators to remove the droplets containing the trapped PCDD and PCDF.

f. Heavy Metals.

(1) The primary sources of toxic heavy metals in MSW incinerators are automobile batteries, cylindrical batteries, "button" batteries, and electronic devices. Additional control must be exerted by source separation or a front-end processing/operator to remove car batteries (primary source of lead), flashlight and electronic device batteries (primary sources of cadmium and mercury), and any other unusual items from waste prior to incineration.

(2) There are no current or proposed regulations governing the emissions of heavy metals from either incinerators or fossil-fueled boilers with capacities below 250 tpd. For plants with capacities between 250 and 1,100 tpd, federal regulation (40CFR 60.33a) specifies a limit of .030 gr/dscf. The lower primary combustion chamber modular SAUs have demonstrated levels of heavy metal particulate emissions in the range of 0.0046-0.0085 grains/dscf (i.e.,for less than one third of the acceptable limit).

(3) The best control alternative is a fabric-filter system. As the flue gases cool, the vaporized heavy metals condense on particulates. Due to their small size (less than 10 microns), heavy metal particulates are not collected effectively by scrubbing systems (less than 50% effective). Fabric-filter systems with "seeded" bags create a tortuous path that effectively controls release of fine particulates.

5-4. OTHER PLANT DISCHARGES.

a. Waste Water. Incinerator plants produce various contaminated waste waters other than normal sanitary and storm water effluents. These discharges come from water drained from the waste or used to wash down the tipping floor, water from the ash system, and gas scrubber solution blow-down. The water from the ash system includes water leaking from the ash collection dumpsters prior to being removed and emptied. This water may contain toxic minerals leached from the ash and should be collected and retained in a separate container. Water from the tipping floor may be slightly acidic and contain significant amounts of bacteria and organic solids. This water should be processed through a grit trap to collect the larger solids before further processing. The liquid from the ash system and the scrubber blow-down will typically be alkaline with a high solids concentration and should be filtered and buffered before release to the sanitary sewer. Liquids will probably require treatment at the incinerator plant for pH balance and removal of solids before discharge. Dumping these liquids into the sanitary sewer system without any treatment may cause problems at the sewage treatment plant. The designer must check with the base sewage plant and review local water pollution regulations to determine treatment requirements at the incinerator plant.

b. Ash. Ash is produced in two forms: bottom ash and fly ash.

(1) Bottom ash is the residue that collects inside the incinerator after the completion of the combustion process. Fly ash consists of the smaller, lighter particles entrained in the flue gases that are collected in the pollution control equipment and mixed with used scrubber sorbent. Bottom ash accounts for 90% (nominal) of the residue and consists mostly of alumina, silica, and oxides of iron. Bottom ash by itself is alkaline and may be acceptable for landfill disposal without treatment.

(2) Fly ash may contain significant amounts of any low-melting-temperature heavy metals which were present in the waste stream. The presence of toxic metals will have a significant affect upon the possible treatment and disposal of the ash. Starved-air incinerators and FBC units typically retain the greatest amount of heavy metals in the bottom ash because the lower combustor bed temperatures produce less volatilization. The high-turbulence, excess-air incinerators have the greatest amount of heavy metals in the fly ash since the higher grate temperatures promote greater volatilization.

(3) The 1994 decision by the U.S. Supreme Court states that the ash and pollution control process residues from municipal waste incinerators are not exempt from RCRA (Resource Conservation and Recovery Act) hazardous waste regulations. This decision now forces all residual ash to be tested to determine whether or not it meets the criteria for hazardous or nonhazardous waste. If significant amounts of heavy metals are found and the ash and other residues fail to meet RCRA requirements, the material will have to be treated as a hazardous waste and be disposed in a hazardous waste landfill. Disposal in a Subtitle C landfill is considerably more expensive than disposal in a RCRA Subtitle D landfill.

(4) The current USEPA-approved method of testing for heavy metals (i.e., TCLP) and its predecessor (EP-toxicity) use different criteria for determining acceptability. The designer should check which test is currently required. The local pollution control authority will most certainly require an initial test burn with a typical sample of waste to check for the presence of heavy metals in the total residue as well as require periodic checks during the operation of the incinerator plant.

(5) Even if test results meet RCRA requirements, local or state pollution regulations may require that plant discharges be disposed in a separate landfill area (monofill). Local regulations may also require the ash be mixed with Portland cement or otherwise stabilized to minimize the possibility of undetected contaminants leaching out after being land filled. The design of the incinerator facility and the ash/ residue disposal facility must include an area of adequate size for handling and storage of all of the ash and other solid residues (e.g., spent scrubber sorbent) produced by the incinerator plant during operation.

(6) The fly ash and the gas cleanup system residues if disposed separately from the bottom ash, may be land filled in a special monofill or may be required to undergo special treatment before placement in a Subtitle D landfill. The amount of material falling into this category is usually a small percentage of the original waste stream (i.e., 1-5% by weight).

5-5. ENVIRONMENTAL PERMITTING.

a. Professional Assistance. Each proposed facility must satisfy unique conditions and limits imposed by the permitting authorities. Regulatory authorities that have jurisdiction must be identified, as well as, the current regulations that apply to the project.

b. Environmental Assessment/ Environmental Impact Statement. An Environmental Impact Statement (EIS) may have to be prepared as part of the permitting process. If several older boiler plants without pollution controls are to be shut down, and less pollutants emitted as a result of operating an incinerator plant with emission controls, credit can be taken for the net reduction in emissions. If an EIS is not required, an Environmental Assessment (EA) will be necessary, if for no other reason than to document why the EIS is not needed. Inordinate concern by the public over an incinerator project may force the issuance of an EIS. This concern may also require preparation of other reports, not required by regulations, in order to demonstrate the thoroughness of the planning process and to preempt legal challenges that can cause long delays in the completion of the project. Some civilian companies found out the hard way that the legal challenges turned out to be considerably more expensive than the cost of dealing with the public's concerns ahead of time. This can be especially true if the regulators or the public believe that the decision to build has occurred without proper consideration of all environmental consequences.

c. Permit Hearing. Local pollution control boards may have stringent, regulations due to public concern over the local ambient environmental quality. Official public hearings as specified in the federal regulations (40CFR 60.23) are required if the state has chosen to accept the provisions of this regulation. Demonstration of compliance to all requirements will have to be made at the hearing. Informal meetings with public officials and citizen groups should be encouraged only after the project planners and the engineers have demonstrated their environmental data base is complete and accurate.

d. BACT, LAER, MACT and RACT.

(1) There are four emission control concepts that the designer should be aware of: Best Available Control Technology (BACT), Lowest Achievable Emission Rate (LAER), Maximum Available Control Technology (MACT), and Reasonable Available Control Technology (RACT).

(2) BACT. BACT refers to a standard of performance and not a specific pollution control technology. However, the standard of performance frequently has been established by a specific

pollution control technology. In the case of incinerator plants, the performance of a spray dry scrubber followed by a bag house is considered the BACT by most states. Dry lime and wet scrubber systems have been shown to provide performance comparable to a spray dry unit. The manufacturers should be able to provide design and performance data to prove their claims in order to get the design approved and obtain a construction permit. Use of a relatively new technology for which there is little or no data to prove it can perform as well as a spray dry scrubber will probably not be approved.

(3) LAER. If the plant is to be built in a non-attainment area (poor ambient air quality), it may be required to comply with the LAER concept. The plant will be designed to achieve the lowest emission rates technically possible, regardless of cost.

(4) MACT. An emission limitation for new sources which is not less stringent than the emission limitation achieved in practice by the best controlled similar source. Reflects the maximum degree of reduction in emissions of hazardous air pollutants that the administrator (taking into consideration the cost of achieving such emission reduction, any non-air quality health and environmental impacts and energy requirements), determines is achievable by sources in the category or subcategory to which such emission standard applies.

(5) RACT. Devices, system process modifications or other apparatus of techniques that are reasonably available taking the following into account:

- The necessity of imposing such controls in order to attain and maintain a national ambient air quality standard.

- The social, environmental and economic impact of such controls.

- Alternative means of providing for attainment and maintenance of such standard.

e. Emission Trade-Offs. If the ambient air quality is extremely poor, it may be necessary to eliminate or reduce emissions from existing sources before the incinerator plant can be built (emission trade-offs).

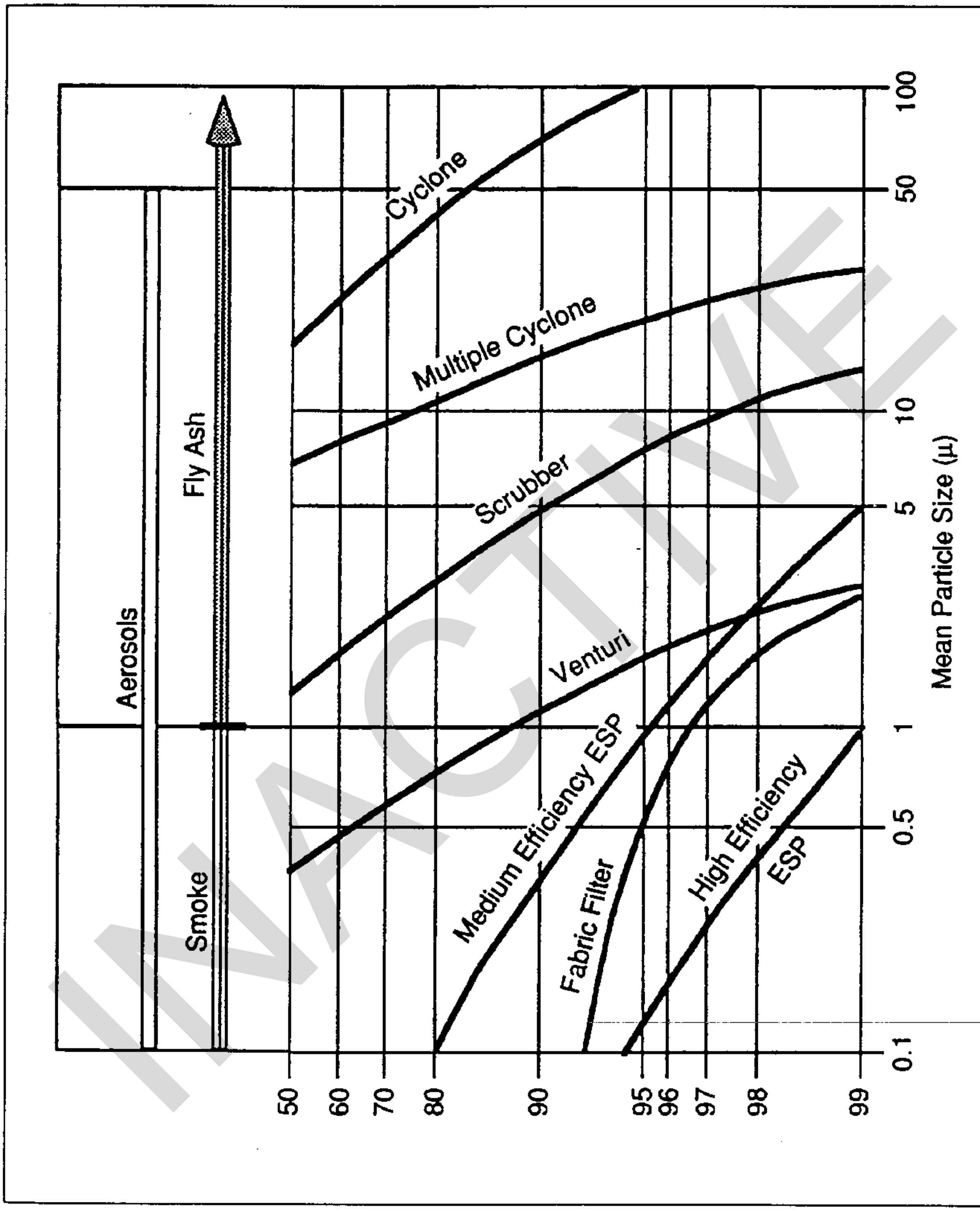

Figure 5-1. Range of concentration and collector performance

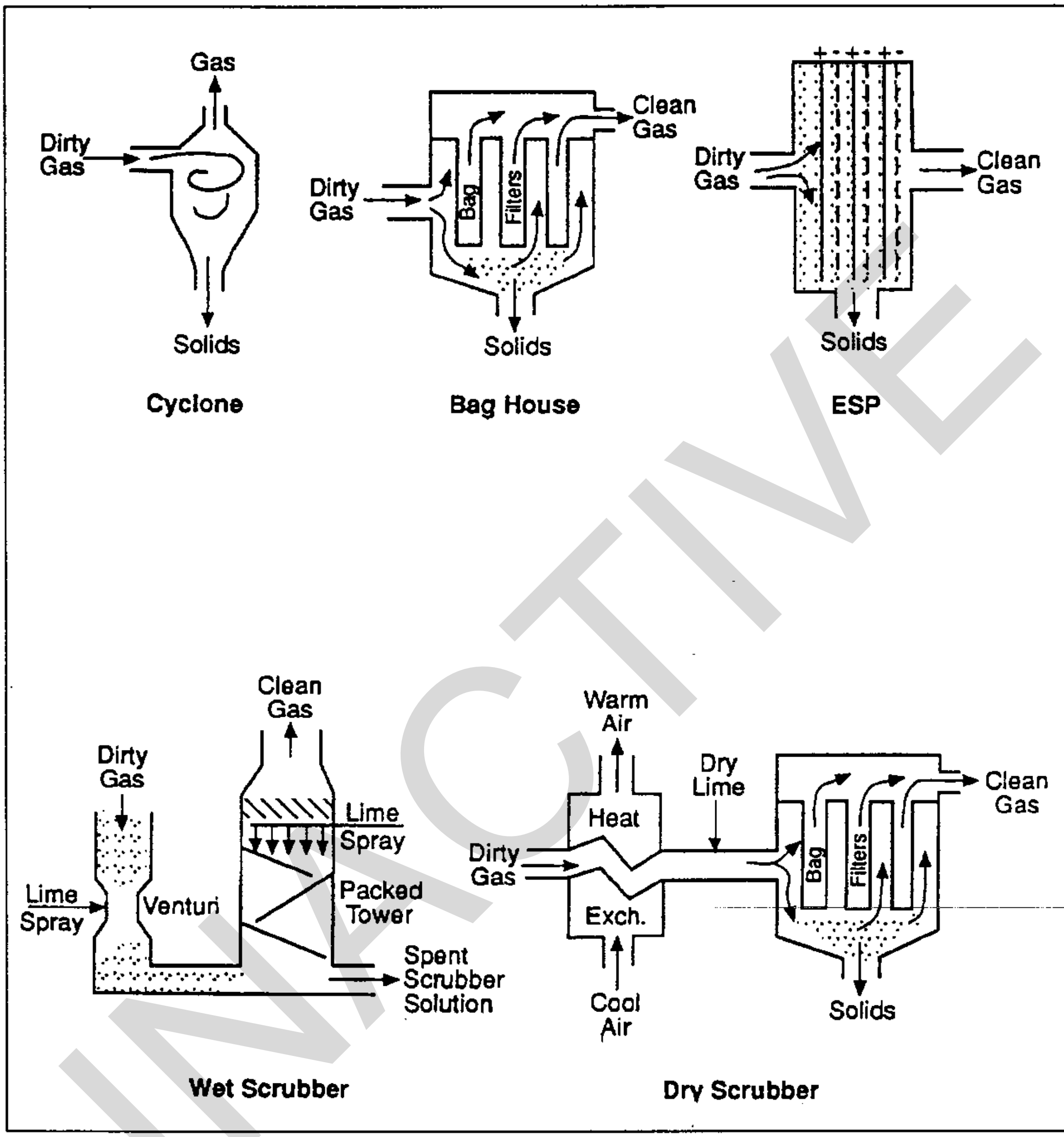

Figure 5-2. Typical air pollution control equipment

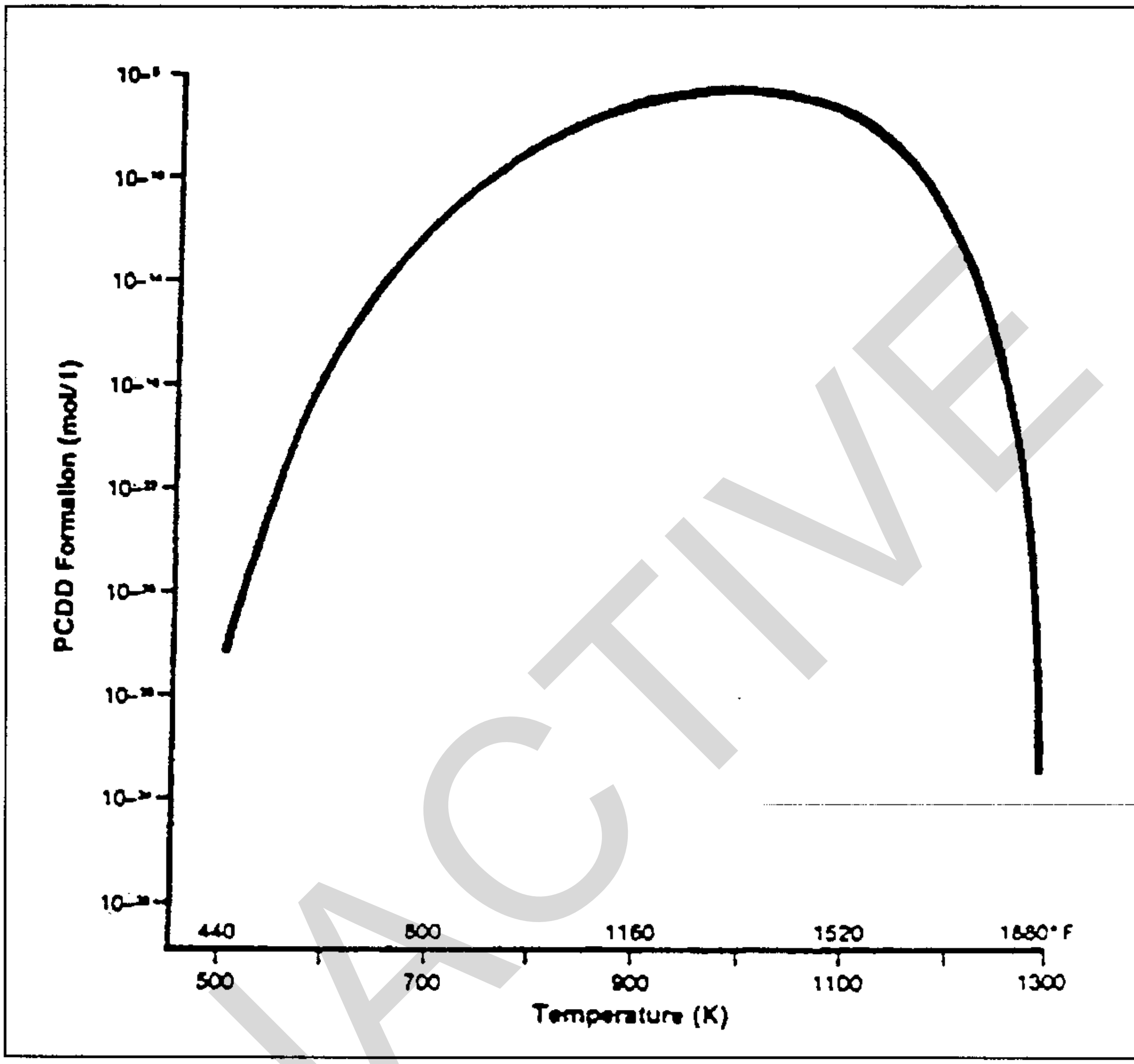

Figure 5-3. Correlation of emissions of dioxins, CO, and THC vs. top temperature

Table 5-1. Bag Fiber Properties for Boiler/Incinerator Applications.

Property	Acrylic	Fiberglass Woven	Fiberglass Tri-Loft	Nomex	Ryton	P-84	Glass Felt	Teflon
Temperature (°F)	275	500	500	375	375	500	500	500
Abrasion	Good	Fair	Fair	Excellent	Good	Fair	Fair	Good
Energy Absorption	Good	Fair	Fair	Good	Good	Good	Good	Good
Filtration Properties	Good	Fair	Good	Excellent	Excellent	Excellent	Good	Fair
Moist Heat	Excellent	Excellent	Excellent	Good	Good	Good	Excellent	Excellent
Alkalines	Fair	Fair	Good	Good	Good	Fair	Good	Excellent
Mineral Acids	Good	Poor	Good	Poor	Good	Good	Good	Excellent
15% Oxygen	Excellent	Excellent	Excellent	Excellent	Poor	Excellent	Excellent	Excellent
Relative Value	$	$$	$$$	$$$$	$$$$$	$$$$$	$$$$$$	$$$$$$$$

SOURCE: BHA Group Inc. for Pulse-Jet Baghouses

Table 5-2. CO Emission Limits Established in 40CFR 60.36.

	Incinerator Type	CO Limit (ppm_v)
a)	Modular Starved Air	50
b)	Modular Excess Air	50
c)	Massburn Waterwall	100
d)	Massburn Rotary Waterwall	250
e)	Bubbling Fluidized Bed	100
f)	Coal/RDF Mixed Fuel-Fired Combustor	150

CHAPTER 6

INSTRUMENTATION AND CONTROLS

6-1. PURPOSE.

a. Instrumentation and control systems for incinerator plants are critical to the successful operation of the plant. As many individual systems are involved, the controls are nearly always distributed type using multi-loop PLC's networked to a central computer based system.

b. Individual systems requiring control include; fuel feed system for refuse, overfire and under-fire combustion air, auxiliary fuel burners, boilers and other heat recovery devices, material handling systems for refuse, fly ash, bottom ash, dry powders, slurries, compressed air systems, water systems, boiler feed controls, scrubber controls, carbon injection systems, urea or ammonia injection, continuous emission monitoring equipment (CEM), fly ash stabilization facilities, etc.

c. Incinerators in the size range of 100 tpd may include the following control and monitoring instrumentation:

(1) Process Instrumentation. This instrumentation monitors the conditions under which the basic processes in the incinerator are proceeding (e.g., chamber temperatures, gas concentrations of CO and CO_2, gas flow rate).

(2) Data Acquisition and Recording. This equipment provides data that will assist in determining operating costs and help determine areas where potential improvement in operations are cost effective (e.g., auxiliary fuel consumed, steam produced).

d. Larger incinerators have more sophisticated instrumentation and control systems.

6-2 . BASIC DESIGN GUIDELINES. Guidance for typical incinerator instrumentation is listed in table 6-1. Basic control areas and their relationships to this instrumentation are shown in table 6-2.

6-3. BASIC DESIGN CONCEPTS. Fundamental concepts for incinerator control design are described below.

a. Combustion Air Control.

(1) To obtain complete combustion of refuse, the proper amount of air must be introduced above and underneath the grate/hearth commensurate with the mode of operation (i.e., starved air or excess air).

(2) Because of the nonhomogeneous nature of raw refuse, the actual under-fire air requirement varies considerably. (Note: pretreatment of the waste in the MRF can significantly reduce the heterogeneity problem). The largest and most sophisticated incinerators have under-fire air control systems involving motor-operated dampers and sensors to adjust the air flow relative to the quality and quantity of waste being fed (as determined by temperature sensors in the furnace). Most smaller units, use manual control of dampers to partition air to the various stages. The

dampers are maintained in a fixed position once they have been set for the waste. In such cases, the feed rate of waste is adjusted to match the flow of air rather than vice versa.

b. Furnace Temperature Control. To insure complete combustion, the furnace outlet temperature must be maintained at its set point. In packaged and small modular units, temperature control is the primary parameter for adjusting the waste feed rate. However, temperature is used by all technologies to influence the firing rate to some degree. Temperature limit controls may be used to initiate a water spray or to activate the under-fire air flow controller to abruptly reduce the chamber temperature. In excess-air units and in the secondary zone of starved-air units, excessive temperature is corrected by increasing the airflow. If the temperatures become too low, the auxiliary gas/oil-fired burners will ignite. In all cases, the temperature is sensed by a thermocouple mounted in the side wall or in the crown of the combustion chamber. The controller will use the temperature signal to initiate alarms or make automatic adjustments.

c. Furnace Pressure Control.. Various actions will cause pressure fluctuations in the incinerator and systems that follow; such as, variations in air flow to the incinerator, operation of internal rams, and feed door opening and closing; therefore, it is necessary to have a draft control system. Normally, a forced draft (FD) fan is used on large units to supply air to the combustion air ducting system. An induced draft (ID) fan is used to draw combustion gases from the incinerator through the heat recovery boiler and air pollution control system. (Note: It is preferable to pass clean air through the fan.) The draft control system balances the operation of these two fans and maintains a nominal primary chamber pressure of (-) 0.1 in. of water column (vacuum). Irrespective of how air flow is controlled, a negative pressure is maintained throughout the combustion gas flow path to preclude toxic gas leaks from the system.

d. Cooling Control System. Heat recovery is used on all but the smallest incinerators. Typically, packaged units and modular unit secondary combustion chambers are followed by a convection heat exchanger that heats hot water or produces steam. The design of the heat-recovery system provides for the cooling of flue gases from a nominal 1,500-1700°F down to 350-450°F. Temperature control of the flue gases is absolutely necessary before the gases go through the pollution control system and ID fan. If an over-temperature upset condition occurs, cooling is accomplished by a water spray in the ducting, dilution of the gas stream with tempering air, and/or "dumping" the gas directly to the atmosphere by means of a "dump valve" located between the secondary combustion chamber and the heat recovery device.

e. Combustion Monitors. The quality of the combustion process is monitored by devices sensing CO, O_2, CO_2, and total hydrocarbon (THC) levels in the flue gas leaving the incinerator. The sensors provide input to the computer control system to automatically adjusts feed rates and air flows to maintain optimal combustion process conditions. Output of these sensors may also go to a recorder for environmental emissions monitoring. As federal and state regulations become more stringent, the use of more sophisticated monitors and controls become commonplace.

Table 6-1. Typical Incinerator Instrumentation Equipment.

APPLICATIONS	MEASURING DEVICES
Very high temperatures for combustion zones (greater than 1100°C)	Pyrometers(infrared, radiation, optical), platinum/rhodium thermocouples (sheathed)
High temperatures for incinerators and pyrolysis reactors (600-1100°C)	Chromel/alumel, chromel/constantan,and stainless steel thermocouples, resistance temperature detectors (platinum)
Moderate temperatures for ambient measurements, water, driers, steam (200-600°C)	Iron/constantan thermocouples, resistance temperature detectors (platinum, nickel, copper), filled elements, bimetallic thermometers, liquid-in-glass thermo-meters, thermistors.
Liquid levels for quench and wastewater tanks, feedwater, and steam drums pressure	Floats, displacement sensors, ultrasonic detectors gage glasses, differential detectors,tape level gages
Solid levels for feed hoppers fly ash hoppers	Capacitance probes, ultrasonic detectors, radiation gages, tape level gages
Draft pressures for furnaces, ducts, air pollution control devices, stacks (0.1 to 1.1 atmospheres absolute) and differential pressures for flow and level determination	Diaphragms, bellows, manometers, inclined gages, bell-type gages
Air, steam, water pressures (greater than 1.1 atmos. absolute)	Bourdon tubes, diaphragms (6-20 atmos. maximum), bellows (6-50 atmos. maximum)

Table 6.1. Cont.

APPLICATIONS	MEASURING DEVICES
Air, flue gas, fuel gas and steam flows	Orifices, venturi tubes, flow nozzles, pitot tubes, elbow taps - with differential pressure measurement
Low gas flows for special purposes	Rotameters, laminar flowmeters, gas displacement meters
Liquid flows for fresh water, boiler feed water, wastewater, fuel, neutralization, water sprays	Orifices, venturi tubes, flow nozzles, weirs, rotameters, turbine flowmeters, liquid displacement meters, metering pumps, self-contained regulators
Electrical measurements for power current lighting, voltage in fans, heaters, pumps, motors, electrostatic precipitators, control systems	Wattmeters, ammeters, voltmeters, spark meters (for use with electrostatic precipitators)
Motion for fans, stokers, conveyors	Tachometers, counters
Position for dampers, valve controls	Deflection meters
Visual observation of furnace and reactor interiors, loading and unloading operations, conveyor belts, stack effluents	Observation ports, mirrors, closed circuit television
Analyzers for stack and waste water emissions, fuel products, ambient air quality	Stack emissions: opacity meter, hydrocarbon analyzer. Water emissions: pH analyzer, dissolved oxygen analyzer

Table 6.1. Cont.

APPLICATIONS	MEASURING DEVICES
Weight of full and empty trucks (raw refuse, resource recovery products, residues), crane bucket contents	Platform scales, load cells
Vibration of fans and other rotating devices	Probes (transducers) to measure displacement, velocity, or acceleration with readout and preferably with warning and shutdown capabilities

Table 6-2. Basic Control Areas.

TYPE OF CONTROL	REMARKS
Underfire Air	Primary source of oxygen; affected by nature of waste, combustibles density, moisture; determined by measuring performance; appearance of bed, reduction of volume, burnout; insufficient underfire air results in incomplete combustion, excess in flyash generation; controlled indirectly by sensing flow in ducts and maintaining levels by dampers on flow speed.
Overfire Air (Secondary Air)	Secondary source of oxygen; used for oxidizing refuse products in gases; primary source of dilution air; affected by nature of waste (see above); controlled by temperature sensing; low temperature results in unburned gases and odors; high temperature results in furnace damage; sometimes overfire/underfire air flow ratios used.
Draft	Maintained by draft fan compensating for variations in underfire and overfire air flow rates.
Auxiliary Burner	Used for additional heat needed to sustain combustion during startup, transient periods, etc.; on-off burners sufficient with standard flame-guard and purging systems for safety.
Grate	Grate speed provides movement, agitation, residence time and temperature; affected by nature of waste; judged by observing performance as with underfire air; manual adjustments required.
Feed Conveyors/Cranes	Conveyors, when used, require speed control to coincide with grate speeds; cranes operated manually to keep feed hoppers full.

Table 6-2. Cont.

TYPE OF CONTROL	REMARKS
Flue Gas Cooling	Reduces gas volume, protects fans, flyash collection equipment, stock; water sprays used; cold air possible but adds greatly to air pollution control cost.
Flyash Recovery	Varies with type of pollution control equipment.
Wastewater	Required to monitor pH, discharge and recycle flow rates, temperature; used to meet pollution regulations, scrubbers, cooling requirements, corrosion minimization.

CHAPTER 7

INCINERATOR PLANT DESIGN

7-1. STANDARD BUILDING TYPE. Pre-engineered metal buildings, typical of small modular plants, can be supplied with a wide variety of sidings, fascia, and other trim for aesthetic purposes. The incineration equipment should draw the combustion air from inside the plant. This helps keep the building under negative pressure to minimize release of odors. Roof fans are needed to insure adequate air circulation, and maintain the slightly negative pressure inside the building.

7-2. WASTE RECEIVING AND PRETREATMENT
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a. Scales. The design of any incinerator plant must include truck scales. The scale is needed to establish the weight of incoming solid waste, outgoing residue, salvaged materials, and to monitor the performance of the facility. State and local regulatory agencies may require this information be made available to ensure the plant is not processing more waste than it is licensed for and is not overloading the incinerators.

b. Receiving Accommodations. Trucks must have adequate room to turn and maneuver after going over the scales. This is especially important for back-in arrangements. There should be several acres of free area around the waste receiving area for maneuvering and parking of trucks and for storage of drop-off containers. At least the receiving area, if not the entire plant site, must be surrounded by a wire-link fence to prevent paper and other debris from blowing out of the immediate area.

c. Tipping Floor.

(1) Typical Layout. The normal configuration for a small modular incinerator facility building is for the trucks to unload their waste onto a tipping floor. If the waste is not processed at an MRF, a front loader will be used to separate out any material that should not go into the incinerators, push some of the waste into the incinerator charging hoppers, and pile-up the rest in storage areas. The front loader used to service the incinerators must be large enough to deliver an adequate amount of waste to the feed hoppers, but have a bucket narrow enough to directly access the feed hopper opening. Irrespective of whether an MRF is used, the tipping floor area at the incinerator should have some provision for reducing the size of large, burnable material that has been delivered. Typically this type of material includes scrap lumber, timber, logs, tree stumps, pallets, and wooden boxes. A shear shredder or a tub-grinder with ample capacity to handle timbers, tree trunks, and large pallets may be required.

(2) Waste Storage Area. For the storage of 3-5 days feed stock, approximately 130 ft^2 of tipping floor area should be provided for each ton-per-day incinerator capacity. This storage capacity is required to insure continuous operation during those periods when waste deliveries are not being made. The actual space allocation will be influenced by the type of floor arrangement selected, the amount of truck and front loader traffic, and how high the front loader can pile the waste in storage (which is also affected by the height of the concrete retaining wall against which the waste is to be piled).

(3) Construction. The tipping floor must be a finished and sealed, reinforced concrete slab designed to carry the truck loads. The floor must have a grate-covered drain to catch water from the waste, water used to wash down the floor, and rainwater that might collect near the truck doors.

d. Pit and Crane. If the incinerator plant is especially constrained for space, it may be necessary to use a pit-and-crane system for waste storage and feeding. A loose (uncompacted) bulk density of 100-150 lbs/yd^3 should be used to determine the required volume of the pit.

(l) Where cranes are used for feed, incinerator plant operation is dependent upon the crane reliability which can operate continuously. Accordingly, the crane should be rated for MHI CMAA 70 Class F (Continuous Severe Service). The best type of bucket for handling garbage is the "orange peel" grapple. In addition, hose bibs must be provided both to wash down the pit periodically, and to put out occasional fires in the pit.

(2) Space and Service. The pit will occupy considerably less floor space in the plant than the tipping floor due to its depth below grade. Waste hauling trucks need to pull only part way into the incinerator building in order to be out of the weather when discharging their loads into a pit.

e. Waste Processing. If the decision has been made to expand the present materials recovery and recycle program, provisions must be made in the design for the waste processing equipment required prior to the incineration. Typically, this will require some form of handpicking operation, preferably using conveyors and certain equipment for removing metals. If possible, the MRF and incinerator should share a common site.

(1) MRF Tipping Floor. In a totally integrated system, the MRF tipping floor needs to provide for the acceptance and preprocessing of waste. All material deemed not recyclable, but acceptable for burning, would be sent to the incinerator facility for storage prior to burning.

(2) MRF Discharge. If an MRF is integrated into the system, the processed waste can be transported via a conveyor to the pit or the incinerator tipping floor, where it would be mixed with the other burnable waste that bypassed the MRF.

f. Waste Bypass.

(1) Normal Operation. Some types of wastes will not be suitable for incineration. Other wastes will not be suitable for processing at the MRF. Therefore, provisions must be made for direct bypass of these wastes or for dumpsters to receive the discards separated from the waste to be disposed by other methods.

(2) Contingency Methods. The design must accommodate and plan for contingencies caused by equipment failures leading to unscheduled outages. Accommodation of these types of occurrences will require either a landfill for temporary disposal or some type of temporary storage capability until the facilities can be brought back up to full capacity.

(a) Loss of Incinerator Capacity. Provisions have to be made for landfilling large amounts of raw (otherwise combustible) waste in the event of a severe mechanical failure that reduces incineration capability to handle the flow beyond the 3- to 5-day storage capacity of the tipping floor or pit.

(b) Loss of MRF Capacity. If there is an MRF, it will probably have sufficient tipping floor capacity to store 1 to 2 days' collection. Such storage capacity will have to be in the building in order to protect the materials from the elements. Once the storage capacity in both facilities is filled, the processed burnable waste would have to be sent to the landfill.

7-3. ENERGY RECOVERY. Energy recovery will normally be in the form of steam and/or hot water. Typical efficiency of modular unit facility heat recovery is a nominal 65%. The more efficient field-erected facilities typically achieve 80-85% recovery of the energy generated.

a. Heat Exchanger System.

(1) Modular Unit Systems. In a modular incinerator facility (i.e., less than 200 tpd), the energy recovery heat exchanger will usually be a packaged convective heat exchanger that serves all the incinerator units in the facility. The heat exchanger may be of the firetube or watertube type. Firetube construction is more common in small units since they are generally the least expensive. If a pressure above 300 psig is required (e.g., for a steam turbine or for steam central heating), a watertube heat exchanger is needed.

(2) Field-Erected Units. Large, field-erected incinerators use a combination of an integral, radiant-heated water-wall boiler that forms the walls of the secondary combustion chamber and convection-heated super heaters and economizers. Each unit has a complete heat recovery system for the gases generated in the incinerator, including its own steam drum.

(3) Heat Transfer Surface Cleaning. Soot blowers must be provided for both types of boilers since cleaning of fly ash from a heat exchanger is frequently the limiting factor on how long the incinerator can continue to operate. Firetube boilers are multi-pass to minimize length and permit cleaning. The thermal efficiency will also be lower if soot is not blown out regularly.

(4) Other Types of Soot Removal. "Hot cyclones" (refractory-lined) have been used between modular incinerator units and the associated heat-recovery system to reduce the dust loading on heat-transfer surfaces. These have seen limited use and then only in small units.

(5) Economizers. Part of the reason for higher efficiencies in the large field-erected incinerator facilities is economizers, which are usually not cost effective in small units. The economizer is designed to remove the heat in the gases leaving the steam and boiler water convection heaters (shown on figure 4-4). As much as 10% of the total recoverable heat in the gases may be removed in the economizer to preheat boiler feedwater or combustion air. Care must be taken to ensure that economizer tube surface temperatures remain in excess of acid gas condensation temperatures. The exit gas temperature from the heat exchanger system will usually be limited to above 450^{o}F to prevent tube metal corrosion. Specially designed equipment may allow a reduction in temperature to 300^{o}F. Acid gas corrosion appears at temperatures below 275^{o}F.

b. Operating Mode. The waste-heat boiler and incinerator must be sized and operated to be base loaded. Thermal cycling (kept warm and on standby) for this type of application is not feasible and will result in damage (e.g., tube buckling and refractory loss) to the equipment.

c. Energy Use.

(1) Typically the steam or hot water produced in the energy recovery system is matched to the existing space-heating power plant conditions. The incinerator is used as a base-load generator due to its need to burn waste at a constant rate of throughput. This inflexibility in operating the incinerator means that the existing fossil-fueled, space-heating plant will be swing-loaded to follow changes in the daily demands.

(2) During the summer months, steam or high-temperature hot water produced by the boiler may be used to produce chilled water for air conditioning. Large, multi-stage, high-pressure (125 psig steam) absorption chillers are available from several manufacturers. Steam turbines running a mechanical chiller and exhausting into low-pressure (12 psig) absorption units are available. It is also possible to purchase ammonia refrigeration units that work off of low-quality waste heat; however, low-pressure absorption units should never be used by themselves because of their low thermal efficiency.

d. Co-generation. It may be desirable to equip the incinerator plant with a steam turbine to produce electricity or do other mechanical work (e.g., pump water, run air compressors) if the incinerator plant is larger than 50-tpd capacity. It is also possible to generate both electricity and district heating steamin small steam generation facilities.

(1) Steam turbines are available that use steam at pressures as low as 300 psig, perform mechanical work, and exhaust the steam at 150 psig or lower.

(2) Electricity Generation. The designer can expect electrical generation rates of 400 kWh from a 50-tpd incinerator plant and more than 1,600 kWh from a 200-tpd plant, despite the relatively low overall plant efficiencies (i.e., 10-12%).

(3) Operation on Demand. Co-generation is often used when high-pressure steam can be delivered to the district heating system via a high-pressure heat exchanger to produce low-pressure steam when the demand for district heating is high. It can also be used to send the high-pressure steam directly to the turbine when the demand for district heating is low.

7-4. ASH SYSTEM.
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a. The hot ash from an incinerator is usually dumped directly into a water-filled quench tank at the discharge end of the primary combustion chamber. The water is maintained at a level that provides a seal at the exit of the incinerator and thereby prevents unwanted air from entering the primary combustion chamber.

b. Removal Methods. Several methods of ash removal may be used, each with their advantages and disadvantages. Problems with ash system design and optimization are reasons why it is vital to hire a contractor with extensive experience in the design of waste incineration facilities. Experience has shown that plants have more trouble with the ash removal system than with any other support system. Two causes stand out: (1) under design, and (2) failure to remove wire-containing products, cable, and band strapping from the incinerator feed stock.

(1) Drag-Chain Conveyor. Drag-chain conveyors are the most common device for removal of ash. Water is allowed to drain from the ash as it is carried up a chute and out of the plant. Due to the gritty environment, the drag-chain conveyor is normally a high-maintenance item. The plant

operations crew should be aware that wire and items containing wire (e.g.,automobile tires) are a primary cause of problems with drag conveyor jamming.

(a) Conveyor Arrangement. Because of the persistent problem of jamming, each combustion chamber must have its own ash conveyor; however, they may share a common water pit.

(b) Maintenance Considerations. Since the ash conveyor is known for its maintenance problems, the designer must make provisions to ensure ease of maintenance and repair. Proper design requires sufficient space be provided on the sides for access, but not excessive room so that ash will accumulate in these areas. The chain must not pass through the falling ash before turning to pick up the ash from the bottom of the tank because metal objects (e.g., cans, bolts, scrap steel) may get caught, jam the conveyor, and break the flights. Provisions (e.g., portable pumps, filter, and floor drains) will have to be made for removing the water from the water pit for repairs and overhaul. The conveyor must lift the ash high enough outside the plant to allow a dumpster to be placed underneath to receive the ash. The ash has a higher density than the original waste, thus dumpsters have to be emptied half full not to exceed truck capacities.

(2) Back-Hoe Conveyor. Some manufacturers prefer the back-hoe type conveyor to remove ash from the quench tank. This type of system allows the chain mechanism to remain out of the water. A mechanism on the chain flips a metal plate (hoe) into the tank, pulls the hoe out of the tank and up the chute, drops the ash into the dumpster, and then flips the hoe back into the up position for the return to the quench tank. This design requires less maintenance and allows for a much steeper rise as the ash is withdrawn.

c. Ash Cooling. Some manufacturers do not quench the ash. Instead, a spray system may be adequate for cooling the ash if a large enough volume of water (deluge) is used. For small incinerators (less than 10 tpd), some manufacturers may dump the hot ash directly into the dumpster. In that case, the operators have to watch for fires in the dumpster from incompletely burned waste. In very small units, ash removal may be done manually after a cool-down.

d. Ash Disposal. In all cases, provisions have to be made in the design for adequate ash disposal.

(1) Dewatering. Dumpsters must have drain provisions because most landfills require the ash to be dewatered; in addition, drained dumpster water must be collected in a sump rather than discharged into the storm sewer.

(2) Treatment. In some cases, if other precautions are not taken to reduce the source of heavy metals, the ash may have to undergo some form of treatment before disposal to minimize leaching of heavy metal. If an MRF is used, the removal and collection of all batteries, electronic equipment, and other sources of lead, cadmium, and mercury from the waste sent to the incinerator will greatly reduce the need for special treatment and/or special disposal of the ash. If the ash does contain excess heavy metals, ash stabilization techniques such as combining the ash with portland cement may be required. Ultimate disposal will usually be in a monofill (i.e., a landfill specially dedicated to receiving incinerator ash). If such a commercial landfill is not available, one will have to be constructed on the base.

7-5. POLLUTION CONTROL EQUIPMENT. The various types of pollution control equipment and possible regulations are described in chapter 5. Provision may have to be made to keep waste water streams from the ash and waste receiving and storage areas separate so that they may be treated before being discharged to the sanitary sewer system. This treatment will undoubtedly include filtering to reduce the suspended solids, and may include chemical treatment to balance pH and remove other contaminants.

7-6. OPERATION AND ASSOCIATION COSTS. The O&M cost portion of the HRIFEAS computer program also gives only a very approximate estimate. As part of the final economic evaluation and preparation of an operating budget for the plant, a detailed estimate of the operating costs of the plant needs to be made.

a. Operations.

(1) Personnel. Incinerator plant operating personnel should be of the same grade and quality as regular boiler plant operators. Operators should be trained and certified under the tri-services program for certification through the National Institute for the Uniform Licensing of Power Engineers (NIULPE).

(2) Responsibilities. Approximately 60% of the operation deals with running the front loader and feeding waste into the charging hoppers. A comprehensive training program is necessary so that each person knows how to effectively function as a solid-fuel-fired boiler operator, a solid waste equipment handler, a maintenance and repair person, and a shift supervisor. In a larger plant, several people may be required to operate front loaders, to monitor the operation of the incinerators, and to provide routine maintenance. A 24 hours per day, seven days per week operation will require an extra "swing" shift of operators. A plant manager will also be needed to supervise all the operators and monitor the plant operation, and may also be used to record the weight of waste being delivered.

(3) Size of Operating Crews. Typically, a small incinerator plant (i.e., less than 50 tpd) will require a minimum of three operations crew members per shift (two operators plus a mechanic who may be shared with another plant) plus the manager or a shift supervisor. If the facility has a dry scrubber and bag house, one to two more people per operating shift may be required.

b. Consumable Supplies. Information should be gathered from major equipment suppliers as to consumable supplies, especially for the gas cleanup system. A detailed list and associated costs need to be developed. The contractor is required by the incinerator CEGS to submit a list of repair parts and supplies that will be needed for a number of months of operation.

c. Operation Schedule. Ideally, the incinerator plant should be designed (i.e., sized) to operate continuously. Minimizing the number of startup/shutdown cycles will prolong the life of the equipment, especially the refractory insulation in the combustion chambers. Depending upon the size of the incinerator, especially packaged units, it may be necessary to shut down on the second shift for an overnight burn-down and cool-off if ash removal is a manual operation.

APPENDIX A

EXCERPTS FROM EPA RESOURCE RECOVERY MANAGEMENT MODEL

A-1. INTRODUCTION. The U.S.A. Environmental Protection Agency developed a model for the planning and construction of resource recovery facilities based on the successes and failures experienced in the civilian sector. This model has been used successfully in subsequent planning and construction of facilities since its issuance. Excerpts from this document are provided here in order to orient the user of this manual to the type of detail and the scope of activities that must be analyzed if the project is to be successful.

a. The management model (SW-768) can be obtained from the National Technical Information Service (NTIS) and though recommended as the basis for the planning and construction scheduling for civilian projects it is applicable to military resource recovery projects as well.

b. The material reproduced from the Management Model document only covers excerpts from the Introduction and the List of Activities required during the Feasibility Screening and the Feasibility Analysis phases. This should help the reader to appreciate the scope of these initial phases in a successful project and should provide the basis for project activity checklists. Failure to provide complete answers to questions or unresolved issues in any of these areas can mean the difference between success or failure of the project.

A-2. GENERAL DISCUSSION. Resource recovery refers to the collection and reuse of solid waste, generally residential and commercial waste, for the production of commodities in the form of energy and materials, either at a central processing facility or by source separation, or both. This effort has gained recognition over the last decade as a partial solution to two major problems confronting this country: the need for environmentally sound disposal of solid wastes, including the need to reduce dependence on land disposal; and the need for alternate energy sources, including energy conservation. While the concept is not new, the potential in more communities for its use as a method for solid waste disposal has stimulated rapid growth in both large- and small-scale systems technology.

A-3. KEY QUESTIONS. In considering resource recovery, the following key questions must be addressed and resolved:

a. Is sufficient refuse available to support a resource recovery project and can it be committed in the long term to a facility?

b. Do realistic long-term markets for energy and materials products exist?

c. Are sites and technologies available which are environmentally sound and politically acceptable?

d. Do local laws permit procurement options and necessary contractual agreements?

e. Is the project financially feasible?

f. How does resource recovery compare to the non-recovery disposal alternatives?

g. Failure to address any one of these key questions may make project implementation impractical. The inability to obtain any critical item, such as a facility site, energy market, or adequate waste supply can spell the termination, or at least the postponement, of a project. The Management Model shows what tasks must be done and where in the planning process they should be accomplished. The Model is presented in considerable detail, which is necessary for those with limited experience in the field, and is useful as a checklist for those with more experience.

A-4. THE NEED FOR A MANAGEMENT MODEL. Because of the time span over which planning and procurement of resource recovery facilities takes place, events such as a change in project manager, departure and replacement of a key appointed official, or a newly elected official taking office can be expected to occur, as well as changes in laws and regulations. The Model provides a systematic approach for charting tasks already accomplished, thus helping to maintain project continuity and mitigate a tendency toward the unnecessary retracing of steps.

a. Recent experience in resource recovery projects indicates that some of the difficult decisions were not addressed in a timely and proper manner; thus time, effort, and money were wasted. The Model is intended to “close the gate” on continuing a project until a needed decision is made, then the gate will be opened to continue with the next major phase. These gates are political decisions conducted publicly based upon written documentation.

b. The Model allows new projects to benefit from past experience in resource recovery implementation by identifying for project managers the critical decisions in the project which must be made before succeeding activities can begin. It defines the proper relationship of all activities and decisions. This should result in improved decisions and smoother implementation with less redundancy of effort.

A-5. DESCRIPTION OF THE MANAGEMENT MODEL. The model is constructed in four phases. Phases I, II, and III are identified as Feasibility Analysis, Procurement Planning, and System Procurement, respectively. These three phases are preceded by a Phase 0, Initial Resource Recovery Feasibility Screening, denoting certain steps necessary to decide whether there is a strong reason not to study and plan for a resource recovery project.

a. Phase 0 depicts an informal preliminary review of certain information which enables decision makers to become aware of the potential for resource recovery even though the information may emerge from past planning efforts. The numeral 0 is used to stress that this phase is less formal than others because it is a test of whether local conditions preclude consideration of resource recovery. The function of Phase 0 is to investigate in rough terms whether to proceed with a resource recovery program at all.

b. Phase I, Feasibility Analysis, includes an evaluation of the feasibility of resource recovery an preliminary identification of alternatives, including source separation and co-disposal. This phase should form the basis for a decision to terminate, postpone, or proceed. It also includes activities necessary to construct a preliminary implementation strategy.

c. Phase II, Procurement Planning, further develops all elements leading to system procurement, including obtaining options to purchase sites (with associated environmental analysis and public meetings), strengthening market and waste supply commitments, risk allocation, and selection of a preferred procurement and financing approach.

d. Phase III, Procurement, covers the steps required for system procurement, including waste supply, market, construction, and operation (if applicable) contracts, necessary pre-construction permits (and associated environmental analysis), and obtaining the debt or equity capital to finance the project.

e. Toward the end of Phases 0, I, and II, a formal report (or statement) is prepared documenting the results and presenting a recommended course of action and associated budget for the next phase. Using the report as a basis, a political/public decision is made either to proceed or terminate.

A-6. MAJOR ISSUES. Major ongoing issues which must be considered in all phases include:

a. Public participation
b. Environmental considerations
c. Waste reduction
d. Source separation
e. Phase-over planning
f. Project communications
g. Assessment of industry roles and offers

A-7. PUBLIC PARTICIPATION.

a. The public may be involved in the project development in many ways, such as public meetings and hearings, presentations, advisory groups, newsletters, assistance, and coordination. The presentation of issues at an early stage promotes an atmosphere of openness and mutual trust.

b. History has taught that early and continuing presentation of issues to the public is essential in gaining public confidence in any program. Not only should the public be informed early, but also continuously for the duration of the project. The importance of this cannot be overemphasized, nor should the lessons regarding the consequences of past failures be forgotten. Without public dialogue, the project may be undermined for no more sufficient reason than a perceived lack of an informed and well-structured process or for the substantial reason that the project does not meet the community's goals and desires.

A-8. ENVIRONMENTAL CONSIDERATIONS.

a. Depending upon the individual state and local environmental assessment requirements, different environmental analyses may be necessary. The Model contains three types of environmental review.

(1) The first is an initial screening in the Feasibility Analysis phase.

(2) The second is a refinement of environmental criteria and analytical work, principally site selection (Procurement Planning phase).

(3) The third may be an assessment or a full Environmental Impact Statement which is system-specific and occurs after selection of a system or completion of preliminary design (Procurement phase).

b. In areas of air quality non-attainment, additional monitoring may be required to be completed prior to design and construction of the facility. This action may be initiated early and may continue throughout a large part of each phase. The Model is more concerned with the position in the process of the completion and in some cases may leave the decision about when to commence this work up to local requirements an customs. Use of the Model should allow careful and timely consideration of all environmental restrictions which have typically impacted resource recovery projects.

A-9. WASTE REDUCTION.

a. Waste reduction generally refers to reducing the quantity of solid waste generated so that there is simply less waste for disposal in landfills, for resource recovery, or for source separation. The reuse and recycling of beverage containers is an example of waste reduction because fewer containers enter the municipal waste streams.

b. While the model is used independently of waste reduction, the two are compatible. The only adjustment needed in the resource recovery planning process is a revision of the estimates of solid waste quantity and composition that will be available to the resource recovery system after all reasonably foreseeable waste reduction systems are in place. The Model does not detail a method for introducing waste reduction programs, but recognizes their potential and allows ample opportunity for a project manager to factor waste reduction into the overall resource recovery management plan.

A-10. SOURCE SEPARATION. Source separation is defined as the setting aside of recyclable waste materials at their point of generation for segregated collection, transport, and delivery to specialized waste processing sites or final manufacturing markets.

a. The Model encourages and promotes the pursuit of a separation program, either independently or in conjunction with a larger-scale program. Analysis of a source separation program is placed early in the consideration of solid waste resource recovery processes. In some cases, source separation may be the only viable recovery program available to a locality.

b. The Model indicates that source separation is carried out independently, but at specific points is factored into the Master Network because the municipal decision process may occur on both systems at the same time.

A-11. PHASE-OVER PLANNING. Most resource recovery projects represent long-term solutions to solid waste disposal for communities. One must, however, count on substantial time to elapse between the initiation of resource recovery planning and the actual commencement of resource recovery plant operations. The transition from the existing solid waste management system to the initiation of the long-term resource recovery program is the phase-over period.

a. In many cases interest in resource recovery is stimulated by a need to abandon the current system, such as an incinerator with excessive emissions or a landfill reaching capacity. In cases such as these, the program manager has two concurrent tasks.

(1) The first is to plan for the shorter-term phase-over solid waste management needs.

(2) The second is to plan for the long-term resource recovery program.

b. Although phase-over planning is required immediately, it should progress along with and be compatible with the long-term planning represented by this Management Model. While the two planning functions are often concurrent and some of their respective activities may be interdependent, the two planning activities may be separate and distinct. Where possible, the same project manager or task force should be involved in both activities. The primary focus is to avoid actions of a short term or phase-over nature that are inconsistent with the long-range goal.

c. It is not the purpose of this Model to address phase-over planning. While the need for this planning, as well as points of interdependence (e.g., site selection and size, residual disposal), are acknowledged the Management Model is designed primarily to assist the project manager in implementation of only the resource recovery program. Concurrent functions, scheduling constraints, and other problems facing the municipality must be resolved by the project manager responsible for the function.

A-12. PROJECT COMMUNICATIONS. There is a need in every project, because of the time that may elapse between project phases, to maintain contact with members of the participating organizations, especially during periods of low activity. For example, after letters of intent are received from markets, time passes while public presentations and political decisions are made. Project momentum should be continued by the project manager, and continuous contact should be maintained with markets and member municipalities so that they are kept constantly up to date and interest and desire for participation is not lost.

Activity Index

Master Activity No.	
	Phase 0 - Conduct initial Resource Recovery Feasibility Screening.
000	Complete Overview of Phase 0.
001	Evaluate Non-Recovery Disposal Options and Associated Environmental Issues.
002	Sample Citizen and Political Interest.
003	Conduct Preliminary Market Survey.

004 Conduct Preliminary Waste Supply Assessment.

005 Assess Source Separation Potential.

006 Assess Economics, Environmental Impacts, and Procurement Methods of Recovery Technologies.

007 Test Appropriateness of Proceeding.

Phase I - Resource Recovery Feasibility Analysis

101 <u>Organize Project Team and Public Process</u>

10101 Establish Project Director.
10102 Establish Project Manager.
10103 Identify Organizations to be Solicited for Membership.
10104 Solicit Members.
10105 Establish Team, Assign Responsibilities.
10106 Establish Policy, Goals, and Guidelines.
10107 Establish Public Release Procedures.

102 <u>Secure Required Resources</u>

10201 Establish Scope of Work for Project.
10202 Establish Scope for In-House Staff and Consultants.
10203 Develop Preferred Contracting Method.
10204 Develop Consultant Selection Method.
10205 Advertise for Qualifications.
10206 Secure Commitments from In-House Staff.
10207 Negotiate with Consultants on Retainer.
10208 Select Short List of Firms.
10209 Interview Short Listed Firms.
10210 Select Preferred Firm.
10211 Negotiate and Sign Contract.

103 <u>Screen Environmental Requirements</u>

10301 Determine Conditions for Requiring A-95 Review.
10302 Determine Zoning Categories and Restrictions.
10303 Determine Ambient Air Quality and Emissions Restrictions.
10304 Determine Surface and Ground Water Use and Effluent Restriction.
10305 Determine State and Local Environmental Review Requirements Including Major Permit.
10306 Determine Other Restrictions and Requirements.

104 <u>Conduct Technology Analysis.</u>

10401 Review the State-of-the-Art.

10402 Analyze Input Requirements and Output Characteristics (Other than Refuse and Products).
10403 Investigate Source Separation Technologies.
10404 Determine Refuse Input Requirements and Co-Disposal Capabilities.
10405 Ascertain Product Specifications.
10406 Ascertain Size, Reliability, and Costs.
10407 Determine Procurement Issues and Industry Service Potential.
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105 Analyze Waste Stream

10501 Obtain List of Industries.
10502 Obtain Population Data.
10503 Obtain Prior Studies and Reports.
10504 Obtain List of Transfer, Processing, and Disposal Sites.
10505 Obtain List of Collection Agencies and Companies.
10506 Obtain List of Sewage Treatment Plants.
10507 Obtain Sludge Checklist Information for Each Sewage Treatment Plant.
10508 Obtain Septic Tank Pumping Data.
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10510 Estimate Municipal Waste Generation.
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10512 Estimate Seasonal Fluctuations of Solid Waste.
10513 Estimate Facility Throughput and Disposal Quantities by Site.
10514 Perform Weighing Survey.
10515 Estimate Disposed Quantities from Survey by Site.
10516 Compare Estimates, Develop Consistent Generation and Disposal Quantities.
10517 Perform Compositional Analysis to Support Materials, Energy, and Source Separation Studies.
10518 Estimate Average Yearly Composition.
10519 Estimate Average Heating Value.
10520 Estimate Quantities of Recoverable Materials.

106 Perform Detailed Energy Market Analysis.

10601 Obtain List of Fossil Fuel Users.
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10603 Identify Potential Markets.
10604 Visit Potential Markets.
10605 Identify Viable Potential Markets.
10606 Plot Commodity Demand.
10607 Develop Commodity Pricing Schedule.
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10609 Conduct Introductory Meeting with Utilities.
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10701 Determine Future Landfill Requirements.
10702 Obtain Data and Costs of Existing Facilities.
10703 Examine Current Operations and Plans of Neighboring Areas.
10704 Analyze Existing Facilities and Expansion Potential.
10705 Define Existing Disposal Options.

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10801 Obtain List of Possible Markets.
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10803 Identify Potential Markets.
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11103 Establish Average Travel Times for Links.
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11202 Obtain Existing and Potential Site Checklist Information.
11203 Categorize Sites According o Suitability.
11204 Rank Higher-Potential Sites.

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11304 Examine Existing Waste Supply Status.

11305 Examine Existing Waste Contracting Capability.
11306 Analyze Risk Assignment for Each Option.
11307 Summarize Options, Needed Legislation, Constraints, and Risks.

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11403 Analyze Regionalization and Transportation.
11404 Assess Risks.
11405 Develop Preferred Financial and Institutional Arrangements for Each Alternative.
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11501 Establish Ordered Briefing List.
11502 Establish Decision Path.

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11601 Rank Alternatives.
11602 Formulate Preliminary Recommendations.
11603 Conduct Review and Incorporate Comments by Project Team.
11604 Obtain Project Team Adoption.

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11703 Proceed with Decision.

APPENDIX B

COMBUSTION CALCULATIONS

B-1. GENERAL.

a. Purpose. The purpose of the following combustion calculations is not to design the incinerator. The details of the incinerator design must be left to the manufacturer since the manufacturer must guarantee its performance. However, information on heat release, gas flow rates, particulate loading, and other pollutants in the flue gas will be needed in order to prepare system performance requirements for the heat recovery boiler, pollution control equipment, certain auxiliary equipment such as ID fans, and as input to an EIS. The data will also be used to fill in the blanks on the flow and instrument diagram that the designer will find among the standardized drawings.

b. Scope.

(1) The combustion calculations described in this appendix are much more detailed than those performed by the HRIFEAS computer program. HRIFEAS only calculates the heat release and the amount of useful heat available based upon an assumed 55% thermal efficiency for starved-air incinerators. The program does determine the optimum fit for the size and number of incinerators to burn the available waste, based on the given operating schedule and assuming an extra, redundant unit for maintenance and backup. In order to perform the following combustion calculations, the characteristics, as well as the amount, of the waste must have been determined during a waste survey as outlined in appendix A.

(2) The combustion calculations may be approximate or as detailed as the designer feels is warranted by the requirements of the project and the accuracy of the waste characterization. The effects of any material recovery performed on the waste stream must be included because both noncombustible and combustible material will be removed. Most of the combustion calculations will be in terms of mass or volume on a per-minute or per-hour basis.

B-2. HEAT RELEASED/RECOVERED.

a. Heat Content of Feed Stock.

(1) The waste characterization study should have determined the average heat content of the waste in Btu per pound of waste on an as-received basis, including effects of material recovery as noted above.

(2) The rate of release of the heat is based on the hourly rate of firing of the waste. If 35 tons of waste are to be burned in a 24-hour period, the rate of firing is as follows:

(35) (2,000 lb/ton) / (24 h/day) = 2,917 lb/h (Eq. B-1)

If a shorter firing period is to be used, the numbers would be adjusted accordingly. This information is also provided by the HRIFEAS program.

(3) The amount of heat that would theoretically be released is the product of the heating value (HHV) of the waste and the firing rate. In the above example, if the waste had a heating value of 4,500 Btu/lb, the heat release rate would be calculated by the following:

$$(2{,}917)\ (4{,}500) = 13{,}126{,}500 \text{ Btu/h} = 13.1265 \text{ MBtu/h} \qquad \text{(Eq. B-2)}$$

b. Actual Heat Available for Recovery.

(1) Unfortunately, not all of the theoretically available heat can be recovered in a useful form.

(a) The combustion process may not consume all of the carbon.

(b) The basic laws of thermodynamics will not allow all of the heat to be recovered as it passes through a heat exchanger.

(c) Large amounts of excess air will further reduce the amount of recoverable heat.

(2) The amount of recoverable heat is determined by multiplying the theoretically available heat by the thermal efficiency. Most incinerator/boiler combinations can be assumed to have a thermal efficiency of 75%, but starved and controlled air should be assumed at 55% because of the large amounts of excess air used in the secondary combustion areas and less complete burn-out of the carbon.

(3) Actual values should be obtained from typical manufacturers whenever possible.

(4) For the above example of a starved-air incinerator, the nominal amount of recoverable heat is calculated using the following equation:

$$(13{,}126{,}500)\ (0.55) = 7{,}219{,}575 \text{ Btu/h} \qquad \text{(Eq. B-3)}$$

c. Efficiency of Energy Recovery Affected by the Temperature of the Media.

(1) If steam or hot water is the form of useful energy produced, the production rate will also depend on the temperature of the water entering, and the enthalpy of the product leaving the boiler/heater.

(a) In the case of hot water, the heat transferred to the media will be based solely on the difference between the inlet and outlet temperature of the water.

(b) If dry, saturated steam is to be produced, the enthalpy will be based upon the exit pressure. The enthalpy of super-heated steam is based on both exit temperature and pressure. Values may be found in most engineering handbooks.

(2) For the above example with a 55% overall thermal efficiency for a starved-air unit, water of 190°F (158.0 Btu/lb), and saturated steam at 150 Psig (1195.5 Btu/lb), the calculation would be as follows:

7,219,575/ (1195.5-158.0) = 6,959 lb/h of steam (Eq. B-4)

B-3. THEORETICAL COMBUSTION AIR. There are several ways to calculate the theoretical air requirement for complete combustion of the waste.

a. Alternative Methods.

(1) If the waste has been carefully characterized by component, tables 3-7 and 3-8 give the ultimate analysis of most of the major components found in waste. A composite ultimate analysis may be calculated by assuming a lot of 100 lb and adding the amount of each element that each component contributes to the lot. If a waste stream was 2% newspaper, there would be 0.9828 lb of carbon (0.02 x 49.14) from the newspaper in the lot. The amount of carbon contributed by each component would be calculated and added to determine the total amount of carbon in the lot. The same would then be done for hydrogen, oxygen, nitrogen, sulfur, and ash. Table 3-5 lists the ultimate analyses for some typical waste streams. Once a composite ultimate analysis is obtained, table B-1 may be used to calculate the theoretical air and flue gases produced. Careful attention should be given to the note on table B-1 regarding chlorine being an oxidizer and the consequent reduction in air required. This also reduces the amount of water and nitrogen produced in the flue gas.

(2) If a less complete characterization has been done, or a less tedious method is desired to calculate the theoretical air requirements, table 3-9 gives values for several major waste stream components on a moisture and ash free (MAF) basis. These values are based on the MAF HHV of each component. The procedure described in the first note on the table may be reversed in order to determine the MAF HHV of the waste stream from the “as received” data developed during the waste survey.

(3) The same criteria may be used to determine the theoretical air requirements for the entire waste stream based on its MAF HHV. The MAF value may also be converted back to the “as received” condition.

b. Use of Tables. Table 3-2 gives an estimated value of theoretical air for a waste stream and compares it to the values for wood and paper. The amount of theoretical air also has to be adjusted for the moisture (humidity) in it. A typical value can be assumed based upon average local climactic data. Using the data from table 3-2 and the above example, the theoretical dry air requirement would be calculated as follows:

(2,917) (6.53) = 19,048 lb air/h (Eq. B-5)

B-4. EXCESS AIR. Because of problems with incomplete mixing and insufficient reaction times, supplying only the theoretically required amount of air will not result in complete combustion. Additional air must be supplied. Different types of fuels (more or less reactive) and different types of combustion systems will require different amounts of combustion air as listed in table 3-10. The third note on table 3-11 gives instructions on how to compute the air mass flow requirements for whatever amount of excess air is required. For the above example and 130% excess air (from table 3-10) the results would be as follows:

(19,048) 100+130) / (100) = 43,810 lbs dry air/hr (Eq. B-6)

B-5. FLUE GAS. Table B-1 and an ultimate analysis must be used to accurately determine the amount of flue gas produced by the combustion process. Excess air can be considered as just passing through. If an ultimate analysis is not available, the mass flow rate can be estimated by assuming that all of the waste, on an ash-free basis, will be oxidized (water evaporated) and come out with what was originally combustion and excess air. Although the chemical combinations have changed, the mass will remain the same. Therefore, the mass flow rate of the flue gas is the combustible portion of the waste, plus the moisture in the waste, the theoretical combustion air, the excess air, and the moisture in the air. Table 3-2 gives an example of flue gas rates for a particular garbage composition and various amounts of excess air. Normally, the additional flue gas produced from the operation of the auxiliary burners should be very small and can be ignored. This is not true if the waste is very difficult to burn and the auxiliary burners are expected to be operating most of the time.

B-6. GAS VOLUMETRIC FLOW RATE. Since air is 78% nitrogen by volume and 76% by weight, both air and flue gas may be treated the same for volumetric calculations with the only adjustment being for the moisture content. The volumetric flow rate may be determined based upon the density of air (temperature, pressure, and moisture content) measured at any specific point in the process. If an actual average moisture value for the specific geographical area is not known, the value of 0.013 lbs/lb of dry air may be used. Table B-2 may be used to perform these calculations.

Table B-1. Theoretical air and flue gas calculations.

Ultimate Element	Analysis lb/lb Fuel	Air lb/lb Fuel	CO_2	Flue Gas O_2	lb/lb N_2	Fuel H_2O	Acid
C		Cx11.519=	Cx3.667	-----	Cx8.852	-----	-----
H_2		H_2x34.557=	-----	-----	H_2x26.557=	H_2x9.0	-----
O_2		-----	-----	O_2x1.0	-----	-----	-----
N_2		----	-----	-----	N_2x1.0=	-----	-----
S		Sx4.32=	-----	-----	Sx3.32=	-----	Sx2.0=
C1*		C1x0.968	-----	-----	C1x0.744=	C1x0.3=	C1x1.03=
H_2O		-----	-----	-----	-----	H_2Ox1.0=	-----
Ash		-----	-----	-----	-----	-----	----
Subtotal	1.00						
Subtract O_2 in Fuel		O_2x1.0=	-----	O_2x1.0=	O_2x3.32=	-----	-----
TOTAL				0.00			

* Chlorine is an oxidizer that will react with the hydrogen and reduce the air requirement. It is assumed that all of the chlorine will react with the hydrogen in the fuel. This will also reduce the moisture produced and the amount of nitrogen in the flue gas as indicated by the minus signs.

Source: Steam by Babcock and Wilcox.

Table B-2. Flue Gas Volumetric Flow Rate.

1. Fuel Fired, lb/h	
2. Theoretical Air to Fuel Ratio, lb/lb fuel	
3. Theoretical Dry Air, (1) x (2) lb/hr	
4. Excess Air, %	
5. Excess Air, (4) x (3) / 100 lb/hr	
6. Actual Dry Air, (3) + (5) lb/hr	
7. Moisture, 0.013 x (6) lb/hr	
8. Total Air, (6) + (7) lb/hr	
9. Moisture in Fuel, (H_2O) x (1) lb/hr	
10. Moisture from Combustion, (H_2O) x (1) lb/hr	
11. Combustion Products, (1) x [1-(H_2O) - (H_2) - (Ash)] lb/hr	
12. Total Dry Gas, (11) + (6) lb/hr	
13. Total Moisture, (7) + (9) + (10) lb/hr	
14. Flue Gas Temperature, ° F	
15. Absolute Pressure, psia	
16. Volumetric Flow of Dry Air, (6) x 0.00617 x [460 + (14)] / (15) ACFM	
17. Volumetric Flow of Dry Products, (11) x 0.00596 x [460+(14)] / (15) ACFM .	
18. Volumetric Flow of Moisture, (13) x 0.00993 x [460 + (14)] / (15) ACFM	
19. Total Volumetric Flow, (16) + (17) + (18) ACFM	

SOURCE: Steam by Babcock & Wilcox.

APPENDIX C

REGULATIONS AND PERMITTING

C-1. AIR QUALITY. Air pollutant emissions from new combustion sources, including power generation facilities and incinerator plants, are regulated by emission limits established by both the USEPA and its equivalent in the state where the plant is to be built. Applicable federal regulations include New Source Performance Standards (NSPS), National Emission Standards for Hazardous Air Pollutants (NESHAPS), and New Source Review requirements (NSR). Regulations vary greatly on a state-by-state basis. The state regulatory agency will usually have been delegated authority by the USEPA to review applications, perform New Source Review, and issue Prevention of Significant Deterioration (PSD) permits. Preparation of the application and supporting documents ordinarily takes 2 to 3 months, and review and approval (including public comment) may take as long as 12 months.

C-2. NEW SOURCE REVIEW. NSR procedures established pursuant to the Clean Air Act are intended to maintain clean air and yet allow for reasonable industrial growth. Under the provisions of NSR, any facility, regardless of size, that requires a federal or state air quality permit must demonstrate through mathematical modeling, that its emissions will not cause a violation of the National Ambient Air Quality Standards (NAAQS). As part of the NSR process, compliance with PSD regulations will also be required. Federal and state air pollution control and NSR focus on NAAQS for six major pollutants established under the Clean Air Act and its amendments. These are particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxide (NO_x), carbon monoxide (CO), ozone (O_3), and lead (Pb).

C-3. PREVENTION OF SIGNIFICANT DETERIORATION. Major new sources of air pollution require additional NSR requirements for emission control and impact assessment under PSD regulations. A source of air pollution is considered to be “major” and subject to PSD regulations if the source will emit more than 100 tons per year of any regulated pollutant and is a fossil-fuel-fired steam electric plant (including combined-cycle auxiliary boilers) with more than 250 MBtu/hr of heat input, or a waste-to-energy plant capable of disposing of more than 250 tons per day of refuse. Any type of source can also be considered major if the emission of any regulated pollutant exceeds 250 tons/year. PSD regulations apply when a source is found to be major for one regulated pollutant. PSD also applies to each additional regulated pollutant which exceeds specified significant emission rate increments. Each pollutant for which PSD regulations apply requires a PSD permit and a Best Available Control Technology (BACT) demonstration.

C-4. BEST AVAILABLE CONTROL TECHNOLOGY. BACT is specific to each pollutant and is determined for each project on a case-by-case basis, considering recent industry practice, engineering reliability, economic impact, and environmental benefits or penalties of the control technology. BACT for fossil-fuel-fired plants may include lime injection or scrubbing for SO_2 high-efficiency particulate control (electrostatic precipitator or fabric filters), and Selective Catalytic Reduction (SCR) technology for NO_x, and possible catalytic control for CO. BACT for waste-to-energy facilities may necessitate acid gas control for SO_2 hydrochloric acid (HC_1), high-efficiency particulate control (electrostatic precipitator or fabric filters), and SCR for NO_x control. PSD permits require a refined modeling analysis of air quality impacts.

C-5. NONATTAINMENT REVIEW. If any pollutant will be emitted by the major facility in an area where ambient air concentrations of that pollutant exceed NAAQS, NSR requires a non-attainment Review. At minimum, this entails application of the Lowest Achievable Emission Rate (LAER) control technologies for each non-attainment pollutant. LAER is the most stringent control technology feasible, and often results in a first-of-a-kind technology.

C-6. WATER QUALITY AND SUPPLY. Both federal and state regulations may influence water supplies for and discharges from condenser cooling, boiler water makeup, boiler blowdown, floor and equipment washes, potable water, etc. If the water supply involves construction in any floodplain, waterway, or wetland, permits may be needed from both the state and the appropriate Corps of Engineers office. The Federal Water Pollution Control Act, which was amended and is referred to as the Clean Water Act of 1977, authorized the USEPA to develop and implement a system to regulate pollutant discharges. The National Pollutant Discharge Elimination System (NPDES) permit is the primary regulatory tool used to control water pollution and is required for any discharge of pollutants to surface waters. The Water Quality Act of 1987 (WQA) contains several provisions that specifically address storm water discharges and provides that states with authorized NPDES programs require permits for storm water discharges to waters of the United States, including those from industrial activities.