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Office of Research and
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Washington DC 20460

Office of Solid Waste
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Washington DC 20460

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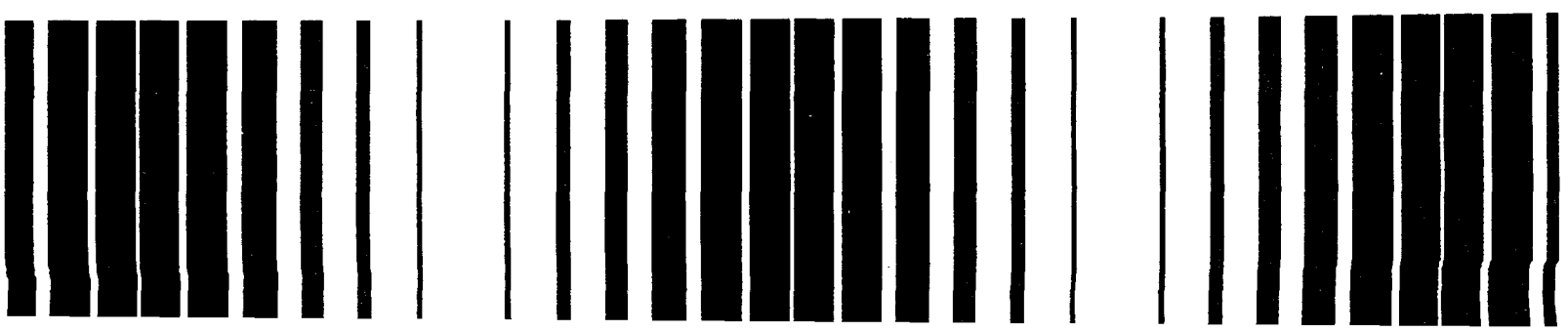
Handbook

Guidance on Setting Permit Conditions and Reporting Trial Burn Results

Volume II of the Hazardous Waste Incineration Guidance Series



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Volume II of the Hazardous Waste Incineration Guidance Series

Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Washington, DC 20460

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Notice

This document has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This guidance document is intended to provide information on how regulatory requirements in 40 CFR Subpart O may be satisfied in a wide variety of situations. This guidance document is not, in and of itself, a regulatory requirement and should not be regarded or used as such. Therefore, although compliance with regulatory requirements is mandatory, compliance with this guidance manual (although useful as a means of satisfying regulatory obligations) is not.

Foreword

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These wastes, if not dealt with properly, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Risk Reduction Engineering Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the Environmental Protection Agency, the permitting and other responsibilities of State and local governments, and the needs of both large and small businesses in handling their wastes responsibly and economically.

A recent study has indicated that two areas of guidance are needed to improve the permitting process for hazardous waste incinerators:

1. Translation of trial burn results into permit conditions by the permit writer

2. Reporting of trial burn data by the permit applicant

The regional and state permit writers are charged with the responsibility to set specific permit conditions deemed necessary to safeguard public health and protect the environment. Considering the complexity of incinerator systems and their operation and the variety of wastes and trial burn cases, this task is clearly difficult. This handbook provides guidance to the permit writer on setting incinerator permit conditions.

Applicants and their contractors now report trial burn test results in a variety of formats. The inconsistencies and deficiencies in the information and technical data provided in such reports result in delays. A consistent format will assist the applicant in drafting a complete and clear trial burn report and facilitate the permit writer's review of the data. This handbook suggests a format for trial burn reporting.

This document is Volume II of the Hazardous Waste Incineration Guidance Series. The other documents in this series are listed in Appendix A, as are sources of further guidance relating to hazardous waste incinerator permitting.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

Abstract

One of the most difficult and time-demanding tasks for a permit writer is to evaluate and interpret incinerator trial burn results and to draft facility-specific operating conditions based on these results. This handbook provides guidance to the permit applicant on reporting trial burn data and to the permit writer on translating these data into meaningful and enforceable operating conditions for incinerators.

This report was submitted in partial fulfillment of EPA contract 68-03-3241 by the Environmental Systems Division of Acurex Corporation. Midwest Research Institute and the Energy and Environmental Research Corporation participated as subcontractors. This work was done under the joint sponsorship of the Office of Solid Waste and the Office of Research and Development of the U.S. Environmental Protection Agency.

Executive Summary

Introduction

Subtitle C of the Resource Conservation and Recovery Act (RCRA) requires the EPA to develop, promulgate, and implement regulations which control the generation, the transportation, and the treatment, storage, and disposal (TSD) of hazardous waste. Regulations promulgated under RCRA at 40 CFR Part 264, Subpart O, specify the following performance standards, which facilities treating hazardous waste by incineration are required to meet:

1. 99.99 percent destruction and removal efficiency (DRE) for each principal organic hazardous constituent (POHC) in its permit for each waste feed (or 99.9999 percent for dioxin listed wastes),

2. 99 percent removal efficiency of HCl or 1.8 kg (4 lb)/hr of HCl emissions, whichever is greater, and

3. Particulate emissions less than 180 mg/dscm (0.08 gr/cu ft), corrected to 7 percent oxygen.

The regulations also require that fugitive emissions be controlled by keeping the combustion zone totally sealed, maintaining negative draft, or an equivalent alternative means of control.

Facilities seeking a permit to incinerate hazardous waste are required to demonstrate the unit's capability to meet the performance standards during a trial burn. Since incinerator compliance with these performance standards cannot be monitored over the long term, the conditions at which the incinerator operated during the trial burn (together with any necessary adjustments to those conditions) are included in the incinerator permit as conditions for continuing operation. Compliance with these operating conditions is then deemed to equal compliance with the performance standards. An incinerator must be operated with a system to automatically cut off waste feed to the incinerator when operating conditions deviate from limits established in the permit.

Although the regulations specify four operating parameters that must be set as permit conditions based on the trial burn (carbon monoxide level, waste feed rate, combustion temperature, and an indicator of combustion gas velocity), it is left to the permit writer to determine how to translate the trial burn data into permit conditions. Because of the technical complexity of setting permit conditions for hazardous waste incinerators and the flexibility the regulations allow in setting these conditions, there has been a lack of consistency in the operational portions of incinerator permits issued across the country. Further, an excessive number of permit conditions may severely limit flexibility of operation, while too few permit conditions may not provide adequate assurance that the performance standards will continue to be met.

Approach

The major goals in developing the guidance were to develop a nationally consistent, technically sound approach to the setting of operational conditions in incinerator permits which would maintain proper performance while allowing a reasonable degree of operational flexibility. Technical rationales were to be stated in the document so that it would also serve as a training tool and to enable the permit writer to identify and address cases where specific portions of the guidance may not apply. Various operating parameters thought to have an effect on achievement of the incinerator performance standards were considered for inclusion in the guidance. "Back-up" parameters which would unnecessarily limit the permittee's flexibility to operate the incinerator were avoided. The conditions were evaluated based on technical knowledge, and, where necessary, consensus of engineering judgment, to develop a set of operating parameters to be set in incinerator permits which would meet with the above goals.

Technical and engineering guidance was provided by a panel of incineration experts from EPA Regional Offices, the Office of Solid Waste, and the Office of Research and Development, and by representatives of the Research Committee on Industrial and Municipal Waste of the American Society of Mechanical Engineers. In addition to providing experts with whom the authors could discuss ideas, the groups reviewed two successive drafts of the document.

Description

The guidance document presents the key control parameters, shown in Table 1, which should be

monitored during the trial burn and for which limits should be set in the incinerator permit. The parameters are divided into three groups.

Group A parameters are continuously monitored parameters interlocked to automatic waste feed cutoff. Most of these parameters are based on trial burn conditions. A minimal amount of lag time may be incorporated into the limits for these parameters by the use of averaging times following the guidelines in the document. Group B parameters are set to ensure that the "worst case" conditions demonstrated in the trial burn are not exceeded during continuing operation. These parameters are not linked with automatic waste feed cutoff, and are not continuously monitored, but, instead, must be recorded in the facility operating record. Group C parameters, which are set independently of trial burn results, are based on equipment manufacturers' design and operating specifications. These parameters are not continuously monitored or linked to automatic waste feed cutoff.

Group A Parameters

Temperature is a key parameter of incinerator performance due to its influence on reaction kinetics and is a required incinerator permit condition under RCRA regulations. The minimum temperature limit is generally set from the lowest temperature trial burn test at which compliance was demonstrated. Combustion chamber temperatures are required by the regulations to be tied to automatic waste feed cutoff. For a two-chamber incinerator, minimum temperatures would be set for each chamber. When minimum temperatures are not maintained in both the primary and secondary chambers, or in the secondary chamber only, waste feed must be cutoff to both chambers. However, if only the primary chamber falls below its minimum temperature, waste may still be fed to the secondary chamber.

Carbon monoxide (CO) concentration in the stack gas is also a parameter which the regulations specifically require. CO is used as an indicator of the degree of mixing achieved in the incinerator and is related, by definition, to combustion efficiency. Separate guidance on setting permit limits on CO to minimize emissions of PIC's (products of incomplete combustion) is being prepared by EPA.

The hazardous waste incinerator regulations require that the permit specify limits for an indicator of combustion gas velocity. Combustion gas velocity is directly related to the gas residence time in the incinerator, which is known to be one of the key parameters of combustion. Residence time becomes more critical at lower combustion temperatures. For this reason, the limit on maximum combustion gas velocity should be based on the maximum trial burn value measured during the lowest temperature test during which compliance was demonstrated.

A waste feed rate limitation is required by RCRA regulations primarily to minimize the potential loss of efficiency from overloading the combustion chambers. For low heating value wastes, the limits are taken from the trial burn test with the minimum temperature during which compliance was achieved, since an increase in the waste feed rate may cause a decrease in temperature. Maximum waste feed rate for high or medium heating value wastes are based on the highest feed rate of these wastes from any run.

The requirement in the regulations to control fugitive emissions is addressed by a permit requirement on the operating pressure. Incinerator chambers designed to operate under negative draft (induced draft) are required by the permit to maintain negative draft. Forced draft or positive pressure incinerators must be well sealed, and the maximum operating pressure is set based on the trial burn.

The guidance recommends that control parameters for air pollution control equipment (APCE) be set to maintain the particulate and acid scrubbing capability demonstrated during the trial burn. For each type of APCE component, one key parameter was chosen to be tied to the automatic waste feed cutoff. For example, since the principal operating parameter controlling ESP collection efficiency is the power utilization, or kVA, the minimum kVA demonstrated during the trial burn at the highest ash feed rate is set as the permit limit.

Group B Parameters

One of the key principles behind conducting a trial burn is that the incinerator should operate under the most severe conditions it is expected to encounter for the duration of its permitted operation. Group B parameters are included in the guidance to ensure that the incinerator will not operate at more taxing conditions than those at which it demonstrated compliance during the trial burn.

Parameters affecting APCE performance included in Group B are total ash and chlorine loading to the incinerator. These parameters affect the concentrations of particulate and HCl at the APCE inlet and the physical and chemical properties of the gas. The ash and chlorine loadings are limited to the maximum rate demonstrated in the trial burn. A minimum scrubber blowdown rate is also set based on the trial burn, since suspended and dissolved solids in recycle water, which may be re-entrained into the flue gas, may contribute to particulate emissions.

Table 1. Control Parameters

Group	Parameter
Group A Continuously monitored parameters are interlocked with the automatic waste feed cutoff. Interruption of waste feed is automatic when specified limits are exceeded. The parameters are applicable to all facilities.	1. Minimum temperature measured at each combustion chamber exit 2. Maximum CO emissions measured at the stack or other appropriate location 3. Maximum flue gas flowrate or velocity measured at the stack or other appropriate location 4. Maximum pressure in PCC and SCC 5. Maximum feed rate of each waste type to each combustion chamber[1] 6. The following as applicable to the facility: • Minimum differential pressure across particulate venturi scrubber • Minimum liquid-to-gas ratio (L/G) and pH to wet scrubber • Minimum caustic feed to dry scrubber • Minimum kVA settings to ESP (wet/dry) and kV for ionized wet scrubber (IWS) • Minimum pressure differential across baghouse • Minimum liquid flowrate to IWS
Group B Parameters do not require continuous monitoring and are thus not interlocked with the waste feed cutoff systems. Operating records are required to ensure that trial burn worst-case conditions are not exceeded.	7. POHC incinerability limits 8. Maximum total halides and ash feed rate to the incinerator system 9. Maximum size of batches or containerized waste[1] 10. Minimum particulate scrubber blowdown or total solids content of the scrubber liquid
Group C Limits on these parameters are set independently of trial burn test conditions. Instead, limits are based on equipment manufacturers' design and operating specifications and are thus considered good operating practices. Selected parameters do not require continuous monitoring and are not interlocked with the waste feed cutoff.	11. Minimum/maximum nozzle pressure to scrubber 12. Maximum total heat input capacity for each chamber 13. Liquid injections chamber burner settings: • Maximum viscosity of pumped waste • Maximum burner turndown • Minimum atomization fluid pressure • Minimum waste heating value (only applicable when a given waste provides 100% heat input to a given combustion chamber) 14. APCE inlet gas temperature[2]

[1] Items 5 and 9 are closely related; therefore, these are discussed under group A parameters.
[2] Item 14 can be a group B or C parameter. See text in Section 2.1.6.

The Subpart O regulations require that POHC's (Principal Organic Hazardous Constituents) be designated for each waste feed. The required DRE must then be demonstrated for the POHC's during the trial burn. Since the POHC's must be representative of the waste feed, they are chosen on factors such as difficulty to incinerate and concentration in the waste feed. The operator is then limited in the permit to burning only waste containing hazardous constituents no more difficult to incinerate than the POHC's for which compliance was demonstrated during the trial burn. The heat of combustion of the hazardous constituents has been used to rank the incinerability of compounds on the premise that compounds with a lower heat of combustion are more difficult to burn. Field data indicate, however, that other ranking systems may exhibit a better correlation with incinerability. The guidance presents a draft ranking of the incinerability of Appendix VIII compounds prepared by the University of Dayton Research Institute based on thermal stability at low oxygen ($TSLoO_2$) conditions.

A limit on the maximum size of containerized waste fed to the incinerator is also recommended to prevent oxygen depletion from the sudden release of volatiles. The containerized waste fed during the trial burn should be representative, with respect to volatile content, of the waste the facility will be burning under the permit.

Group C Parameters

Group C parameters were formulated on the need to ensure that incinerator operation adheres to good combustion and APCE operating practices. To allow a reasonable degree of flexibility and to avoid over-complication of the trial burn, limits for these parameters are based on manufacturer's design and operating specifications rather than on the trial burn settings.

To maintain proper atomization of liquid waste and promote efficient mixing, burner settings for liquid injection and afterburner chambers will be limited to manufacturer's specifications or other acceptable settings if data show that they are adequate. These conditions include maximum waste viscosity, minimum atomization fluid pressure, and maximum burner turndown. The handbook recommends that a minimum waste heating value be set in the permit for liquid injection chambers where 100 percent of the heat input comes from the waste feed. Total heat

input to the incinerator is limited to the incinerator design heat input capacity.

The guidance recommends limiting APCE inlet gas temperature due to its effect on APCE performance as well as to prevent equipment deterioration. The maximum inlet temperature to the APCE would be set at the trial burn value and a higher temperature would allow less condensation and thus render less of the particulate-forming material subject to collection. These uncollected gases may then condense downstream of the APCE as temperature decreases and form additional particulate matter. The maximum temperature should not be higher than the manufacturer specification for maximum temperature.

Other Permit Conditions

The guidance also includes additional conditions related to waste feed cut off. The permit should require that minimum temperature be maintained in the secondary combustion chamber after a waste feed cutoff until wastes remaining in the unit are burned out. This heating would necessitate use of auxiliary fuel but must not conflict with the unit's flame safety management system. The guidance recommends a condition requiring quarterly reporting of automatic waste feed cut offs, reasons for the cut offs, and corrective actions taken.

Translating Trial Burn Results into Permit Conditions

The guidance presents a strategy for determining the limits on operating parameters and converting them into permit conditions. The goal in translating the trial burn results into permit conditions is to ensure that the incinerator is operating in a manner sufficiently similar to the successful trial burn conditions to maintain compliance but still allow adequate operational flexibility. The approach commonly employed is patterned after "mode-based" operation. The permit contains a different set of operating conditions for each waste combination the facility will burn. This approach is best suited for a facility dedicated to treating a well-defined set of uniform composition hazardous wastes.

The above approach, however, is not practical for facilities such as commercial facilities which burn a wide variety of wastes. The guidance presents an approach to developing a single set of operating conditions (termed a "universal set of conditions" or the "universal permitting strategy") which defines the allowable range of operation for burning all of the wastes in the facility permit. Under this approach, the trial burn must attempt to achieve worst-case conditions for all permit parameters at a single operating point by varying factors such as combustion air flow and steam injection, or to achieve worst-case conditions in multiple tests with the key operating parameters kept constant.

In the general approach set forth in the guidance, the parameters are divided into three groups:

1. Control parameters set from trial burn data that are related to waste destruction
2. Control parameters set from trial burn data that are related to APCE performance
3. Control parameters that are independent of trial burn data

Limits on parameters are set according to the hierarchy above. The groupings of these parameters are shown in Tables 2 through 4. Permit limits must be set only from trial burn tests that show compliance with the performance standards. Limits should be set using these basic rules of thumb regarding "worst case" conditions. The maximum combustion gas velocity should be set from the trial burn test conducted at the minimum temperature during which compliance was achieved. The maximum feed rate of each low heating value waste stream to each combustion chamber should be that demonstrated during the minimum temperature test. The maximum feed rate of high heating value wastes and the maximum combined feed rate should be the maximums demonstrated at any point.

Table 2. Waste-Destruction-Related Control Parameters Set from Trial Burn Data

Type	Parameter
A	Minimum temperature at each combustion chamber exit
A	Maximum CO emissions
A	Maximum flue gas flowrate or velocity
A	Maximum pressure in PCC and SCC
A	Maximum feed rate of each waste type to each combustion chamber
B	Maximum size of batches of containerized waste

Permit limits for APCE parameters relating to particulate collection should be set from the trial burn test at the maximum inorganic ash feed rate and the maximum flue gas flow rate, because ash feed rate determines the load to the APCE and an increase in the flue gas flow rate may increase entrainment of particulate matter. Minimum liquor flow rate to the absorber and minimum pH to the absorber should be set from the trial burn test at the maximum total halides feed rate and the maximum flue gas flow rate.

In some instances, it may not be possible to set the conditions in the manner described due to interrelationships among parameters which prevent certain conditions from being achieved at the same time. The guidance presents an approach to estimate, through calculations, whether the effect of setting the

Table 3. APCE-Performance-Related Control Parameters Set from Trial Burn Data

Type	Parameter
A	Minimum differential pressure across particulate venturi scrubber[1]
A	Minimum L/G and pH to absorber[1]
A	Minimum caustic feed to dry scrubber
B	Minimum scrubber blowdown rates or maximum total solids in scrubber liquid[1]
A	Minimum kVA settings to ESP (Wet/Dry) and kV for WS's[1]
A	Minimum pressure differential across a FF[1]
A	Scrubber nozzle pressure
B	Maximum total halides and inorganic ash feed rate to the incinerator system
B	Minimum particulate scrubber blowdown rate

1 Select as applicable to APCE system.

Table 4. Trial Burn-Independent Control Parameters

Type	Parameter
C	Maximum total heat input for each chamber
C	Liquid injection chamber burner settings • Maximum viscosity of pumped waste • Maximum burner turndown • Minimum atomization fluid pressure • Minimum waste heating value (if applicable)
C	APCE inlet gas temperature

conditions based on less than worst-case runs will be significant. For example, if the permit limit for the maximum flue gas velocity is to be set from a data point other than the minimum temperature test, the permit writer would calculate whether it is likely that the flue gas flow rate at the minimum temperature could be increased to the maximum flue gas flow rate without causing DRE to decrease below 99.99 percent. This is done by relating flue gas flow rate to residence time to DRE assuming a first-order reaction.

The guidance emphasizes the importance of planning the trial burn to obtain the desired permit conditions. The applicant and permit writer should agree, prior to the trial burn, on the permit conditions that will result from the trial burn as planned, assuming compliance is demonstrated. This will allow the applicant to make modifications to the trial burn plan, if necessary, to obtain the desired operating conditions.

Trial Burn Reporting

The permit writer is often faced with reviewing a trial burn report which is incomplete or which is not structured such that the information necessary to evaluate compliance and set permit conditions can be readily located in the report. The permit writer may need to go back to the applicant to request clarification or additional data, which slows down the review process. To assist both applicants and permit writers, the guidance describes the information which should be included in the trial burn report and presents a trial burn report format. Example reporting forms for the design, process, and performance data required in a trial burn report have been developed and are presented in the document.

Summary

The Guidance on Setting Permit Conditions and Reporting Trial Burn Results has been developed to assist permit writers in translating trial burn results into site-specific operational conditions in an incinerator permit. These parameters are presented in the document along with guidance on how to develop permit operating conditions using the trial burn data.

The guidance will also assist applicants in planning trial burns to address the key operating parameters that must be measured and emphasize the necessity to test "worst-case" operations to enable applicants to tailor their proposed operating conditions to the needs of their facility. One of the key points made by the guidance is that the permit writer and applicant should agree, prior to the trial burn, on what permit conditions will result from the trial burn as planned. In this way, it can be determined whether it is necessary to make modifications to the plan to obtain the desired operating conditions.

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List of Terms

ACFM — Actual cubic feet per minute

APCE — Air pollution control equipment

CE — Combustion efficiency

$$\frac{CO_2}{CO_2+CO} * 100 \text{ (percent)}$$

CEM — Continuous emission monitor

CO — Carbon monoxide, compound from partial oxidation of hydrocarbons

DE — Destruction efficiency of the combustor (only)

$$DE = \frac{POHC_{in} - POHC_{out\ combustion\ chamber}}{POHC_{in}} * 100 \text{ (percent)}$$

DOE — Department of Energy

DRE — Destruction and removal efficiency of the incinerator (including APCE)

$$DRE = \frac{POHC_{in} - POHC_{out\ APCE}}{POHC_{in}} * 100 \text{ (percent)}$$

EERC — Energy and Environmental Research Corporation (Irvine, California, Telephone (714) 859-8851)

EPA — United States Environmental Protection Agency

ESD — Environmental Systems Division of Acurex Corporation (Mountain View, California, Telephone (415) 961-5700)

ESP — Electrostatic precipitator

FF — Fabric Filter

HCl — Hydrochloric acid emissions regulated under RCRA to 1 percent of organic chlorine feed or 1.8 kg (4 lb)/hr maximum emission rate

HHV — Higher heating value

HWCTDB — Hazardous Waste Control Technology Data Base at ORNL

List of Terms (continued)

ID	Induced draft
I&M	Inspection and maintenance
IWS	Ionizing wet scrubber
kVA	kilovolt-amperes
L/G	Liquid-to-gas ratio
LHV	Lower heating value
MM5	EPA Modified Method 5 Particulate Stack Test Procedure
MRI	Midwest Research Institute (Kansas City, Missouri, Telephone (816) 753-7600)
NPDES	National Pollutant Discharge Elimination System
ORNL	Oak Ridge National Laboratory
PCC	Primary combustion chamber
PIC	Products of incomplete combustion[a]
POHC	Principal Organic Hazardous Constituent[b]
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act of 1976 and Amendments
RREL	Risk Reduction Engineering Laboratory, USEPA, Cincinnati, Ohio
SCC	Secondary combustion chamber
SCFM	Standard cubic feet per minute
TSD	Treatment, Storage, and Disposal
$TSLoO_2$	Thermal stability at low or deficient oxygen level
$TSHiO_2$	Thermal stability at high or oxygen rich level
TUHC	Total unburned hydrocarbon
UDRI	University of Dayton Research Institute
VOST	Volatile organic sampling train

[a]For this document, PIC refers to RCRA Appendix VIII organic compounds (100 ppm) not present in the feed that results from combustion of waste.
[b]RCRA Appendix VIII organic compounds selected for evaluation of DRE during trial burn.

Conversion Factors

Multiply	By	To Get
atmospheres (pressure)	101.3	kilopascal 0(kPa)
centigrade (C)	°F = (1.8 x °C) + 32 °K = °C + 273.17	Fahrenheit (F) Kelvin (K)
centimeter (cm)	0.254	inch (in)
centipoise (cP)	0.01	gram/(centimeter•second) [g/(cm•s)]
cubic centimeter (cm^3)	0.061	cubic inch (in^3)
cubic meter (m^3)	35.31 1.31 1,000	cubic foot (ft^3) cubic yard (yd^3) liter (L)
cubic meter/second (m^3/s)	2119	cubic feet per minute (cfm)
gram (g)	0.001 0.0022	kilogram (kg) pound (lb)
gram/(centimeter•second) (g/[cm•s])	1	poise (P)
gram/cubic centimeter (g/cm^3)	62.427961	pound/cubic foot (lb/cu ft)
gram/cubic meter (g/m^3)	0.437	grain/cubic foot (gr/cu ft)
gram/liter (g/L)	1,000 0.0624	part/million (ppm) pound/cubic foot (lb/cu ft)
gram/milliliter (g/mL)	1	gram/cubic centimeter (g/cm^3)
inch of water @ 4°C (in H_2O @ 4°C)	0.0025 0.0361	atmosphere (atm) pound/square inch (psi)
kilogram (kg)	2.205	pound
kilogram/minute (kg/min)	132.3	pound/hour (lb/hr)
kilojoule (kJ)	0.9478	British thermal unit (Btu)
kilojoule/kilogram (kJ/kg)	0.43	British thermal unit/lb (Btu/lb)
kilojoule/second (kJ/s)	3,412	British thermal unit/hour (Btu/hr)
liter (L)	0.035	cubic foot (cu ft)
liter/cubic meter (L/m^3)	7.48	gallon/1000 cubic feet (gal/1,000 cu ft)
meter (m)	3.281	foot (ft)
pascal (Pa) (kPa = 10^3Pa)	9.869233×10^{-6} 10	atmosphere (standard) (atm) dyne/square centimeter ($dyne/cm^2$)
pascal•seconds (Pa•s)	10.00	poise

Multiply	By	To Get
poise (P)	100.00	centipoise (cP)
	1	dyne•second/square centimeter
	1	gram/(centimeter•second) (g/[cm•s])
	0.0672	pound/(second•foot) [lb/s•ft]
square meter (m^2)	10.76	square foot (sq ft)
stoke (St)	1×10^2	centistoke (cSt)
	1	square centimeter/second (cm^2/s)
	3.875	square foot/hour (ft^2/h)
	0.001076	square foot/second (ft^2/s)
ton (metric)	1,000	kilogram (kg)
	1.1023113	ton (short 2,000 lb mass)

Acknowledgments

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Additional technical contributions and review were provided by a panel of incineration experts from selected EPA Regional Offices. This panel included Gary Gross of Region III, Betty Willis of Region IV, Y. J. Kim of Region V, and John Hart of Region IX.

Drafts of this document were also reviewed by the Incinerator Permit Writers' Work Group of the EPA and by the Research Committee on Industrial and Municipal Waste of the American Society of Mechanical Engineers, as well as Joseph J. Santoleri of Four Nines, Inc.

CHAPTER 1
Introduction

When an owner or operator of a hazardous waste incinerator is issued a permit, conditions are specified that must be satisfied during operation. These conditions include limits on operating parameters such as temperature, gas residence time, and CO emissions that are chosen to ensure that legal and safety standards are met. The limits are chosen by analysis of the results of a "trial burn" that demonstrates the performance of the incinerator. This handbook provides guidance on using trial burn data to set realistic and enforceable permit conditions. Conversely, the guidance in this handbook can be used to design a trial burn for an incinerator. The handbook also provides suggested formats for presentation of trial burn data.

This chapter describes the impact of the trial burn and the data it generates on the permitting process. This is not a comprehensive review of the regulations and permitting procedures but is a summary to provide background for the reader.

1.1 RCRA Regulations

The Resource Conservation and Recovery Act (RCRA) requires the Environmental Protection Agency (EPA) to establish regulations governing the handling of hazardous wastes. Regulations governing incineration of hazardous waste were first promulgated on January 23, 1981, and have since been amended numerous times. These regulations, codified in 40 CFR Part 264, Subpart O and Part 265, Subpart O, are part of EPA's comprehensive set of regulations that prescribe design and performance standards for hazardous waste production, storage, transport, disposal, and treatment. A permit program that is used to administer the regulations.

The RCRA regulations cover a wide variety of facilities. They set standards for generators and transporters of hazardous wastes and for owners and operators of treatment and disposal facilities. The general permit requirements for all treatment, storage, and disposal (TSD) facilities are described in *Standards for Owners of Hazardous Waste Treatment, Storage, and Disposal Facilities*, 40 CFR 264. These regulations require that an owner or operator satisfy requirements such as to:

- Develop a contingency plan and emergency procedures
- Maintain extensive records
- Develop a closure and post-closure plan
- Meet financial requirements
- Manage containers, tanks, surface impoundments, waste piles, and landfills properly

The permit regulations governing hazardous waste incinerators are covered in 40 CFR 264, Subpart 0, which requires that the owners or operators also perform the following:

- Analyze wastes as specified in the permit
- Meet the following performance standards:
  - 99.99 percent destruction and removal efficiency (DRE) of selected principal organic hazardous constituents (POHCs) and 99.9999 percent DRE for dioxin listed wastes
  - 99 percent removal of hydrochloric acid (HCl) or 1.8 kg (4 lb)/hr HCl emissions, whichever is greater
  - 180 mg/dscm (0.08 gr/cu ft) of particulate emissions (corrected to 7 percent O_2)
- Operate the incinerator according to operating conditions specified in the permit for the following:
  - Carbon monoxide (CO) level in exhaust
  - Waste feed rate and composition
  - Combustion temperature
  - Indicator of combustion gas velocity
  - Allowable variations in design
  - Other requirements necessary to meet performance standards
- Control fugitive emissions
- Install automatic waste feed cutoff
- Perform inspections and monitoring (I&M)
- Remove all hazardous waste and hazardous waste residues upon closure

Although not addressed herein, upcoming amendments to the incinerator regulations may include:

- Changes in the requirements for carbon monoxide (CO) emissions
- Risk-based limits on metals emissions
- Risk-based verification of HCl emissions
- Lower particulate emission limits based on the best demonstrated available technology

1.2 Incinerator Permitting Requirements

The RCRA regulations require all owners and operators of TSD facilities to obtain an operating permit from the appropriate regulatory agency: the EPA Regional Office or, if authority has been so transferred, a State agency. To obtain a permit, the applicant submits the following information:

- Description of the facility
- Security procedures and inspection schedule
- Contingency plan
- Description of preventive maintenance procedures
- Description of the waste
- Personnel training program
- Plan and cost estimates for closure
- Assurance that the operator of the facility is financially responsible

The permitting process for an incinerator usually includes a "trial burn," which is a test to determine whether the unit can meet the performance requirements specified by the regulations. Although it is possible to satisfy this requirement by submitting information showing that a trial burn is not required, this is a rare occurrence that will not be discussed here. As part of the permitting process for a new incinerator, the owner or operator is required to obtain prior approval of a trial burn plan from the regulatory authority. Table 1-1 lists the major information that must be included in a trial burn plan.

Table 1-1. Contents of Trial Burn Plan

- Analysis of waste(s)
- Quality Assurance/Quality Control (QA/QC) Plan
- Engineering description of facility
- Sampling and monitoring procedures
- Test schedule
- Test protocol (operating conditions)
- Emissions control operating conditions
- Shutdown procedures
- Other necessary information

There are different procedures for permitting new and existing hazardous waste incinerators. Existing incinerators are those that have been operating under interim status. These incinerators receive a RCRA permit after the trial burn. The trial burn plan does not require prior approval from the permitting agency, although this is highly recommended.

The other permitting procedure is for new incinerators. Because these are not allowed to be constructed or to operate without a permit, they are permitted prior to construction. Typically, the permit allows them to operate for a limited period of time after construction and prior to the test burn to allow time for startup and shakedown.

1.2.1 New Facilities

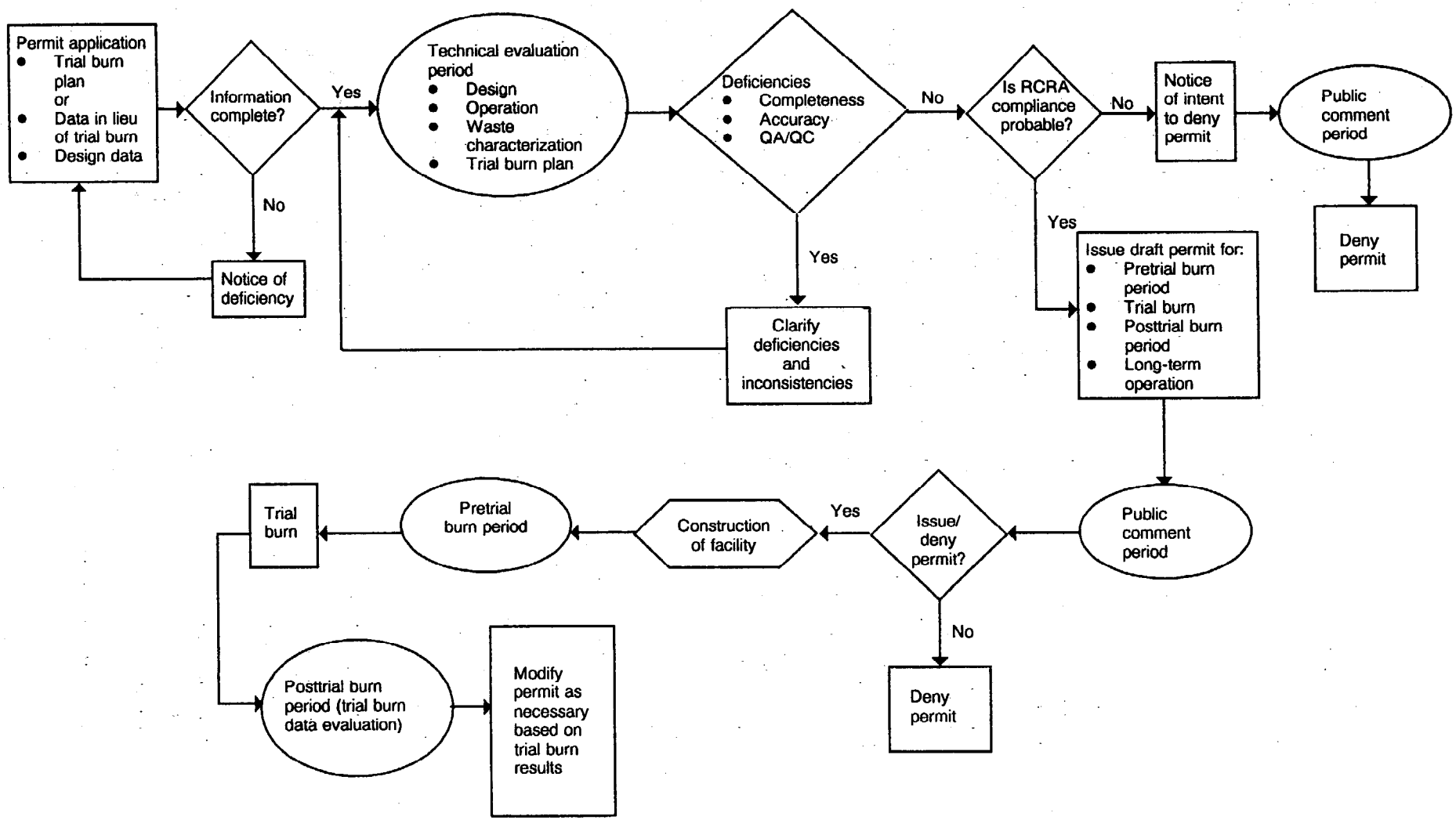
Figure 1-1 outlines the major steps in the permitting of new facilities. First, the permit application including the trial burn plan (or in rare cases, data in lieu of the trial burn) is submitted to the permitting authority. Then the application goes through an administrative review to ensure that the application and test plan include all the major components required by the regulation. After this review, the application is evaluated to determine whether all the technical information required is provided and if it is internally consistent. It is important to note that even though the regulations provide for a two-step administrative and technical review process, many offices combine these steps and do not consider the application complete until it contains all the information necessary to issue the draft permit.

The permit writer then makes a determination about the likelihood that the facility will achieve compliance with the RCRA regulations and that its operation will not be a hazard to public health or the environment. This procedure is complex, and the permit writer may seek assistance from a number of the manuals listed in Appendix A. At this point, a tentative decision is made to issue or deny the permit. This decision is followed by public notice, a public comment period, and final issuance or denial of the permit.

After the permit is granted, the facility is built and operated under the startup/shakedown provisions of the regulations. The permit will include restrictions on operation during this period. This "pretrial burn" period may last up to 720 operating hours (defined as hours of operation while hazardous waste are burned rather than elapsed time or time when only nonhazardous fuels are burned) and may be extended for an additional 720 hours of operation. It is followed by the trial burn.

Following the trial burn, the facility operates under conditions set by the Director (the EPA Regional Administrator or State Director for States with permitting authority) until the trial burn results are submitted and evaluated. The evaluation is designed to answer the following two questions:

Figure 1-1. Incinerator permitting process – new facilities.



- Under what operating conditions (if any) did the facility satisfy the RCRA requirements?

- Are the conditions in the permit adequate, or must they be modified to reflect the results of the trial burn?

Assuming that the trial burn was successful, the permit conditions are modified, if necessary, and the facility proceeds to operate.

1.2.2 Existing Incinerators

The permitting procedure for existing incinerators, i.e., those operating under interim status, is shown in Figure 1-2. As can be seen, the procedure is similar to that for new incinerators. The principal difference is that because the facility is already operating prior to being issued a permit, it does not need one for either startup and shakedown or for the trial burn. As a result, the decision to approve or deny the permit is deferred until after the trial burn results have been submitted and evaluated. Once again, the simplified flow diagram (Figure 1-2) should not be interpreted to mean that the public comments cannot alter this issue/deny decision for the permit.

The sections above describe the permitting process in general terms. Regulations in 40 CFR Part 270 and in Part 284, Subpart O, should be consulted for full information.

1.3 Evaluating a Trial Burn Plan and Establishing Permit Conditions

Sections 1.2.1 and 1.2.2 briefly described the permitting process for both existing and new incinerators. They identified the point where the trial burn fits into the overall permitting procedure and the points where the permit writer must evaluate the trial burn information. The remainder of this handbook gives guidance on assessing the trial burn plan (if prior agency approval is sought or required) and the trial burn results and on establishing the operating conditions specified in the permit that is issued for the facility; they are referred to as the "permit conditions."

Figure 1-3 illustrates steps 1-3 that are followed in evaluating the trial burn plan and in establishing the permit conditions relating to the plan. Figure 1-3 also illustrates steps 4-6 that are followed after the trial burn to set permit conditions. After the permit application is received and found to be complete and technically acceptable, the trial burn plan is reviewed. The evaluation process described here is for a new incinerator; however, because the procedure for new and existing units is virtually identical except for the point in the process where the permit is actually written (before the trial burn for a new incinerator and after the trial burn for an existing one), the remainder of this handbook will not differentiate these two permitting scenarios further.

Step 1 in evaluating the trial burn plan involves selection of the appropriate design and operating parameters (referred to as control parameters) that form the basis of the permit. During this evaluation, the permit writer and the applicant should agree on the following:

- Key incinerator operating parameters
- The parameters for which limits will be specified in the permit
- The effect of the trial burn on establishing these limits

Prior to finalizing the trial burn plan, agreement on these points between the applicant and permit writer is very important and highly recommended. In many cases, operational difficulties can be minimized and regulatory compliance can be achieved by proper design of a plan agreed to by the two parties.

Step 2 in evaluating the trial burn plan involves a comparison of the incinerator system design parameters and the control parameters. This review examines the control parameters for both internal consistency and for consistency with the design parameters. This review also determines whether the operation of this system is likely to comply with the pertinent regulations and, more importantly, if the test is likely to result in an imminent hazard to public health or the environment.

In step 3 of the trial plan evaluation process, limits are set on the control parameters consistent with the step 2 review. These limits are included in the permit as conditions, the permit conditions, that define the range of acceptable operation for the incineration system for the four phases of operation applicable to a new incinerator:

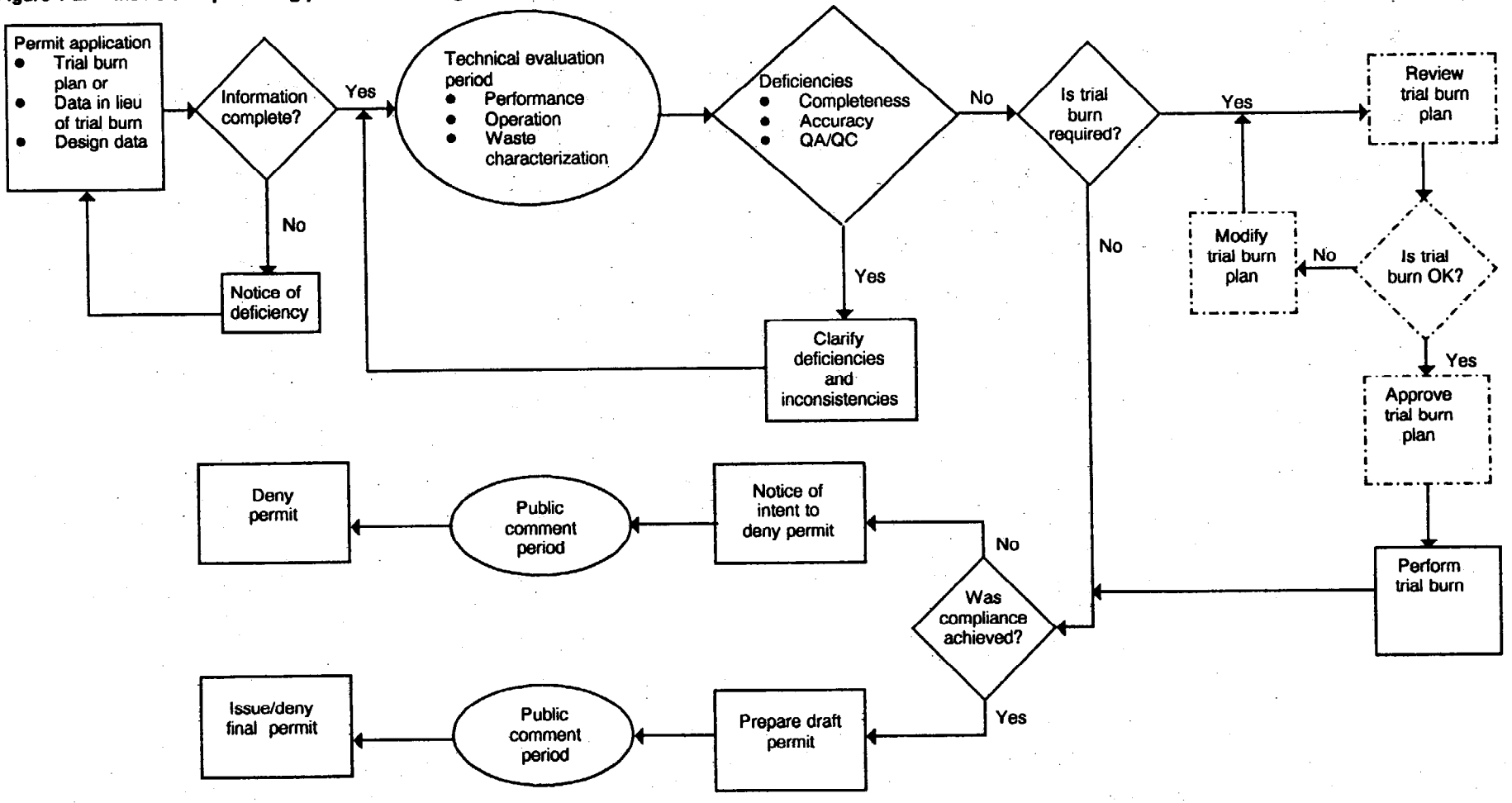
- Startup/shakedown
- Trial burn
- Post-trial burn
- Continuing operation

The permit conditions also include monitoring and automatic cutoff requirements on some of the control parameters. The monitoring conditions are included to validate compliance and facilitate enforcement activities.

This handbook does not deal specifically with the trial burn except for a discussion of the format recommended for presenting the results. The reader is referred to the appropriate manuals listed in Appendix A for further guidance on this subject.

During the trial burn, the control parameters are measured, and the values are recorded in an

Figure 1-2. Incinerator permitting process – existing facilities (interim status).



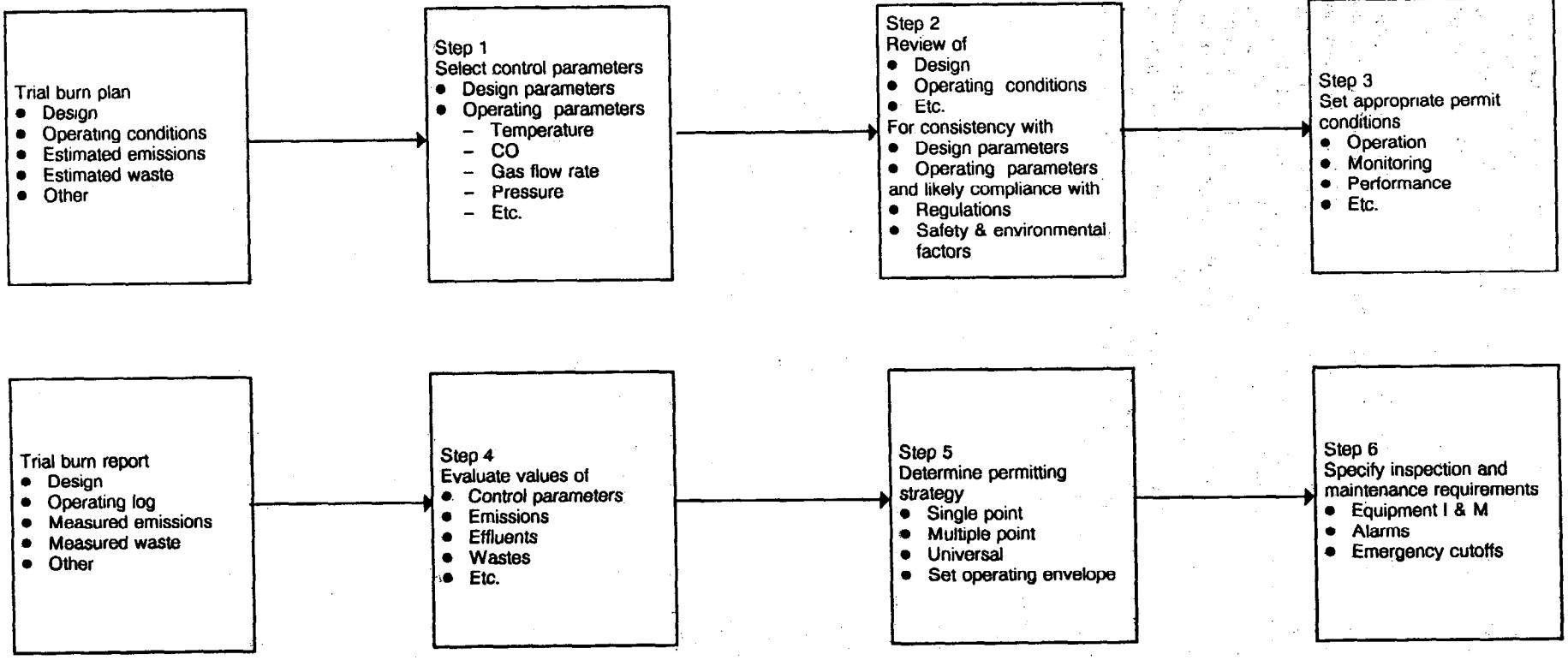
"operating log." This log is as important as the emission and pollutant release data and must be included in the trial burn report. It is submitted along with the results of the trial burn to the permitting agency.

In step 4, the permit writer compares the values of the control parameters with the measured levels of emissions, effluents, and wastes produced by the incinerator during the trial burn. The intent of this evaluation is to verify that the limits set in step 3 do, indeed, result in compliance with the regulations and with safe and environmentally acceptable operation. If necessary, the limits on the control parameters are adjusted at this point to reflect the results of the trial burn.

Step 5 of the permitting process is setting the permit conditions for the incinerator. The permitting strategy for the incinerator is designed to organize the limits on the control parameters into a consistent, enforceable set of permit conditions. See Sections 3.4, 3.5, and 3.6 for methods that can be used to develop the strategy.

The final step, step 6, in this process is specification of the I&M requirements in the permit as required by 40 CFR 264.347. These requirements can include operational, safety, and other hardware that does not directly relate to the trial burn and the permit conditions developed from it. The I&M conditions discussed here emphasize those requirements that relate to the control parameters. Other I&M procedures, i.e., those put on the thermocouples, pressure sensors, alarms, and circuitry that monitor the control parameters and trigger actions such as waste feed cutoffs are outside the scope of this handbook.

Figure 1-3. Steps to evaluating trial burn plan and establishing permit conditions.



CHAPTER 2
Control Parameters

Incinerator operating conditions are defined by "control parameters" such as temperature, pressure, waste feed rates, and limits on halogens in the wastes, which can be reliably measured during incinerator operation. Control parameters are important because performance parameters such as DRE and particulate emissions cannot be directly and continuously measured during actual operation. As a result, limits are placed on the control parameters, i.e., ranges are set for measurable parameters, and these limits are set as conditions in the final operating permit. The ranges of acceptable conditions are determined from the trial burn. As long as the incinerator is operated within these ranges, it is assumed to be operating under the same conditions as during the successful trial burn and, hence, to be in compliance with the regulations. It is necessary, therefore, to select the control parameters before the trial burn and to measure their values throughout the trial burn so that the results may be used to set their limits.

This chapter recommends the control parameters that should be used and explains the reasons they were chosen. Note that it is assumed that the reader is familiar with the construction and operation of the common types of incinerator systems and ancillary equipment. See Appendix B for a discussion of incinerator designs and guidance on reviewing them during the permitting process.

Control parameters fall under the following two classifications:

1. System Parameters, defined as basic design specifications that typically are fixed for a given incinerator or incinerator configuration
2. Operating Parameters, defined as easily changeable parameters that control the day-to-day performance of the incinerator

The system parameters are functions of the design and construction of the incineration system and normally cannot be changed once the incinerator is built. They include such items as:

- Size and shape of the primary combustion chamber (PCC) and secondary combustion chamber (SCC)
- System configuration
- Size of pipes and ducts
- Capacity of the fans and pumps
- Location and type of monitoring equipment
- Type and configuration of the air pollution control equipment (APCE)
- Dimensions of components such as feed chute, auger, and screw feeder for solids handling

Generally, system parameters are incorporated into the permit by reference to design drawings and specifications and are not directly discussed further here. Operating parameters are easily changed to accommodate fluctuations in the demand on the system and other constantly changing factors. These parameters include the following:

- Temperatures at various points in the PCC, SCC, APCE, stack, etc.
- Pressure at various points in the system and pressure drops across key pieces of equipment within the system
- Carbon monoxide (CO) and O_2 concentrations at a selected CO monitoring point
- Gas flowrates in the system
- Waste and primary fuel feed rates
- Waste composition such as ash, moisture, volatile content, and halogen content
- Excess combustion air into PCC and SCC
- Burner atomization setting
- APCE-related parameters, i.e., pressure drop, scrubbing liquor flowrate, pH, and plate voltage

To establish meaningful and enforceable permit conditions and to avoid mutually exclusive requirements, the operating parameters should be considered in relation to each other and in relation to the system parameters. A goal of this handbook is to

avoid setting redundant parameters, where consistent with technical judgement and regulatory requirements; however, it is important to be aware of the interactions between the various permit conditions and ensure that they are internally consistent. For example, for some facilities, a limit on minimum temperature and maximum gas throughput would also define the minimum and maximum thermal duties (total heat input), waste feed rate, and excess O_2. Since the regulations require that at least some of these other parameters be regulated, it is important that they be internally consistent. Wherever technically possible and consistent with the regulations, it should be the permit writer's goal to eliminate redundant restrictions.

The remainder of this chapter discusses the control parameters and selection of their limits. Table 2-1 lists the control parameters pertinent to most incinerator facilities. As can be seen, they have been grouped into three categories identified as groups A through C. This nomenclature is somewhat arbitrary and was chosen simply to clarify the ensuing discussions.

Group A parameters are based strictly on trial burn results and require continuous monitoring and automatic waste feed cutoff when permit limits are exceeded. Because these may fluctuate rapidly during normal operation, short-term deviations from the acceptable range may be tolerated. These variations are discussed further in Section 2.1.

Group B and C parameters are not continuously monitored and, consequently, are not interlocked with automatic waste feed cutoff. The primary difference between groups B and C is that operating limits for group B parameters also are based strictly on trial burn results, whereas limits for group C parameters are based on equipment design specifications and do not necessarily reflect operational settings recorded during the trial burn.

The only requirement for group C parameters is that the operating conditions recommended do not deviate from those specified by the equipment manufacturer and are compatible with good operating practices. This treatment of group C parameters allows greater flexibility in the permit because worst-case operational settings for these parameters are not investigated during the trial burn to demonstrate compliance with a desired envelope. This procedure formally and legally requires that the operator use the equipment in the manner and under the conditions for which it was designed. For example, nozzles will typically be designed to properly atomize a liquid or slurry of specified ranges of viscosity, vapor pressure, etc. The nozzles will not perform well if these ranges are exceeded, and incinerator performance may deteriorate. Permit conditions that require adherence to manufacturer specifications thus ensure good operating practices.

The issue has been raised that, in some cases, there are no manufacturer's specifications because the equipment may have been made by the applicant or custom built for this application. Also, in some cases, the applicant may find that the equipment works well outside the specified ranges. In that case, the applicant should provide design specifications and, if the reviewer requests, backup material on the adequacy of the specifications and of the equipment. It may be necessary to incorporate testing of the proposed ranges for these parameters into the trial burn. If the trial burn shows the incinerator to perform properly when the equipment in question operates well outside the manufacturer's or design specifications, the permit limits may be set at the demonstrated levels.

Note that a waste feed cutoff is not the same as an incinerator shutdown. In a cutoff, the incinerator may keep operating on auxiliary fuel and on nonhazardous waste until the problem is corrected; and, except in extreme situations, continued operation is desirable so that furnace temperature is maintained. A control parameter such as temperature that exceeds specification triggers a waste feed cutoff, not a total shutdown of the system.

A final word of caution regarding the type of systems used for the waste feed cutoffs. The systems must be fully automatic to satisfy the requirements of the regulation. A meter or strip-chart output that is periodically checked by an operator who shuts off the waste feed if a problem is noticed is not an adequate substitute for an automatic system. An automatic system must monitor the parameter and initiate the waste feed shutoff when an excursion is detected. It is highly desirable that the system also trigger an alarm as the parameter approaches the cutoff limit to allow for corrective action.

The following sections explain the reasons these parameters were selected. The discussion provides insight on the selection and interdependence of the control parameters. It also suggests alternative approaches that may be more appropriate in special cases. The section closes with a discussion of those parameters which were considered for inclusion but were not selected along with the rationales for excluding these parameters and a discussion of situations when they should be considered.

2.1 Group A Parameters

There are six "group A parameters":

1. Temperature of the gas at each combustion chamber exit
2. CO emissions

Table 2-1. Control Parameters

Group	Parameter
Group A Continuously monitored parameters are interlocked with the automatic waste feed cutoff. Interruption of waste feed is automatic when specified limits are exceeded. The parameters are applicable to all facilities.	1. Minimum temperature measured at each combustion chamber exit 2. Maximum CO emissions measured at the stack or other appropriate location 3. Maximum flue gas flowrate or velocity measured at the stack or other appropriate location 4. Maximum pressure in PCC and SCC 5. Maximum feed rate of each waste type to each combustion chamber[1] 6. The following as applicable to the facility: • Minimum differential pressure across particulate venturi scrubber • Minimum liquid-to-gas ratio and pH to wet scrubber • Minimum caustic feed to dry scrubber • Minimum kVA settings to ESP (wet/dry) and kV for ionized wet scrubber (IWS) • Minimum pressure differential across baghouse • Minimum liquid flowrate to IWS
Group B Parameters do not require continuous monitoring and are thus not interlocked with the waste feed cutoff systems. Operating records are nevertheless required to ensure that trial burn worst-case conditions are not exceeded.	7. POHC incinerability limits 8. Maximum total halides and ash feed rate to the incinerator system 9. Maximum size of batches or containerized waste[1] 10. Minimum particulate scrubber blowdown or total solids content of the scrubber liquid
Group C Limits on these parameters are set independently of trial-burn test conditions. Instead, limits are based on equipment manufacturers' design and operating specifications and are thus considered good operating practices. Selected parameters do not require continuous monitoring and are not interlocked with the waste feed cutoff.	11. Minimum/maximum nozzle pressure to scrubber 12. Maximum total heat input capacity for each chamber 13. Liquid injections chamber burner settings: • Maximum viscosity of pumped waste • Maximum burner turndown • Minimum atomization fluid pressure • Minimum waste heating value (only applicable when a given waste provide 100% heat input to a given combustion chamber) 14. APCE inlet gas temperature[2]

[1] Items 5 and 9 are closely related; therefore these are discussed under group A parameters.
[2] Item 14 can be a group B or C parameter. See text in Section 2.1.6.

3. Indicator of combustion gas velocity (flue gas flowrate)
4. Maximum waste feed rate
5. Pressure in the PCC
6. APCE

The regulations (40 CFR 264.345(a)) specifically require that the levels of the first four parameters be set in the permit based on the trial burn results. They also allow additional conditions to be set as deemed necessary by the permit writer. In addition, 40 CFR 264.347 requires continuous monitoring of the first four parameters. It is recommended that those parameters for which the permit sets conditions but does not require continuous monitoring be logged at least every 15 min. The following sections discuss each of the parameters and setting conditions for them.

2.1.1 Temperature

The regulations require that suitable interlocks be provided to shut off the hazardous waste feed if the temperature drops below a value specified in the permit (see 40 CFR 264.345(f)). This section gives guidance on establishing the minimum temperature in each combustion chamber which will trigger the automatic waste feed cutoff.

A minimum temperature must be specified for each chamber of an incinerator. It is recommended that the temperature at which the waste feed is cut off be specified as not less than the lowest mean temperature at which a successful test (minimum of three runs) occurred. If this level is not appropriate for a facility, a rolling average temperature limit similar to that which will be used for CO emissions is acceptable. When these limits are established, it is important that the minimum temperatures for both the PCC and SCC be determined from the same test. As discussed in the example given in Chapter 4, it is possible for the SCC to achieve its minimum temperature during one test while the PCC achieves its minimum during another.

It is not necessary to cut off all waste feeds when the temperature in only one chamber drops below the

minimum. Table 2-2 summarizes the recommended guidelines for specifying this.

Table 2-2. Recommended Waste Feed Cutoffs

Gas Temperature Below Minimum In:		Waste Feed Is Cut Off To:
SCC only	→	Both PCC and SCC
PCC only	→	PCC only
SCC and PCC	→	Both PCC and SCC

PCC = Primary combustion chamber.
SCC = Secondary combustion chamber.

As shown, hazardous waste feed to both chambers should be stopped if the temperature in the SCC drops below the trigger value. If only the PCC temperature drops below the trigger value, the hazardous waste feed to the SCC may continue, and only the hazardous waste feed to the PCC needs to be stopped.

The rationale for waste feed cutoff to both chambers when the gas temperature in the SCC drops below the minimum is that the gas leaving the PCC may still contain undestroyed POHCs and hazardous products of incomplete combustion (PICs). These compounds may not be destroyed if the SCC is not maintaining an adequate temperature. Continued operation of the SCC if the temperature in the PCC drops below the minimum is necessary since the waste usually contributes energy to maintain the SCC temperature. Sudden changes in the SCC fuel feeds should be avoided when there are problems with the PCC that may be releasing POHCs or PICs. As long as the SCC temperature is being maintained, waste feed to it may continue.

In performing this evaluation, the permit writer is cautioned to consider the location and placement of the temperature sensor. These factors are especially critical when upset conditions are being monitored; for example, during the extreme case of "flameout" in the SCC. The temperature of the bulk gas in the chamber would quickly drop; however, the walls, which have a very high thermal mass, would remain hot for a long time. If improperly installed, the temperature sensor would absorb heat by radiation from the walls and indicate a higher temperature than that to which the residual POHCs are actually being exposed. See the *Engineering Handbook of Hazardous Waste Incineration*, (1) SW-889, and *Hazardous Waste Incineration Measurement Guidance Manual* (2) for more information on this subject.

The remainder of this section discusses the effects of temperature, gives additional information to explain the above recommendations, and shows how the temperature limits are calculated from test data.

Mechanics of POHC Destruction

Destruction of a POHC is a multistep process. First, the compound is vaporized either in a solids handling system such as a rotary kiln, hearth, or fluidized bed or, if a liquid, by a nozzle. Then, the vaporized materials are exposed to a flame where the majority of the POHCs are destroyed. A small fraction of the POHCs that typically escape the flame zone requires an extended residence time (~1 sec) at elevated temperatures [~1,000°C (1,830°F)] to be destroyed.

The time/temperature dependence of the destruction process is described in Appendix C. Generally, the longer the residence time and the higher the chamber gas temperature, the greater the destruction of the POHC fraction that escapes the flame; the different segments of the complex flow patterns in the combustion chamber will have different temperatures. The area immediately around the flame will be very hot and poor in oxygen. As the gases move away from the flame, they mix with additional oxygen (secondary air), but their temperatures drop. Along the walls, the refractory will be relatively cool, and it will keep the adjacent gases cool.

The degree of POHC destruction that will be achieved in any one slug of material that passes through the combustion chamber will be a function of the time/temperature (and oxygen) regime that the particular slug is exposed to as it follows a somewhat random path through the chamber. The majority of the slugs of gas that contain POHCs will pass through the flame and be destroyed. A small percentage, however, will bypass the flame and follow a path which typically results in a lower level of POHC destruction. This complexity does not lend itself to detailed analysis without a major investment in time and testing that is beyond the permitting process in all but special cases. Fortunately, the trial burn data preclude the need for a detailed temperature profile of the incinerator.

Determining Temperature Limit

As discussed above, the temperature at which waste must be cut off to the incinerator is determined from the trial burn. This subsection discusses how such a determination can be made and gives additional rationale to support the decision.

According to EPA policy for trial burns, three runs must be conducted at each temperature although a larger number of replicates may performed to provide insurance against loss of data from any one run. The minimum operating temperature for the incinerator is defined as the lowest temperature at which a set of runs was performed during the trial burn. If a test is conducted at only one temperature, that temperature is defined as the minimum.

During each test, the replicate runs are performed under as similar conditions as practical; however, a slight variation in the mean temperature is common. The mean temperature used to set the minimum is the average of the mean temperatures of the replicate runs constituting the test.

The permit condition for the minimum operating temperature is the lowest mean temperature that resulted in a successful test. The automatic interlock should be set so that the waste feed to the appropriate chamber is cut off when the temperature drops below this value.

It is recognized that this is a somewhat conservative automatic waste cutoff level. If the incinerator is operated at the lowest mean temperature at all times, frequent cutoffs are likely. The operator can avoid the cut-off trips by operating the incinerator at a slightly higher temperature than this minimum. Thus, the trial burn would be performed at a temperature slightly lower than that desired for operation.

The second method that can be used is to base the waste feed cut off on an hourly rolling average of the temperature during operation. The hourly rolling average has been defined as the mean of the 60 most recent 1-min values measured by the continuous monitoring system. For calculation of each hourly rolling average value, the new data point is added to those taken over the specified time period and the least recent data point is excluded from the average. The permit condition then would specify that waste feed should be cut off when either (1) the temperature drops below a minimum (which is the lowest temperature measured during the trial burn) or (2) the rolling 60 minute average temperature falls below the mean determined from the trial burn. The absolute minimum temperature for waste cutoff, condition (1) above, should be the lowest temperature from the trial burn. Its purpose is to trigger an immediate waste feed shutoff in case of a sudden, catastrophic temperature decrease.

The following example illustrates the function and intent of the lower temperature limit. Consider an incinerator whose secondary chamber's temperature is being maintained with a high heating value hazardous waste. Assume, further, that because of improper blending, water has accumulated in the waste storage tank and the feed system begins sending this water instead of the combustible waste to the high heating value waste burner. The flame would become very unstable and the temperature in the SCC would drop rapidly; however, the temperature sensor would continue to average the drop in temperature with the values from the paste hour of operation and not trigger waste feed cutoffs, or alarms, for several minutes. A secondary cutoff at a low temperature would eliminate this problem. It is recognized that the flame instability described above would most likely trigger a waste feed cutoff because of CO limits; however, these are also based on a rolling average and could, conceivably, also result in a delay.

In order to assure that normal fluctuations in the temperature do not trigger waste feed cutoffs, the lower temperature should be set at the absolute lowest (not the mean) temperature encountered during the trial burn. This is essential since the purpose of requiring the added complexity of a rolling average temperature would be defeated if normal variations in the temperature could trigger a waste feed cutoff.

For example, Table F-15 of Appendix F lists the SCC and PCC temperatures for each minute during a trial burn. The "sampling time" for these data is, therefore, 1 min. The rolling average of the SCC and PCC temperatures for the first 60 min is the mean of each set of temperatures recorded between 1,250 and 1,309 min. At 1,251 min, the rolling average becomes the mean of that calculated between 1,251 and 1,310 min. This pattern is continued for each new interval.

A rolling average type of permit condition requires that the temperature monitoring system include a computer capable of calculating the rolling average continuously. Because of the added complexity, the rolling average conditions should only be used when requested by the applicant.

The remainder of this section gives background information to support the two approaches for establishing the waste feed cutoff level and describes methods for calculating the mean temperature and the other values needed to set the permit conditions on temperature.

The temperature limits recommended can usually be readily specified. The trial burn report normally includes copies of the temperature monitor outputs and a summary of the mean, maximum, and minimum values for each run. The temperature of an incinerator is always monitored continuously by at least a strip-chart recorder and usually a data logger that also records the temperature at 30-sec to 1-min intervals. The time-weighted average is the arithmetic mean of the temperatures recorded at these intervals. If a mean is not given in the report, it can be calculated from the temperature log (if given) or the strip-chart recorder output by the following method.

Figure 2-1 is an example of a strip-chart recorder output. Because fluctuating data usually have a rough periodicity, a visual examination will identify some minimum period to the fluctuation. A period smaller than this minimum is selected as the sampling rate. For example, if the fluctuations vary at a 1- to 3-min rate, the 1-min rate is used. Then, the strip-

Figure 2-1 Example of a temperature trace.

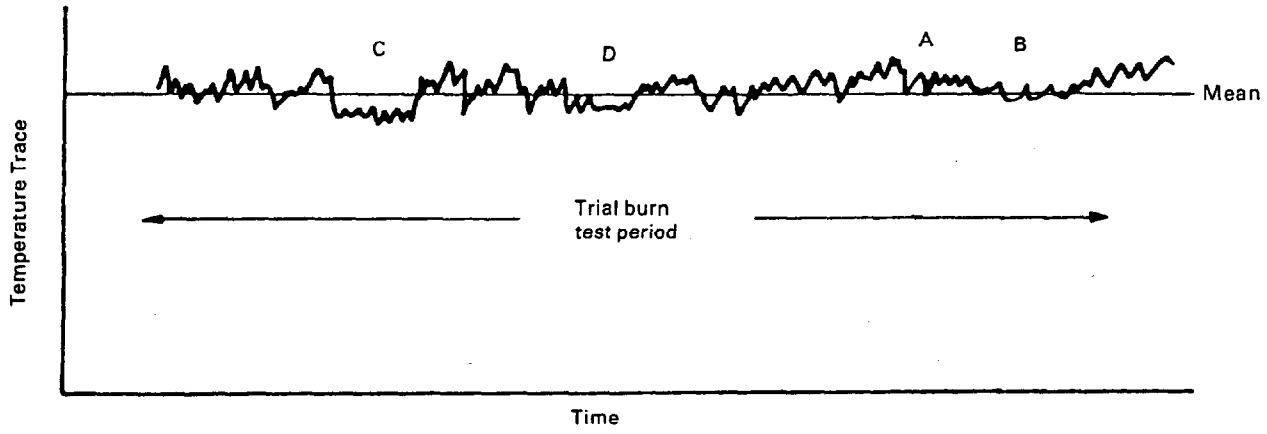


chart output at this interval is read, and temperatures at that time interval are listed. For a 2-hr test, such a calculation would result in 120 data points. The mean can then be calculated from these results.

A graphic alternative procedure can be used to estimate the mean temperature directly from the strip-chart output. It is not as rigorous as the numerical procedure described above, but it is quick and usually adequate. Simply draw a line through the strip-chart output, visually dividing the fluctuations into a approximately equal areas above and below the line. The line is a good approximation of the "estimated mean" temperature.

The mean temperature for each run in the test may be calculated by either of these two methods. The minimum mean temperature is determined by averaging the mean temperatures for the runs at the lowest temperature test, as discussed above.

In addition to fluctuations characterized by brief excursions from a constant mean temperature, the short-term mean temperature may drift up or down during the course of a run. This trend is not shown in Figure 2-1 and appears as a general upward or downward drift in the temperature trace. Finally, the mean temperature itself can oscillate periodically; this variation appears as a general sinusoidal trend to the temperature trace. These two situations are often indicative of an improperly operating temperature control system, and guidance for handling them should be sought.

2.1.2 CO Emissions

The rationale for monitoring CO emissions is the premise that a sudden increase in CO emissions is indicative of poor mixing of combustion products and air or some other form of combustion upset. The complete mixing of reactants achieved in a well-stirred reactor is never realized in full-scale incinerator combustion chambers. When temperature, gas residence time, and oxygen are sufficiently high, other combustion parameters such as turbulence (mixing) become the rate-limiting mechanism. Manufacturers of burners and combustion chambers go to great lengths to maximize the contact of air, fuel, and waste in and near the combustion zone to avoid hot spots and minimize temperature gradients in the chamber.

The concentration of CO in the flue gas is particularly sensitive to poor combustion conditions, and this parameter is used as an indication of combustion efficiency (CE). High CO emissions can be the result of insufficient combustion air, poor mixing, improper atomization, excessive volatility (solids), or flame quenching. High CO emissions tend to indicate combustion or mixing problems which increase the likelihood of PIC formation. Products of incomplete combustion are not specifically addressed in the current RCRA regulations. However, there is considerable public and regulatory concern about the potential risks of PICs from hazardous waste incinerators.

While the present regulations simply require that CO limits in the permit are based on the trial burn as long as DRE is achieved, there appears to be a technical rationale for basing limits on the level of PICs emitted. Guidelines on setting CO limits to minimize PIC emissions will be provided in the *Guidance on Carbon Monoxide Controls for Hazardous Waste Incinerators* now being formulated by EPA. The Office of Solid Waste should be consulted on the present status of these guidelines.

2.1.3 Gas Velocity Indication

Regulation 40 CFR 264.345(b)4 requires that "the permit will specify acceptable operating limits . . ." for "an appropriate indicator of combustion gas velocity." To satisfy this requirement, it is necessary to

measure parameters which can be related to the combustion gas flowrate. Upper limits need to be placed on combustion gas flowrates for the following three reasons. The first is to control the gas residence time in each chamber. The second is to control the gas throughput throughout the system to minimize back pressure at joints and seals; for example, at the inlet of a rotary kiln to the SCC. The third is to control the gas flowrate through the APCE to ensure that it is not overloaded.

Note that while the measurement of "an indicator of gas velocity" is required by the RCRA regulations (or more correctly, they require that limits be placed on this parameter), it is not an independent variable. The flue gas flowrate is interrelated with the pressure measurements described in subsequent sections. Limits on gas flowrate cannot be set without affecting the limits on pressure parameters in the incinerator.

This section is not intended to provide detailed guidance on the type of flue gas measuring device that should be used. See the *Engineering Handbook for Hazardous Waste Incineration* (1), SW-889, and the *Hazardous Waste Incinerator Measurement Guidance Manual* (2) for such guidance. Some advice is given below on the placement of such monitors.

The combustion gas flowrate can be monitored in several different ways. The preferred method is the use of a direct gas flow monitor at the outlet of the SCC. In some systems, however, conditions such as high temperature, high particulate loading, and high acid gas loading could result in unsatisfactory life and performance of the monitor.

Another option, and often the more practical one, is to place the monitor just before the stack. Although this practice increases the likelihood of introducing errors due to air infiltration or changes in the water content of the gas stream, which can be difficult to predict, it results in an increased life and performance reliability for the monitor. If this site is chosen for the combustion gas monitor, the permit writer should add constraints on the water content and permissible air infiltration upstream of the monitor to maintain conditions consistent with those achieved during the trial burn.

When neither of these alternatives is practical, it may be possible to measure the combustion air flowrate instead of the combustion gas. For a given temperature, the flowrate of the combustion gas (the products of combustion) can be approximated within reasonable accuracy by the flowrate of the combustion air, i.e., the primary and secondary air being fed to the combustor. In most cases, the combustion air constitutes 95 percent or more of the combustion gas, as illustrated by Figure 2-2, which shows the consistency of this correlation for different conditions. In many cases, especially for forced-draft incinerators, the primary and secondary combustion air can be measured fairly easily. When this is the case, to monitor combustion air is a good alternative to monitoring combustion gas.

Another method of measuring the combustion gas flowrate is to monitor the power usage (voltage and current are adequate, in most cases) of the induced draft fans, although sufficient technical justification in the form of actual power usage versus gas flowrate should be given to document its accuracy in a given system.

The limits on the flue gas velocity set by the permit conditions should be based on the maximum combustion gas flowrate that was measured during the trial burn. This flowrate measurement should be taken at the minimum observed temperatures during the test to ensure that the condition includes the lowest temperature and shortest residence time that achieved acceptable incinerator performance.

2.1.4 Combustion Chamber Draft or Pressure

The draft or pressure in the chambers of an incinerator is regulated to minimize the release of partially burned POHCs and other untreated products of combustion as fugitive emissions from the PCC. Fugitive emissions are regulated under 40 CFR 264.345(d). These emissions are of concern in multichamber and especially in rotary kiln systems that partially degrade the wastes into gaseous components in the PCC and feed the off-gases containing large amounts of POHCs, PICs, acids, and particulates, first into the SCC where the PICs and POHCs are destroyed and, then, into the air pollution control devices where the pollutants are removed to below the required level. The release of these intermediate gases is normally prevented by setting limits on the maximum pressure at which the PCCs and SCCs can operate.

Normally, the gases from the PCC are forced into the SCC by the pressure differential between the two. If there is a sudden increase in the gas production rate in the PCC or a draft decrease in the SCC that may be caused by a fan failure or an increase in the burning rate, partially burned POHCs and PICs as well as particulate and acid gases from the primary chamber can be released. Increases in the pressure in the PCC can be caused by an explosion or when a drum of exceptionally flammable waste ignites. Any condition that results in the sudden release of more gas than the upstream system can accept will result in an overpressure. Normally, the system between the PCC and SCC is equipped with seals that can contain the gas from a specified level of overpressure. When this level is exceeded, however, untreated gases are released.

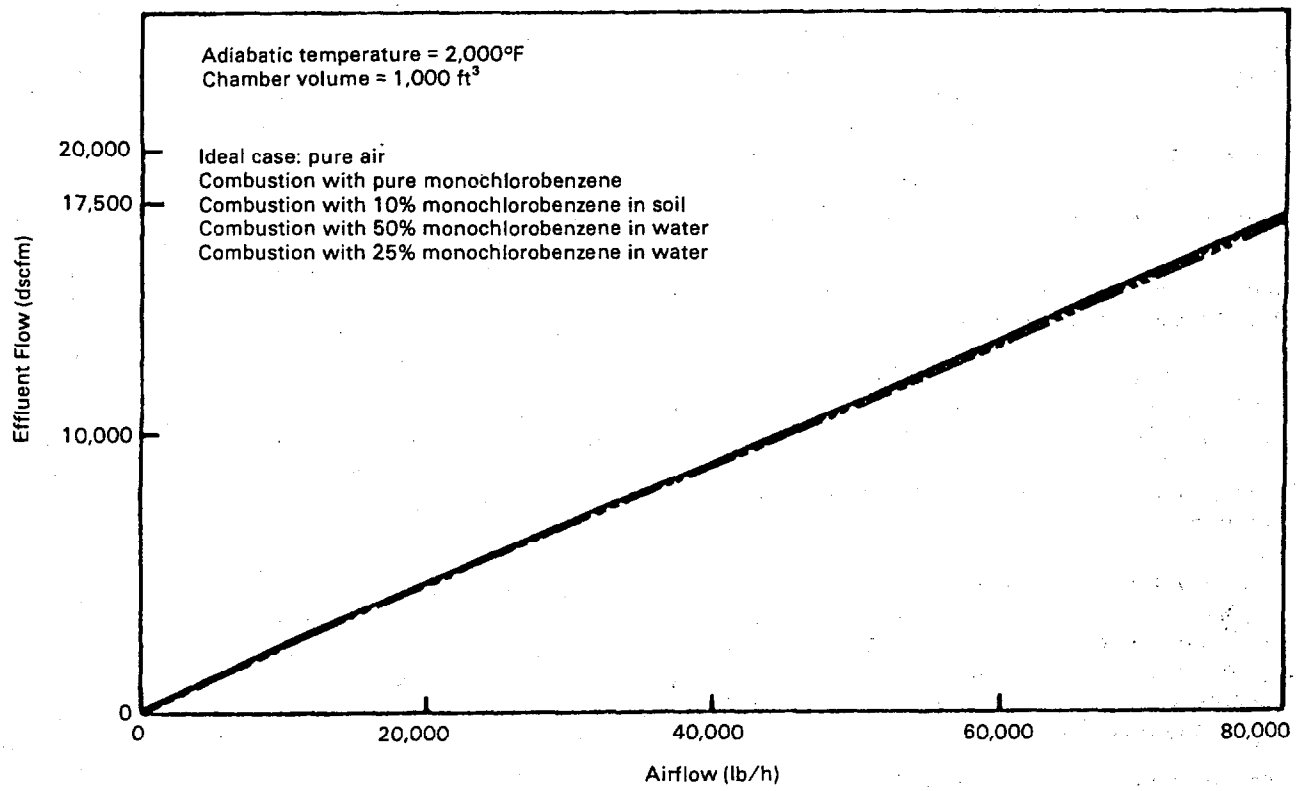


Figure 2-2. Effluent flow versus air flow for combustion.

The fugitive emissions problem is most common in rotary kiln incinerators where the kiln must rotate against a seal between it and the secondary chamber. Typically, these units are operated at a sufficient draft to ensure that normal fluctuations in the burning rate will not result in a pressure above atmospheric. In addition, the waste and supplemental fuel guns typically are mounted in openings at the upstream end of the kiln, and an overpressure would result in hot gases "backfiring" past the guns. This is a dangerous situation and indicative of a poorly designed or operated unit.

A relatively uncommon rotary kiln design is particularly sensitive to overpressures and the resulting fugitive emissions. In the typical rotary kiln design, the kiln enters the SCC without any constrictions in the gas stream following the rotating seal. If the kiln, however, is attached to a seal leading to a hot gas duct that is followed by an elbow, diameter reduction, or other restriction to the hot gas flow between the two chambers, the likelihood of frequent overpressures increases dramatically.

For the majority of the hazardous waste incinerators that a permit writer is likely to encounter, frequent fluctuations in pressure at the exit of the PCC usually indicate highly heterogeneous wastes that burn unevenly or periodic overfeeding of waste to the incinerator. If the overpressures are sufficiently high to result in fugitive emissions from the seals or other openings between the PCC and SCC, they should be considered an upset condition that requires the shutoff of hazardous waste feed to the PCC.

Limits on the PCC draft or pressure should be set in one of two ways, one for incinerators that are designed to operate under positive pressure and that are much more likely to tolerate a short overpressure without releasing fugitive emissions and the second for those operating under negative pressure that must rely on draft to keep the combustion gases in. Table 2-3 summarizes the recommended limits for the pressure in the PCC.

For forced-draft systems, the automatic waste feed cutoff for both chambers should be set at the time-averaged pressure during the trial burn, provided that there were no fugitive emissions. Brief excursions above this pressure can be tolerated if they do not

Table 2-3. Limits on Chamber Draft or Pressure

	Forced Draft (Positive Pressure)	Induced Draft (Negative Pressure)
Primary Chamber	Time-averaged pressure determined during trial burn	Slightly below atmospheric pressure
Secondary Chamber	Time-averaged pressure determined during trial burn	Always below that of the primary chamber

exceed the frequency and maximum excursion encountered during the trial burn.

For induced draft systems, the PCC pressure level activating waste feed shutoff can be the lower pressure of either of the following:

1. Time-averaged pressure measured during the trial burn, or

2. 2 mm water gauge below atmospheric for the PCC.

The 2-mm water gauge draft is only a guideline, and a lower pressure should be specified if highly toxic materials are involved, or if the incinerator appears to have poorly designed seals.

If pressure variations occurred during the trial burn, they can be permitted in the permit condition as well; however, the maximum pressure in the PCC may never exceed atmospheric pressure under any circumstances. In fact, if the results of the trial burn indicate the possibility of surges that result in a PCC pressure in excess of atmospheric, the operating conditions of the unit should be evaluated to determine the cause of these surges, and limits should be placed on other parameters such as waste feed and maximum size of container waste to ensure that this type of surge does not occur.

It is necessary that the maximum pressure in the SCC must always be below that in the PCC to ensure that any gases produced in the PCC are drawn directly into the SCC.

One other point should be mentioned. For those incinerators incorporating a rotary seal between the primary and secondary combustion chambers, it is important that the permit conditions include a rigorous I&M program for these seals in addition to limitations on the size and duration of the overpressure. The seals between the primary and secondary chamber are exposed to high temperatures, acid gases, and mechanical wear from the rotation. They must be properly maintained to prevent a release of unburned gases during a pressure surge.

2.1.5 Maximum Waste Feed Rate

Regulation 40 CFR 264.345(b) requires that a permit set limits on the rate at which hazardous waste is fed to the incinerator. The limits on this parameter serve several purposes. First, they prevent overload of the combustion chamber and, thus, reduced incinerator performance. If low heating value waste is added to the incinerator at too great a rate, it may cool the flame and inhibit combustion. Second, waste feed rate limits keep the residence time above the minimum level required to destroy the POHCs. The larger the fuel and waste feed, the greater the flue gas flowrate and, hence, the lower the residence time. Also, limiting the waste feed rate also limits (to a degree) a group C parameter, the heat released per unit volume (see Section 2.3.2). Finally, limits to the waste feed rates are often necessary to fix other parameters such as chlorine or ash feed rates.

Two types of limits should be placed on the total waste feed. The first is total waste feed per unit time for each waste stream or waste stream type such as solid wastes, aqueous wastes, or organic liquids. This limit is based on the average over time achieved during the trial burn. The second factor that should be regulated is the instantaneous waste feed rate. This parameter is referred to in Table 3-2 as the "maximum size of batches or containerized waste to the PCC." This is a group B parameter but is addressed in this section because of its close relation to the maximum waste feed rate. The instantaneous waste feed rate is not important if the waste is fed by nozzles, a continuous conveyor, or a screw feed. If, however, the waste is fed in batches as with a ram feeder or in drums, there is a danger that the batch that hits the PCC can instantaneously either quench the flame if, for example, the waste is aqueous or wet soil, or result in an instantaneous release of heat and flue gases that exceeds the capacity of the downstream air handling system. The latter event would result in puffing at the joint between the PCC and SCC and in fugitive emissions, as discussed in Section 2.1.4.

The volatile content of the waste influences the rate at which such a sudden release would occur. An excessive amount of volatile material in a waste will result in a rapid release of hydrocarbons, which, in turn, will lead to a rapid increase in the PCC pressure and an increase in the CO level. A shutdown would be triggered on that basis. This event is discussed further in Section 2.4.

Drum feeding of waste is particularly susceptible to this occurrence. To illustrate, consider the case where an incinerator is fed one 208-L (55-gal) drum of waste every 15 min in addition to other wastes on a continuous basis. When that drum hits the kiln or grate, for example, it will be cold, and it will first quench the flame and the burning waste in the PCC. As it heats up, the drum will melt or burn, if it is a fiber drum, and release the flammable material within it. A very rapid heat and gas release that may now overpower the gas handling system will result. As discussed in Section 2.1.4, this release can result

in puffing and fugitive emissions, or even if they do not occur, such an event can result in a significant change in the temperature and the residence time of the gases in the SCC. This change can affect the destruction efficiency and, hence, the DRE for the POHCs.

Such a scenario can be regulated by designing the trial burn to match both the mean and instantaneous waste feed rates for the incinerator. For example, the permit condition could specify that a given waste stream may not be fed at a rate exceeding 300 kg (660 lb)/hr with individual batches not exceeding 30 kg (66 lb) fed at no less than 6-min intervals. Other ways of specifying this type of limit such as by maximum drum size can be used depending on the unique requirements of a given system. Although an important factor, maximum volatile content of the containerized waste is not recommended as a permit condition because it is impractical to measure this parameter during continued operation. However, it is recommended that the containerized waste fed during the trial burn be chosen so as to equal the greatest amount of volatiles expected during subsequent operation.

The above approach needs to be modified to consider different waste streams. An incinerator which burns all the wastes at a fixed feed ratio will be the exception rather than the rule. When a variety of wastes are fed, the trial burn should be designed to incorporate a combination of waste feeds to ensure sufficient operating flexibility. The limits on the waste feeds should be such that the combination of wastes fed at any one time would result in a total heat release rate in each chamber that matches the conditions in the test run. Data from a test burning one set of wastes should not be used to set limits on the feedrate for a different category of wastes, but a certain amount of flexibility in the waste flows based on the above guidance is acceptable.

In operation, the heating value of the waste does not have to be known to great accuracy to adhere to the variations in the waste feeds. Typically, the operator will feed the waste with the lowest heating value to the incinerator and then control the temperature at the exit of the combustion chambers by varying the feed rate of the wastes with higher heating values. If the temperature cannot be maintained in this manner, the operator can either lower the feed rate of the lower heating value wastes, use supplemental fuel, or vary the air feed rate.

This procedure will translate into a reasonably constant heat release rate and, under most circumstances, a reasonably constant flue gas flowrate. See the *Guidance Manual for Hazardous Waste Incinerator Permits* (3) for further information on how the heat release rate relates to flue gas flowrates. Appendix B also briefly describes how the flue gas flowrate can be calculated.

2.1.6 Air Pollution Control Equipment

The final sets of group A parameters that must be limited with permit conditions are those relating to the APCE. Typically, the APCE on a hazardous waste incinerator removes acid gases (commonly HCl) and particulate. There are cases where either or both of these categories of pollutant do not require control. For example, if the incinerator does not burn halogenated wastes, no acid scrubber is required and no limits need to be set on the respective APCE. Hydrogen chloride emissions will then be regulated by limiting the chloride content of the wastes so that the burning of halogenated materials is limited. Monitors of HCl emissions may prove to be an alternative for control purposes. Such monitors are now becoming available, and information on their reliability is being gathered.

Similarly, if the system does not require particulate control equipment (because the waste burned during the compliance test did not contain sufficient inorganic material to form excessive particulate), the limits should be placed on the amount of ash and the cleanliness of the quench water, if appropriate. These limits are discussed below.

Acid Gas Formation and Control

Incineration of hazardous waste can generate a variety of acid gases such as SO_2, SO_3, NO_x, HCl, and HF. The NOx can be formed by oxidation of the nitrogen in the air and in the wastes. The other gases are typically formed by the chemical reaction of sulfur, chlorine, or other elements in the waste. The most common occurrence is the formation of HCl, and in most hazardous waste incinerators, acid gas control is synonymous with HCl removal. As a result, the remainder of this discussion will deal with HCl removal. The reader is referred to the *Guidance Manual for Hazardous Waste Incinerator Permits* (3) for information on the mechanisms of formation of this and the other acid gases.

Briefly, during combustion, the organic chloride in the waste reacts with hydrogen from the waste, fuel, or water in the combustion chamber to form HCl. A small percentage (typically 3 to 5 percent) of the chlorine will normally be released in the elemental form as chlorine gas. It is possible for larger quantities of free chlorine to form when the combustion chamber contains an insufficient quantity of hydrogen to convert all the organic chlorine to HCl, but because this is highly uncommon, it will not be discussed further here. The permit writer is advised to seek assistance from the Office of Solid Waste if this situation is encountered.

Hydrogen chloride gas is readily soluble in water and is most commonly removed by a packed-bed scrubber. It can also be removed by the scrubber used to control particulate such as the Venturi scrubber. Recent developments in "dry scrubbing" technology has resulted in incinerators utilizing some form of lime-slurry injection to remove the acid gases. The variety of acid gas removal devices is large. Fortunately, for the purpose of setting permit conditions, the performance of these devices can be determined from the trial burn and, if it is shown to be adequate, the operation can be monitored with only a few readily measurable parameters.

The RCRA regulations require that any hazardous waste incinerator which emits HCl at a rate greater than 1.8 kg (4 lb)/hr must be equipped with an APCE whose collection efficiency for HCl exceeds 99 percent. The actual performance of the scrubber is a complex interaction between the types of packing, the ability of the system to distribute the flue gases and scrubbants in the absorber intimately, the alkalinity or acidity of the absorbant, and the liquid-to-gas (L/G) flow ratio. Of these, all but the last two are fixed for the facility and, if the compliance test is satisfactory, the design is assumed adequate. Any changes in the design, however, constitute a change in the operating conditions of the incinerator and should be considered as a possible deviation from the permit.

Four parameters need to be limited to ensure that the absorber performs as during the compliance test. These are (1) the L/G ratio, (2) the pressure of liquid feed to the nozzles, and the pH of the aqueous solution (3) entering and (4) leaving the absorber. The L/G ratio and the pH should be specified as no less than that measured during the successful compliance test. Because these parameters can be controlled independently, there is little difficulty in maintaining them within constant bounds in a properly operating incinerator, and variability does not usually have to be considered. If variability does occur during the test, a time-averaged value of these parameters should be used. The pH of the aqueous solution entering the scrubber should be limited to assure that the scrubbing solution has adequate capacity to remove the acid gases. The pH of the solution exiting the scrubber should be limited to assure that the scrubber is not being overloaded with acid.

The pressure of the liquid feed to the air pollution control device should be a control parameter for the types of systems discussed below to reduce the risk of deterioration of APCE performance. For many but not all types of scrubbers, this parameter, which is an indicator of how well the scrubbing liquid (water) gets distributed in the APCE, will have a major influence on the equipment's performance. Some simple scrubbers inject the water into the gas stream through one or more nozzles; others, such as packed towers, can have complex manifolds to distribute the scrubbing liquid across the packing. In those cases, clogging or deterioration of the liquid distribution system (such as the nozzles) could result in a decrease in APCE performance. Clogging or deterioration of these systems would be manifest as a change in the operating pressure outside the design range or the range determined during the trial burn. Clogging increases the pressure drop; erosion or corrosion decreases the pressure drop. Because such failure is usually gradual, nozzle pressure does not have to be interlocked with an automatic waste cutoff. It should, however, be included in the operating log, and significant changes in it should initiate a corrective action.

An important type of control equipment where the pressure of the water feed will not indicate a change in scrubbing liquid distribution is an absorber which uses a distribution plate to spread the water across its diameter. The water is released onto the plate, and it then flows by gravity over the top of the packing or onto the top plate. In this case, there is little advantage to setting limits on the liquid feed pressure. The pressure drop across the column along with the L/G ratio, which is a control parameter, will usually indicate a deterioration in the liquid distribution and, hence, scrubber performance. If possible, some form of regular inspection of the column interior, especially of the water distribution system, is desirable; however, a sight glass or inspection port is usually of limited value for such an inspection. A good inspection, which usually involves shut down of the scrubber and careful examination of its innards, should not be normally required except during maintenance.

Pressure drop of the gas across the scrubber is of operational concern in a packed tower, but, except for a massive failure in the packing, deviation from the design specification is unlikely to cause an environmental problem. If liquid flow to the tower and flue gas flowrates are monitored, pressure does not need to be in the permit specified for this type of absorber. It should be noted that pressure drop across a packed absorption column is frequently monitored and regulated for operational reasons.

When a Venturi scrubber is used as the acid absorber, pressure drop across the scrubber will influence its performance. In that case, the pressure drop should be maintained at a level at least as high as that used during the test. Again, because pressure drop will be a function of L/G ratio and of the throat area (for a variable throat Venturi), there is little reason to expect major variability in this control parameter.

A type of acid absorber which is coming into more common use is a dry scrubber, which also is called a spray dryer. In this application, a slurry of caustic or lime is injected into the flue gas, and the HCl reacts

with it in suspension. The reaction products are captured as particulate in either a fabric filter or an ESP.

When the acid absorber is a dry scrubber, neither L/G ratio nor pH has technical meaning. In that case, the limits in the permit would have to be based on the ratio of the flowrate of the absorbent slurry to that of the acid gas, i.e., "the system should not be operated at a caustic or lime feed rate of less than X kg lime to Y kg HCl," where X and Y are determined from the compliance tests. This type of limit is difficult to enforce since the personnel evaluating the performance log would have to correlate the waste composition and feed rate with the caustic or lime feed rates to determine the acid production rate.

Continuous HCl monitors are becoming available which, based on EPA evaluations, appear to be sufficiently accurate and reliable to use as a stack sensor. The output of this type of monitor can be used to control the caustic or lime feed rates to a dry scrubber. If the applicant chooses to use a dry scrubber for a given application, the permit writers should consider requiring a continuous HCl monitor whose output regulates the scrubbant feed to the dry scrubber.

An HCl monitor is a highly desirable feature for any incinerator that burns chlorinated species. Its use can reduce the scrubber parameters e.g., pH and L/G ratios, that need to be monitored. For example, an HCl monitor in place at a facility that uses a packed-bed absorber for acid gas control could be used to control the absorber's operating parameters to ensure the proper HCl release as an alternative to limits on parameters such as L/G ratio, pH, and pressure of the nozzles. A continuous HCl monitor simplifies the permit, operation, and enforcement procedures. Its use should be encouraged for all but the smallest and simplest incinerators.

Particulate Formation and Control

To understand the method of setting limits on the control parameters for particulate emission control devices in a hazardous waste incinerator, it is useful to understand the major mechanisms of particulate formation. The following are the most common sources of particulate formation in an incinerator:

1. Ash in the waste and supplemental fuel
2. Volatilization of metals and salts
3. Abrasion and corrosion of the waste particles and the incinerator hardware, refractory, etc.
4. Suspended and dissolved solids in the quench and scrubber water

Particulate releases may be caused by other, transient mechanisms as well. For example, rapping of an ESP or the cleaning of the bags in a fabric filter can result in the release of a large amount of particulate. It is important to ensure that the trial burn runs include such cycles of potential high particulate release. The remainder of this discussion will deal with the mechanisms relating to the four sources of particulate emissions listed above.

The ash in the waste and in the supplementary fuel of an incinerator will be released during the combustion process. This ash will either be entrained by the solids in the incinerator and leave with the bottom ash, or it will be carried by the combustion gas into the APCE. In the case of an incinerator designed to burn solids, the ash content of the fuel is insignificant compared to the ash of the solid materials being burned; and this mechanism can be ignored in favor of some others discussed below. Liquid injection incinerators often do not produce a bottom ash. In that case, the ash in the waste and the fuel will be released as a particulate and carried through the incinerator into the APCE.

The composition of the inorganic fractions of the waste and fuel can be extremely important when the potential air pollution impacts from it are evaluated. Many compounds including metals such as tin, zinc, and lead and salts such as sodium chloride will turn into vapors at the flame temperatures in an incinerator. When the gases containing these vapors cool, as in a quench, these materials form very fine particulate often in the 1-μm-diameter or smaller range. This fine particulate is difficult for the APCE to remove. In addition, because of their small diameter, these particulates present a respiratory hazard. The potential health risk from many of these particulates is due to both their very fine size and their toxic metal content.

Abrasion of the wastes between the waste feed and the refractory is one mechanism for particulate formation, especially when waste, such as paper, has a large amount of friable ash; however, the particulate formed by this mechanism is usually very large in diameter and is readily removed by most types of air pollution control devices. The burning of solid wastes with these characteristics should trigger an evaluation of whether an APCE is needed.

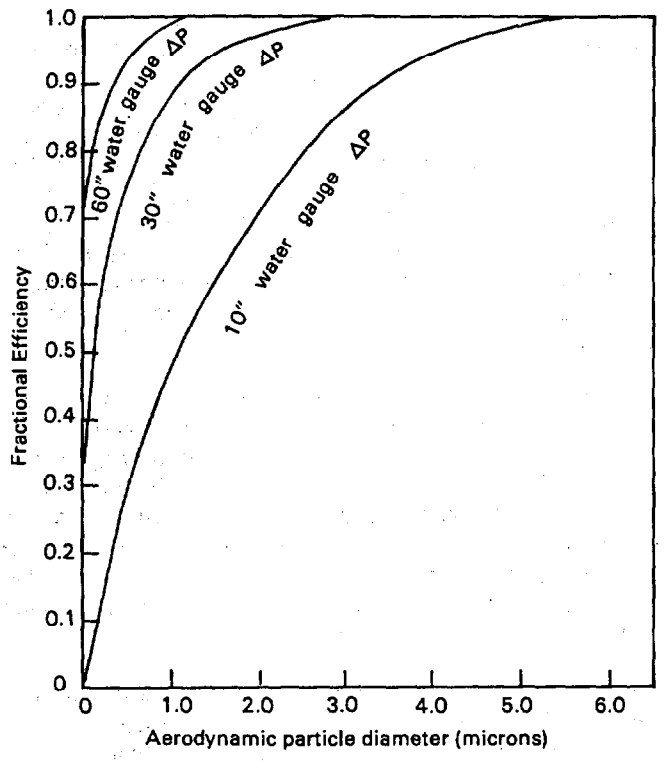
The final source of particulate emissions is not commonly considered when an incinerator is evaluated. When water is injected into the hot flue gas to cool it, a significant fraction of the water is evaporated. Any suspended or dissolved solids in the water are then released as a fine particulate. Often, the quench and scrubber water is recirculated or comes from a source of wastewater. Even if the water used for this purpose is once-through well water, it may contain a sufficient level of dissolved salts (hard water, even when softened, is an example) to release significant amounts of particulate. Limits on solids in the ash and water are discussed as

"minimum scrubber blowdown," under "group C" parameters.

The particulate that is produced by these mechanisms is controlled by the APCE. The most common type of APCE used on incinerators is an impaction scrubber, usually of the Venturi design. Other particulate control devices used are fabric filters, ESPs, and ionizing wet scrubbers (IWSs). The concept for each is discussed briefly in Appendix B and in greater depth in the references given in Appendix A.

The most commonly used APCE on an incinerator is a Venturi scrubber. This device is discussed above concerning acid gas removal. Figure 2-3 illustrates the effect of particle diameter and pressure drop across the scrubber on Venturi scrubber collection efficiency. As can be seen, very large pressure drops are required to achieve high collection efficiencies for submicron particles.

Figure 2-3 Effect of pressure drop on venturi scrubber efficiency.



The important control parameters that must be set to ensure that Venturi scrubber performance is maintained are pressure drop across the scrubber and L/G ratio. Both should be specified as minimums as determined by the trial burn. Variations in the values should not be large enough in most cases to warrant concern with variability of the results. As discussed earlier, pH of the scrubbant is only important if the Venturi is also used for acid gas removal.

Fabric filters (FFs) are not commonly used for particulate control in hazardous waste incinerators. This situation is changing as FF technology is modified to fit the new application. Fabric filters are sometimes used in conjunction with dry acid removal devices as discussed above. The particulate collection efficiency of an FF depends primarily on the following factors:

- Fabric type and weave
- Face velocity (gas flowrate divided by the surface area of the filters)
- Cake buildup on the filters
- Frequency and level of cleaning of the bags

It is normally only necessary to specify the minimum differential pressure across the FF as a permit condition. This parameter is needed in order to shut off the waste feed in case of a ruptured bag. This value should be set as the minimum pressure drop observed during any successful trial burn. When it becomes necessary to replace one or more bags in the fabric filter, the bags can often be pre-coated by artificial means or by burning auxiliary fuel. If precoating will not be feasible, a lower minimum pressure drop can usually be specified for the cutoff for a relatively short period of time (under an hour) until the new bags are coated with filter cake. The particulate removal efficiency of new bags is somewhat lower until they have been coated with filter cake. Thus, it may be desirable to reduce the ash feed or restrict the amount of metal or fume-forming wastes during this period in cases where there is concern about excessive particulate or metals emissions.

Limits may be considered on other parameters, including those listed above, but they normally are not needed. To illustrate, consider the consequences of setting limits on the frequency of cleaning and the upper pressure drop across the bags. The point at which the bags are cleaned (by shaking, for example) is typically determined by the pressure drop across the FF. As the filters accumulate dust, the pressure drop increases. When it reaches a predetermined upper value, the cleaning cycle is initiated. A limit on the maximum pressure drop could identify problems in the cleaning cycle such as defective equipment or blinding of the filter media but normally is not necessary.

An excessive pressure drop will not normally affect APCE particulate removal performance adversely. However, it may result in bag rupturing or "caving in,"

which would then release excessive particulate. When such failure occurs, the low pressure drop cutoff would shut down the waste feed and the incinerator in an orderly manner. In theory, this scenario could be handled by the low pressure cutoff limit; however, a waste feed cutoff when the pressure rises above a maximum specified by the equipment design provides additional time prior to failure and is highly recommended when particulate removal efficiency is a critical parameter.

The ESP is a well-established device for particulate control. It is usually used only in very large incinerator installations. For a given installation and fixed particulate loading, its performance is determined by the voltage and power consumption in kilovolt-amperes (KVA) approximately equal to kilowatts (KW). Alternatively, a minimum value can similarly be required for the current in mA and the power consumption in KVA. The permit should specify a minimum value for the KVA as established in the trial burn. It should be noted that, at least in theory, the current can go to zero when the particulate loading on the input gas stream is very low. This is not common because an ESP would normally not be used for installations where it is only required occasionally because of its high capital cost. If such a situation is encountered, additional guidance should be sought. One possible approach in this case is to maintain the minimum voltage but suspend the minimum current requirement under selected operating conditions.

The IWS combines the collection principles of the ESP with acid gas removal of a conventional packed-bed scrubber. In the IWS, the incoming particles are charged in a small ionized section with high voltage DC power. Charged particles are scrubbed in the packed-bed section. During the operation, the KVA usage will vary with gas composition. The only two factors that need to be regulated are minimum liquid flowrate (L/G as in an absorber) and minimum DC voltage. Both of these should be the minimum measured during the trial burn.

2.2 Group B Parameters

The group B parameters are those which do not require continuous monitoring and, thus, are not interlocked with the waste feed cutoff. They are typically monitored by sampling and analyzing the wastes and controlling the quantities of wastes being fed and other operating parameters for the incinerator. The results of these monitoring activities are maintained in an operating log which is used to ensure that the worst-case conditions established on the basis of the trial burn are not exceeded.

Three classes of parameters are included in group B. The first relates to the organic hazardous constituents that the incinerator is allowed to burn and to the selection of those (POHCs) that will be measured during the trial burn to verify incinerator performance. The second limits the amount of halides and ash that the waste is permitted to contain so that the APCE is not overloaded. The third regulates the quality of the water used for the scrubber and quench.

As can be seen, the group B parameters are very closely connected to the group A parameters discussed earlier. They are actually not different when the impact on incinerator operation is considered. They are differentiated here largely because the group B parameters do not require interlocks with waste feed cutoffs as do the group A parameters.

A category of parameters that are not addressed under the incinerator regulations but may at times be important are those which influence the level of solids burn-down that the incinerator achieves. This is normally a function of the solids residence time in the PCC and it will affect the quality of the ash produced. This can be important in situations such as:

- The applicant requests that it be "delisted"; that is, tested and shown not to be hazardous.
- The waste is subject to land disposal restrictions under 40 CFR 268.
- The incinerator is used to destroy toxics contaminating a material, such as soil, for the purpose of returning it to a site which is not necessarily a hazardous waste disposal facility.

In all of these cases, the incinerator is intended to achieve a specific, maximum level of contaminant in the residues or ash. This may be achieved during operation by setting limits on the maximum kiln rotational speed at a value where the ash was determined to meet the applicable criteria. As discussed above, these conditions are not specifically required under the incinerator regulations, but can be included in the permit to address other regulations, or when determined necessary to minimize risk from contaminants remaining in the residues, under the authority of the "omnibus" provisions of Section 3005(c)(3) of RCRA, as amended.

2.2.1 POHC Selection and Incinerability Ranking

The type and amount of POHCs in the waste are very important to the overall performance of the incinerator. This information is typically specified by the applicant when the waste streams that are to be burned are identified. The only permit condition that needs to be placed on POHCs is one which specifies that no hazardous organic constituents which were not represented in the waste burned during the trial burn may be burned in the incinerator during subsequent operation. The condition should also specify that only those waste streams that contained

the specified type of POHC during the trial burn may contain it during operation.

For example, if a POHC representing chlorinated aliphatic compounds only exists in one type of waste stream during the test, it cannot be introduced in another one. Types of waste streams refer to categories of waste such as high BTU, low BTU, aqueous, sludge, or solid. A corollary to this limitation is that no POHC different from that used during the trial burn can be introduced into a combustion chamber. The reader is referred to Sections 2.4 and Chapter 4 for further discussions on how permit conditions on POHCs are to be treated.

According to 40 CFR 264.342(b)(1), "One or more POHCs will be specified in the facility's permit from among those constituents listed in Part 261, Appendix VIII of this chapter, for each waste to be burned. This specification will be based on the degree of difficulty of incineration of the organic constituents in the waste and on their concentration or mass in the waste feed . . . ," and "Organic constituents which represent the greatest degree of difficulty of incineration will be those most likely to be designated as POHCs . . . ."

To satisfy this requirement, the permit writer must do the following:

1. Designate (or approve the applicant's designation) the POHCs that will be measured during the trial burn
2. Based on the results of the trial burn, identify those organic compounds that may be burned in the system during operation, i.e., those that are "less difficult" to incinerate

To satisfy this requirement, it is necessary to have a method of ranking Appendix VIII compounds into an order of "degree of difficulty of incineration." Such a ranking is commonly referred to as an "incinerability ranking" or "incinerability index."

At present, many EPA Regional Offices use a ranking system based on the heat of combustion of the Appendix VIII organics as a guide for selecting those POHCs that are the most difficult to incinerate. This system is described in the *Guidance Manual for Hazardous Waste Incinerator Permits* (3). The higher the heat of combustion of a compound, the easier it is assumed to be to incinerate. This procedure is presently under review, and data now being gathered by the University of Dayton Research Institute (UDRI) indicate that more appropriate ranking systems may exist. A draft of the UDRI Ranking system (called the TSLoO2 ranking) and the rationale for its use is presented in Appendix D. This work is still under review.

Incinerability indices other than heat of combustion can be used without a regulatory change because the regulations do not mention a specific incinerability hierarchy. This was done to allow flexibility in POHC selection. At the time OSW developed the current regulations, it was recognized that changes may occur as new data became available. Thus, thermal stability at low oxygen may be used as a criterion for POHC selection. Additional considerations that can be applied to POHC selection include concentration of the constituent in the waste stream (the higher the concentration, the more likely the compound is to be chosen as a POHC), toxicity (choosing a particularly toxic compound in the waste to be sure it is destroyed), and compound structure (choosing a compound to represent each of the structural classifications of compounds such as aromatics and chlorinated compounds in the waste). Finally, availability of sampling and analysis methods for potential POHCs and whether it is a common PIC are other considerations.

When the thermal stability ranking is used, it is recommended that POHCs be chosen from those compounds for which actual experimental data exist. Because the ranking will be changing as additional laboratory testing is done, compounds fairly close together in the ranking should not be considered significantly different with respect to incinerability. Therefore, when there are testing or availability problems with the preferred POHC, it would be reasonable to choose another POHC from the same class.

Some of the compounds in class I of the TSLoO2 ranking present sampling and analysis problems. For example, reactive compounds such as hydrocyanic acid and cyanogen and water soluble compounds such as acetonitrile would require either special sampling techniques or alternative POHCs. Sampling and analysis problems should not be encountered with compounds such as chlorinated benzenes. Guidance on POHC selection will be issued in the near future.

2.2.2 Maximum Halides and Ash

As discussed in Section 2.1, the amount of acid-forming compounds (usually halides) will affect HCl emissions, and ash in the wastes and the amount of dissolved and suspended solids in the quench and scrubber water will affect the particulate emissions. The permit conditions must include upper limits on these parameters. The maximum amount of acid-forming compounds which may be burned in the incinerator during normal operation should be set at the maximum that was burned during the trial burn (assuming the trial burn demonstrated compliance with performance standards). Care must be taken to ensure that when more than one acid-forming material is burned, the condition reflects the amount of total alkalinity required to remove them. For example, in a case where sulfur- and chlorine-bearing compounds are burned, sulfur will consume

two equivalents of alkali while chlorine will consume only one. This situation is uncommon, but the limit should be written to include these factors.

Limits are set on the maximum amount of ash in the waste that may be fed to an incinerator to avoid emissions of excessive particulate and overloading the APCE. For the purpose of this analysis, ash can be defined as any constituent of the waste that, when properly burned, forms a particulate in the stack. These can include a number of inert materials such as sand, dissolved compounds such as sodium chloride or inorganic elements, metals, and metal salts.

In general, the total amount of ash that may be burned in an incinerator is limited by specifying the maximum total ash feed rate that met particulate emissions limits during the trial burn. There are times, however, when it is necessary to place restrictions on specific components of that ash. The following discussion outlines some of the circumstances when such restrictions should be considered.

For example, consider the following hypothetical waste feed:

Waste Stream	Ash Components, kg/hr
A	10 - SiO_2
B	5 - NaCl

Silicon dioxide (as opposed to silicanes or silicones which are organosilicon compounds that can form a fine particulate fume) is not volatile under the conditions of a typical incinerator; sodium chloride can volatilize and form a fine particulate. Assume the trial burn demonstrates acceptable particulate releases at these maximum feed rates of the two compounds.

Based on these tests, the total ash feed rate normally could be limited in the permit to 15 kg (33 lb)/hr. If, however, the amount of sodium chloride is increased and silicon dioxide decreased during operation, an increase in the fine particulate loading to the APCE and in the total released particulate could occur. If this release appears to be of concern, the permit condition might specify a total maximum NaCl feed of 5 kg (11 lb)/hr as well as a limit on the total ash feed rate. If B is the only waste stream likely to contain NaCl, that limit could be converted to a maximum feed rate and NaCl concentration for waste stream B. While this conversion reduces operator flexibility to blend wastes, it also reduces the need for waste analysis during operation and makes the ash limit easier to enforce.

Typically, fine particulate can form from ash containing the following categories of materials:

- Sodium salts, especially sodium chloride
- Volatile metals such as mercury, lead, tin, antimony, arsenic, and chromium
- Inorganics whose oxides are volatile under the conditions of the combustion chamber
- Silicon-organic compounds such as silanes or silicones

When these conditions are encountered, the effect of an increase of the fine particulate loading on the APCE should be explored, and, if necessary, restrictions on the amounts of such components of the ash should be included in the permit conditions. These restrictions should be considered especially when the waste includes Appendix VIII metals. Feed limits for individual metals should be set where metals emissions are of concern as outlined in *Guidance for Permit Writers for Limiting Metal and HCl Emissions From Hazardous Waste Incinerators* (4).

Another important parameter related to particulate emissions is the APCE inlet gas temperature. Certain types of particulate, especially the fine particulate discussed above, form in the incineration process. They form as gases in the combustion zone and condense as the temperature decreases downstream. The amount of condensed particulate is a function of the temperature. As the temperature to the inlet of the APCE increases, less of this "condensible fraction" enters the APCE as a particulate subject to collection. It can condense as a particulate downstream, typically in the stack. Under this scenario, as the inlet temperature to the APCE increases, particulate emissions would also increase. As a result, the maximum APCE inlet temperature should be the maximum measured during the trial burn. To protect the APCE from damage due to excessive temperature, this level should not be higher than the manufacturer's specification for maximum temperature.

2.2.3 Maximum Batch and Container Size

The maximum size of batches or waste containers fed to the PCC is recommended as a group B parameter because of the effect of the instantaneous waste feed rate on the ability of the incinerator system to maintain steady-state operation and minimize phenomena such as instantaneous oxygen deficiencies, puffing, and flame quenching. This parameter is discussed along with maximum waste feed rate in Section 2.1.5.

2.2.4 Minimum Particulate Scrubber Blowdown

The final group B parameter to be discussed is the scrubber blowdown. As discussed in Section 2.1, it is

possible for particulate to be produced in the quench and even in the scrubber. The greater the amount of solids present in the quench and scrubber water, the greater the potential for particulate to be produced. The operator of an incinerator controls the quality of the scrubber water by varying the fraction of the water leaving the scrubber that is recycled back to it and the fraction being "blown down" or discharged. The larger the blowdown, the cleaner the scrubber and quench water tend to be. The permit writer limits the degree of contamination of the scrubber and quench water by specifying the minimum amount of blowdown during operation.

Clearly, blowdown is only an issue when the scrubber and quench utilize recycled water; for example, when the (liquid) water leaves the scrubber and quench is collected in some form of reservoir such as a tank, sump, or pond where it is partially treated and neutralized. To control the quality of the water in the reservoir, a fraction of it is sent to the sewer or other discharge (the blowdown), and the remainder is recycled to the incinerator. In some incinerators, the blowdown can come from a reservoir in the scrubber or quench equipment. In cases where once-through water enters the scrubber, "blowdown rate" has no meaning, and no limit needs to be set for this parameter.

The minimum blowdown rate for the incinerator cannot be easily determined directly from the trial burn. If the operator starts the trial burn with clean water and then uses the normal blowdown rate, the scrubber water will start clean and then become contaminated with dissolved and suspended solids. The trial burn can, therefore, show a satisfactory level of particulate removal, but this could be due to a transient phenomenon associated with this technique.

One method of reducing the probability of such an occurrence is to design the trial burn so that the system is operated for a sufficient time before the tests to ensure that the quality of the water in the sump has reached steady state. For example, the applicant could be required to have not cleaned the sump or changed the water for a specific pretest period.

Another approach would be to specify the blowdown rate such that the combined dissolved and suspended solids in the scrubber and quench water pond or sump do not exceed the mean determined during the successful trial burn with the highest solids in the quench and scrubber water.

2.3 Group C Parameters

Recommendations for group C parameters are based on the need to ensure that incinerator operation adheres to recommended combustion and APCE operating practices. These practices, which include waste liquid and slurry burner settings, APCE inlet gas temperature, and maximum heat input for each incinerator chamber consistent with design specification, are based strictly on design limits and equipment manufacturer specifications. Thus, permit conditions for these parameters are not based on trial burn conditions, and compliance verification does not require continuous monitoring, although maintaining records in the facility operational logs is necessary.

2.3.1 Burner Settings

The burners in liquid injection and afterburner chambers should be set to operate according to manufacturer design and operating specifications. These settings should also be consistent with the ability of the burners to atomize the liquid waste properly and promote efficient mixing. These specifications vary according to the waste burned, burner and nozzle type, and method of atomization. To restrict the operation of these burners to trial burn settings possibly would constrain the operation of the facility and limit the types of wastes that can be incinerated, which is not the intent of the permitting procedure. The permit should allow sufficient operational flexibility in waste viscosity, burner pressures, and turndown limits as long as these settings are compatible with burner manufacturer recommendations. Additionally, a minimum waste heating value should be set in a permit for burners providing 100 percent of the heat input to a liquid or afterburner chamber. A liquid waste with a LHV of 11,600 kJ/kg (5,000 Btu/lb) should be sufficient to maintain a stable flame consistent with good operating practices.

2.3.2 Total Heat Input

The total heat input requirement states that the incinerator should not be allowed to operate beyond its design capacity. Typically, maximum heat input and maximum temperatures are not important considerations for the permit writer because facilities are rarely subjected to operation outside manufacturer design specifications. Because such operation can result in refractory damage, it may be self-limiting. To exceed them will also result in exceedance of other imposed permit conditions such as the maximum waste feed rate and combustion gas velocity. Thus, compliance with the incinerator design heat input capacity is considered good operating practice and should be a permit condition for the facility as long as the limit imposed is consistent with the other control parameters. The maximum total heat input would normally be the manufacturer's specification for the equipment; however, if a greater heat input is successfully demonstrated during the trial burn, it may be specified instead.

2.3.3 APCE Inlet Gas Temperature

Typically, some reduction in the temperature of the incoming gases is required to comply with material specification of the downstream equipment. For FFs, the maximum inlet temperature is specified by the

type of cloth material. This temperature limit can vary between 120 and 290°C (250 and 550°F) for an FF; for a dry ESP, the inlet gas temperature affects the particulate resistivity and, thus, the performance of the ESP. In this context, it is difficult to specify a maximum inlet temperature because this parameter depends on the type of control equipment and its manufacturer. Therefore, it is recommended that the permit writer obtain the equipment design specifications from the permit applicant and that the operating temperature be defined according to those specifications. It may, however, be necessary to set the maximum temperature limit at a lower level, as discussed in Section 2.2.2 (concerning fine particulate formation) to assure that all particulate forming fumes condense prior to entering the APCE.

2.4 Other Parameters

Below are listed a number of parameters that were considered but not selected as control parameters:

- Minimum oxygen concentration
- Maximum gas volumetric flowrate, maximum velocity, or minimum residence time in each combustion chamber
- Maximum volatile content of containerized waste
- Minimum total heat input to each combustion chamber
- Maximum kiln slope
- Maximum kiln rotational speed
- Minimum liquid flow to the Venturi scrubber

The rationale for not selecting these parameters is discussed below. It is recommended that the permit writer consider this discussion and note that to impose more permit conditions may not necessarily improve compliance since many parameters interrelate and each condition has an effect on the operational flexibility of the unit. However, if the unit is unique in some manner, some restriction on the above or other parameters may be desirable. This contingency, while unlikely with fairly standard incinerator designs, cannot be ruled out in all cases. The permit writer is urged to seek assistance from the Office of Solid Waste when an unusual design appears to require that conditions be set for any parameters not specifically recommended in the guidelines.

While the complete combustion of POHCs and PICs requires the presence of sufficient oxygen, there are several major arguments against setting minimum limits on oxygen. The most important reason is that it is difficult to pick one oxygen level that is satisfactory for the combustion of a wide variety of wastes. An oxygen limit based on one type of waste would not necessarily be adequate for destroying other wastes. While it may be theoretically possible to determine a suitable "worst-case" feed to test oxygen demand during the trial burn, it is extremely difficult to do so for facilities that burn a range of waste compositions because of the lack of detailed knowledge on the mechanisms of waste destruction. Fortunately, it is unnecessary to set such a limit for the following reasons:

- Insufficient oxygen results in a rise in CO concentration. Because CO is already a permit parameter, to limit oxygen as well would be redundant.
- It is difficult to continuously and reliably measure oxygen concentration at combustion chamber exit conditions; thus, oxygen measurements are normally made at the stack. Often, air inleakage occurs between the combustion chamber exit and the stack. The oxygen in this leakage air can mask oxygen deficiencies in the combustion chamber, thus limiting or negating the value of such measurements.
- Several combustion chambers are designed to operate under oxygen-starved (pyrolytic) conditions with additional air supplied in downstream combustion equipment. Minimum oxygen requirements for these pyrolytic chambers would be inappropriate and unenforceable.

To monitor residence time, it is conceptually preferable to monitor the maximum gas flows or velocities in each chamber rather than the flue gas flowrate or velocity at the stack, which is recommended in Section 2.1.3. For the majority of incinerators, however, the gas flow in the stack or the duct leading to the APCE correlates reasonably well with that in each chamber, especially in the SCC, and it is far easier to measure. As a result, the gas flows in each chamber do not need to be measured in most circumstances.

It should be noted that in cases when there is reason to believe that a significant amount of air infiltration or other gas addition occurs between the SCC and the point at which the stack velocity is being measured, it may prove necessary to add some form of additional monitoring of gas velocity. The permit writer is advised to seek outside guidance in these cases.

The maximum volatile content of containerized waste was not selected as a control parameter because it is difficult to measure during operation and because other control parameters will be impacted should a highly volatile material be in a container. An excessive amount of volatile material in a container of waste will result in a rapid release of hydrocarbons. These releases will manifest themselves in several ways.

First, the pressure in the PCC will increase. Second, the added hydrocarbons will starve the flame and increase the CO level. If neither of these increases result in the triggering of the alarms or automatic shutoffs, the increases can be deemed to be within the capability of the system. If, however, the limits on these two parameters is exceeded, an automatic shutoff of the waste feed will be triggered. In either case, there is no need to regulate the volatile content of the containerized waste.

While these guidelines do not recommend that the maximum volatile content of the waste be set as a permit condition, it is recognized that to feed excessive amounts of highly volatile materials in containers is not desirable. It is suggested, therefore, that the type of containerized waste chosen for a trial burn contain the largest amounts of volatiles expected in continuous operation.

The minimum heat input to each combustion chamber was not selected as a control parameter as it is very difficult to measure during normal operation and it is, in reality, specified by the minimum temperatures of each combustion chamber. If the heat input to a combustion chamber is reduced, so, also, is the temperature. If the heat input is reduced too much, a temperature cutoff will occur. There is normally little need to regulate both parameters.

The kiln slope and rotation speed were considered but not chosen as control parameters. The slope was not chosen because it is fixed at the time of construction. It cannot be changed (except, conceivably, in very unusual designs) without rebuilding the incinerator, which would require a new permit or a modification to the existing one. The kiln rotational speed has a major influence on the quality of the ash and a minor one on the particulate emissions. It was not chosen because there are, at present, no incinerator regulations pertaining to the quality of the ash and because its impact on the particulate emissions is small. The ash quality, while not addressed under the incinerator regulations, can be important if the applicant requests that it be "delisted" or subjected to other requirements as discussed in Section 2.2. Then, limits of the maximum kiln rotational speed may be necessary.

A kiln's rotation rate also can have an impact on the particulate released from the waste. An increase in kiln rotation will result in the "grinding" of the ash and its increased release into the flue gas. Fortunately, this type of particulate-forming mechanism results in large particulate which can easily be removed by a well-designed APCE. In almost all cases, the kiln would have to rotate much faster than prudent operation dictates to generate sufficient particulate to overload the APCE. Therefore, there is little need to restrict kiln rotation rate for this purpose unless incinerator particulate emissions during the trial burn are close to the maximum allowable.

The final parameter that was considered and not chosen as a control parameter is the minimum liquid flow to the Venturi scrubber. Minimum L/G ratio, which is closely related, was selected instead. Venturi scrubber efficiency can be related to the L/G ratio and the velocity through the Venturi. Because the pressure drop across a Venturi is a function of the liquid and the gas flow and because the gas flow and velocity can be related to the flue gas flowrate, permit limits on the minimum pressure drop across a Venturi and maximum flue gas flowrate are sufficient. There is no need to set a limit on the minimum liquid flow to the Venturi scrubber as well.

2.5 References

1. *Engineering Handbook for Hazardous Waste Incineration.* EPA Publication SW-889. September 1981.2.
2. *Hazardous Waste Incineration Measurement Guidance Manual.* Midwest Research Institute. 1988. (Draft under EPA review.)
3. *Guidance Manual for Hazardous Waste Incinerator Permits.* Mitre Corp. NTIS PB84-100577. July 1983.
4. *Guidance for Permit Writers for Limiting Metal and HCl Emissions From Hazardous Waste Incinerators.* Versar, 1988. (Draft under EPA review).

[A brief description of each of these documents is presented in Appendix A.]

CHAPTER 3
Setting Permit Conditions

Chapter 2 discussed the control parameters for an incinerator and how they interrelate and affect the performance of the incinerator system. This chapter discusses how the limits on the operating parameters are determined and converted to the conditions in the permit. The same strategies that are used for setting permit conditions are also used to determine the conditions such as temperature and waste feed rate at which the incinerator should be operated during the trial burn. In both cases, it is necessary to identify a range of conditions broad enough to allow the operator sufficient "elbow room" in which to operate but still ensure that the incinerator operation complies with the environmental regulations, i.e., DRE, HCl emissions.

The conditions in a permit for an incinerator could encompass many more factors than those discussed in Chapter 2. These can be related to other features of the installation; for example, the presence of an emergency vent stack, or the burning of waste materials which are unusually toxic or of extreme concern to the local population. This handbook only discusses the setting of permit conditions on the system and operating parameters. It is limited to those system and operating parameters discussed in Chapter 2. The reader is referred to the appropriate manuals listed in Appendix A for guidance on how to set other permit conditions.

This chapter begins with a discussion of permitting approaches that may be used by the applicant. It will then discuss how the control parameters covered in Chapter 2 interrelate and how variations in their trial-burn values should be handled. It will end with specific guidance for setting permit conditions for the permit approach used. First, however, it is worthwhile to define several terms relating to the trial burn.

A trial burn is the testing that is done to determine whether an incinerator can meet the performance standards and to determine the operating conditions that should be set in the permit. A "test" must be done for each set of operating conditions for which the applicant desires to be permitted. Three replicates or "runs" must be performed for each test. One set of conditions constitutes a test; the overall trial burn consists of one test for each set of operating conditions. Each run of a test must be passed for the incinerator to be permitted to operate at that set of conditions. If the permitting authority determines that there is good cause, one run may be thrown out provided that the permit conditions do not include any operating conditions at which the incinerator was shown to be out of compliance with the performance standards.

3.1 Permitting Approach

Three approaches to permitting incinerators are suggested in this guidance. Table 3-1 summarizes them and highlights some of the major advantages and disadvantages of each. The approach that should be used for a given incinerator is determined almost completely by the number of different combinations of wastes and waste types that would be burned at any one time. The three approaches are called:

1. single waste/single operating condition -- single point
2. multiple waste/multiple operating conditions -- multiple point
3. multiple waste/single operating condition -- universal

The third approach is the most commonly used and can, in reality be used for all incinerators. The single point approach is a subset of the universal approach. It is presented as a separate method of setting permit conditons because it can be used to permit a relatively common category of simple incinerators, those that burn only one set of well-defined wastes. The multiple point approach is a relatively uncommon method of setting permit conditions; it can be considered as a variation to the single point approach.

The first approach, the "single point approach," is the least complex. It applies to incinerators that burn only a well-defined set of waste streams and operate under unvarying operating conditions. Hence the name "single waste/single operating condition." These dedicated units are typically located at the site where the waste is generated and operate in an on-off mode, where "on" is defined by a relatively

Table 3-1. Permitting Approaches

Objective	Approach	Advantages	Disadvantages
1. Single waste/single conditon "single point"	Determine one set of operating parameters based on trial burn tests on a series of progressively worse conditions (single point)	• Closely related to conditions tested • Well-defined operating conditions	• Constraining
2. Multiple waste/multiple condition "multiple point"	Determine multiple sets of operating conditions, each applicable to a specific mode of operation (multiple point)	• Closely related to conditions tested • Well-defined operating conditions	• Constraining • Potential redundancy • Requires detailed support documentation • More complicated to enforce
3. Multiple waste/single condition "universal"	Determine one set of universal operating conditions (universal conditions)	• Operational flexibility • Easily enforced	• Complex trial burn • Requires greater engineering evaluation of trial burn data

constant composition, waste feed rate and operating temperature. An example of a facility that could be permitted with this type of approach is one which burns a specific high BTU waste, a specific low BTU waste and a specific sludge. Each of these waste streams come from one or two well-defined processes. While the composition and amount of each waste stream could vary, it only does so within narrow bounds. No new hazardous constituents (whether organic or metal) are introduced.

For these facilities, the permit objective may be satisfied by setting limits on the specific type of waste to be incinerated and on the operating parameters. The permit conditions are based on one trial burn test. The wastes burned during this test are the actual wastes normally burned possibly fortified with some of the POHCs for ease of sampling and analysis. During operation, no changes in the waste composition or source are allowed.

The second approach, called here the "multiple point" approach, is to set multiple limits for ech operating parameter: each limit is based on individual test conditions or modes of operation investigated in the trial burn. This approach is typically best suited for incinerator facilities dedicated to treating a well-defined set of hazardous wastes of uniform composition; for example, when drummed waste is burned with liquid wastes A and B, then one set of operating conditions apply. When bulk solids are burned with wastes C and D and waste gas, then a second set of operating conditions apply. As can be seen, the multiple point approach is equivalent to setting a series of single point conditions for the incinerator when it burns a discrete, consistent mix of wastes. Each mix of wastes must be defined in the permit.

The conditions for multiple point permits are readily defined, but the enforcement agency needs to be aware of the operating mode to verify compliance with operational limits. For example, to verify that the incinerator is operating at the proper conditions for a given mix of wastes, it is necessary to check the log of the waste types being fed at the time and compare it to the logs of the control parameters. Nevertheless, because the permit conditions are based strictly on the results of the trial burn, the multiple point strategy is recommended whenever the incinerator will be operated at more than one condition. There are, however, situations when neither approach is appropriate. Thus, a third approach is suggested below.

The third approach, referred to here as the "universal approach," is to develop one set of operating conditions which allow a given facility to burn a relatively broad range of wastes. Hence the name, "multiple waste/single condition." This approach, while being the most complex, offers the greatest operating flexibility. It is, hence, the most commonly used one. The approach requires that the trial burn be carefully designed to represent the worst case mix of wastes and operaing conditions that the incinerator could conceivably encounter during operation. One set of operating conditions is then set based on that test. This approach allows the incineration of a relatively wide variety of wastes but at conditions which are, generally, more severe than most of these waste streams require. One, in effect, buys operating flexibility by requiring that the operating conditions be sufficiently severe to burn the worst-case combination of wastes.

The greatest difficulty in using the universal permitting approach is designing the trial burn. If at all possible, it should be structured to achieve with one test the target limits for maximum feed rates for all feeds, minimum temperature, and maximum combustion gas velocity. This may require water injection or exceptionally careful control of the supplemental fuel compositions and feed rates during the tests. Energy and mass balance calculations with a computer program as described in Appendix E may be required to identify the condition that best satisfies the worst-case conditions.

If it is impossible to find a worst-case condition for the mix of wastes the applicant wants to burn, it may be necessary for him to accept less than optimum target limits for the control parameters, or some

restrictions on waste feed rates. The added complexity is well worth the increased effort in the design of the test as it results in a single set of permit conditions that are directly based on the trial burn without any need to "massage" the data.

It is especially important when the trial burn is this complex (although this should be done in all cases) that the permit writer and applicant have a clear understanding of the permit conditions that will result from a successful trial burn at the conditions specified. This gives the operator the option of changing the test plan to achieve workable conditions.

In general, the simplest strategy that can be used to set permit conditions that still allow reasonable operating flexibility is the most desirable. As such, a single or multiple point strategy is preferable whenever the waste types burned justfy it. When the waste characterization does not allow it, the universal strategy can be used.

At times, the applicant may want to conduct tests at more than one operating condition for "insurance." For example, if he wants to operate the incinerator near the minimum temperature that will do the job, a series of tests could be conducted at progressively lower temperatures. This situation is fundamentally the same as the case when a test is conducted at only one condition and is clearly acceptable as long as, in the judgement of the permit writer, no dangerous situations occur when the incinerator is pushed to its design limit. The permitting strategy in this case is the same as for the single point strategy.

If a facility cannot achieve the critical target limits for all the contol parameters simultaneously, two or more tests will be required. At that point, the question becomes whether a multiple point or universal permitting strategy is preferable. The discussions below address the advantages and disadvantages of each strategy. First, however, it is necessary to discuss the interrelationship between the control parameters and how to treat normal data variability.

3.2 Interrelating Control Parameters

In many cases, the guidelines for setting permit conditions from certain control parameters may be in conflict. For example, as the temperature is raised, the gas density decreases, and the gas residence time falls. Limits cannot, therefore, be set independently on temperature and gas flowrate since they interact so closely. Most of the parameters discussed in Chapter 2 are interrelated to a certain degree. To address this interrelation in an orderly fashion so as to avoid detailed system modeling calculations, it is convenient to order the control parameters in the following groups:

1. Control parameters set from trial burn data that are related to waste destruction (Group A)
2. Control parameters set from trial burn data that are related to APCE performance (Group B)
3. Control parameters that are independent of trial burn data (Group C)

These parameters are listed in order of importance, i.e., item 1 is more important than item 2, which is more important than item 3. Individual control parameters within each group are listed in Tables 3-2, 3-3, and 3-4, respectively.

It is recommended that limits be set on the control parameters according to this hierarchy. That is, the permit writer should first establish the limit for the first parameter in group 1, i.e., minimum temperature in each combustion chamber, then proceed down the list, making sure that the limit on each parameter is consistent with the limits on those above it.

Table 3-2. Waste-Destruction-Related Control Parameters Set From Trial Burn Data

Type	Parameter
A	Minimum temperature at each combustion chamber exit
A	Maximum CO emissions
A	Maximum flue gas flowrate or velocity
A	Maximum pressure in PCC and SCC
A	Maximum feed rate of each waste type to each combustion chamber
B	Maximum size of batches or containerized waste

3.3 Treatment of Variations In Data

Setting final permit conditions from actual data is somewhat different from setting tentative limits based on a trial burn plan because the permit writer must deal with data variability. Data can vary in three ways:

1. Variations with time within a single run
2. Variations between repeats of the same nominal operating conditions
3. Variations due to changes in the operating conditions about the nominal operating point

Incinerators do not operate under totally steady conditions. Thus, most parameters vary somewhat with time over the course of a single test run. The

Table 3-3. APCE-Performance-Related Control Parameters Set From Trial Burn Data

Type	Parameter
A	Minimum differential pressure across particulate venturi scrubber[1]
A	Minimum L/G and pH to absorber[1]
A	Minimum caustic feed to dry scrubber
B	Minimum scrubber blowdown rates or maximum total solids in scrubber liquid[1]
A	Minimum kVA settings to ESP (Wet/Dry) and kV for IWS[1]
A	Minimum pressure differential across a FF[1]
A	Scrubber nozzle pressure
B	Maximum total halides and inorganic ash feed rate to the incinerator system
B	Minimum particulate scrubber blowdown rate

[1] Select as applicable to APCE system.

Table 3-4. Trial Burn Independent Control Parameters

Type	Parameter
C	Maximum total heat input for each chamber
C	Liquid injection chamber burner settings • Maximum viscosity of pumped waste • Maximum burner turndown • Minimum atomization fluid pressure • Minimum waste heating value (if applicable)
C	APCE inlet gas temperature

effects of this type of variation on the specification of permit limits are dealt with in Chapter 2.

Random factors make it impossible to repeat exactly the same nominal operating point. Results from repeats of the same nominal operating point should be averaged to yield a single mean value for each control parameter and other performance. For example, three repeats of the same nominal operating point yield SCC temperatures of 1,100, 1,120, and 1,090°C (2,010, 2,040, and 2,000°F) and DREs of 99.996, 99.998, and 99.990 percent, respectively. The composite temperature for that nominal operating point would be [(1,100 + 1,120 + 1,090) ÷ 3] 1,103°C (2,017°F), and the composite DRE would be [(99.996 + 99.998 + 99.990) ÷ 3] 99.994 percent. It should be noted that DRE values from individual runs at a nominal operating point may not be averaged to demonstrate compliance; for example, 99.99 percent DRE must be achieved for each run. The calculation of a composite DRE for a nominal operating point is shown only for use in the equations presented in Section 3.6.1 for interpolating between two nominal operating points.

How closely must the data match to qualify as a repeat of a nominal data point? No criteria are recommended. Variations are unacceptable only if they result in a failure to meet performance standards. For example, if the last repeat in the example was performed at 1,000°C (1,830°F) and resulted in a DRE of 99.94 percent, that data point would be unacceptable because it resulted in a DRE lower than the 99.99 percent performance standard. In such a case, the permit writer must exercise judgment on the proper course of action. A possible course is to not use the "failing" condition as a permit limit. For example, set the minimum temperature above 1,000°C (1,830°F). An alternative course of action may be to require that a better repeat be performed. Note that a "failing test" is defined as one in which any one of the three runs did not achieve the specified performance goal. The mean DRE cannot be used to show compliance if all runs did not show compliance.

3.4 Single Point Approach

The single point approach is the least complex permitting strategy suggested here. It is appropriate for incinerators that burn one type of waste with relatively constant properties. Typically, this type of incinerator is integrated into a process and destroys the one waste stream to which it is dedicated.

Single point permit conditions are defined as the codification of the minimum demonstrated operating and system conditions resulting in satisfactory performance of the incinerator. They are set from one trial burn test (three runs minimum) with each of the operating parameters established as described in Chapter 2. The order of setting the operating parameters should be that listed in Section 3.2, although the order is not usually important, since the trial burn showed the operating conditions to be consistent with each other and realistic.

3.5 Multiple Point Approach

A straightforward variation on an incinerator which burns only one waste is one that burns a number of well-defined sets of wastes. Typically, these wastes will be burned in combination; for example, a caloric (high Btu) waste will be burned along with an aqueous waste stream. If the types of wastes to be burned can be clearly identified, i.e., waste 1 = 30 percent stream A and 70 percent stream B, waste 2 = stream C, etc., it is possible to specify that each waste combination requires a unique set of permit conditions.

The conditions for each point are arrived at by testing the incinerator at each clearly defined condition, and if the test is successful, these conditions are used for the permit. This approach is actually equivalent to setting single point conditions for each unique waste

stream combination and writing several sets of single point conditions.

Such a strategy is conceptually simple, but unless care is taken to design the trial burn properly, it can prove to be difficult to both implement operationally and to enforce. The conditions must be selected so that worst-case operating conditions are met during each test with that set of wastes. The permit conditions are set for each unique waste combination in the same way as for a single point approach.

3.6 Universal Approach

For most incinerator applications, it is desirable to select a single set of permit conditions to apply to all modes of incinerator operation. This approach gives the incinerator operator the flexibility to deal with a variety of wastes and waste combinations while limiting the number of trial burn data points that have to be gathered, i.e., every combination need not be tested. The universal approach allows such a set of permit conditions to be determined. It must be noted that this strategy will typically require a much higher degree of complexity in the trial burn and will result in operative conditons that in all cases are severe enough to destroy the worst-case waste. The interrelationships of the various operating parameters need to be carefully considered to determine how worst-case conditions can be achieved for the major operating parameters simultaneously.

The preferable method for establishing the permit conditions under a universal approach is to conduct the test under worst-case conditions. This procedure will likely involve blending the wastes and adjusting the feed rates so that the applicant achieves maximum feed rates for all waste types, maximum feed rate of the POHCs, minimum temperature, and maximum combustion gas velocity at the same nominal operating point.

It is usually possible to set the permit conditions from one set of trial burn conditons with the proper choice of the test conditons. For example, worst-case values for temperature and combustion gas flow rate can usually be achieved at close to worst-case values of the firing rates of individual waste streams by adjusting excess air and auxiliary fuel. If for a given system normal variation of these parameters does not allow this to be done, it may be possible to adjust the temperature and/or the combustion gas flow rates by injecting water or steam to the incinerator during the trial burn. In this way, the applicant demonstrates the system under worst-case conditions, and the permit writer can base the permit conditions on hard data.

If, in spite of best efforts to do so, the facility cannot achieve the critical target limits for all the control parameters during the trial burn at one combination of waste feed rates, excess air, etc., and this failure is confirmed with mass and energy balance calculations, it will be necessary to conduct the tests at different conditions. Usually, some form of incompatibility between the waste streams and the conditions that are required to destroy them is indicated. Tests then need to be conducted at two or more conditions.

When two tests are necessary, it is advantageous that they be conducted at the same thermal duty, temperature, and combustion gas velocity if at all possible. While difficult to achieve maximum thermal duty, combustion gas velocity, and minimum temperature simultaneously, it is not impossible in most cases. It is often possible to adjust the excess air, inject water, and use synthetic or modified wastes. The condition that facilities may not be able to achieve under one set of test conditions is the simultaneous maximum feed rate for all streams combined. This can be achieved by varying each individual waste feed rate to maximize its flowrate for each individual test. The individual feeds can be varied to maximize different ones in different tests as long as all feeds are present in each test in a sufficient quantity to demonstrate 99.99 percent DRE for the POHCs in that waste stream.

Maximum feed rates for each stream could still be allowed in the permit. The restrictions on temperature, combustion gas velocity, and thermal duty would prevent the operator from maximizing all of them simultaneously. Another way of looking at this approach is that the total feed rate (i.e., thermal duty) does not really change; only the individual component feeds change.

An important caveat to this approach is illustrated by the situation when one stream contains a preponderance of particulate-forming or acid-gas-forming constituents. In that case, the above restrictions can be used only to set the conditions on those parameters that impact the DRE. The test at which the particulate and HCl parameters, for example, are worst-case would be used to set the conditions on these parameters.

As stated earlier, the control parameters are grouped into the three categories, A, B, and C, listed in Tables 3-2 through 3-4:

- Control parameters set (i.e., converted to permit conditions) from trial burn data that are related to waste destruction
- Control parameters set from trial burn data that are related to APCE performance
- Control parameters that are independent of trial burn data

The following subsections discuss each of these three categories and how they should be set as permit conditions.

3.6.1 Control Parameters Related to Waste Destruction

Control parameters set from trial burn data that are related to waste destruction are listed in Table 3-2. As discussed above, these parameters should be set directly from tests at a single value for each whenever possible. In those cases when it proves impossible to minimize temperature, maximize feed rate of each stream, maximize flue gas flowrate, and maximize size of containerized waste at the same time, these limits can be varied as discussed in Section 3.6, above. When the permit conditions must be set on the basis of data from different trial burn conditions, the following guidelines may prove helpful.

The regulations generally consider temperature the most important of the control parameters, followed closely by residence time of the gas in the combustion chamber. The rationale for this priority is given in Section 2.1. Briefly, it is assumed that in a properly operating incinerator, most of the POHCs are destroyed in the flame. Of the fraction that is not destroyed in the flame, a portion will be destroyed in the post-flame zone. Post-flame POHC destruction occurs slowly and, assuming all other parameters remain constant, will be a function of temperature and residence time. It is recognized that other factors such as turbulence and oxygen, or excess air, as well as residence time and temperature can affect the destruction of POHCs in the post-flame zone. Total POHC destruction is a function of incinerator operating conditions. Thus, the destruction of the small fraction of the remaining POHCs can be correlated with different and successful operating conditions. It is critical to recognize the basic assumptions and limitations of this relatively simple approach. This type of analysis can be used to interpolate (but not extrapolate) the trial burn results.

Basically, the approach consists of fixing the incinerator operating temperature and relating the other parameters to it. Limits on the maximum flue gas flowrate or maximum velocity measured at the stack are then set to maintain the residence time in the SCC, which is inversely proportional to the gas volumetric flowrate in the SCC, to be greater than that during the successful trial burn. Whenever possible, the maximum flue gas flowrate should be achieved during the test conducted at the minimum temperature by varying air flow, injecting steam or water into the system, or by changing the fuel (or waste) feed rate.

When this is not possible, the minimum temperature can be achieved by reducing the feed rate of the waste or auxiliary fuel. In this case, the flue gas flowrate at the minimum temperature will be less than the maximum flue gas flowrate unless the excess oxygen can be increased proportionally. If the permit limit for the maximum flue gas flowrate (or maximum velocity) is to be set from a test at a condition other than the minimum temperature, it must be shown that the flue gas flowrate at the minimum temperature could be increased to the maximum flue gas flowrate without causing DRE to decrease below 99.99 percent. This involves relating flue or stack gas flowrate to DRE. The following theoretical evaluation, which is based on the above assumptions regarding the dependence of DRE on temperature and residence time, may be useful when it proves necessary to interpolate data between trial burns at slightly different conditions.

The first step in the process is to relate the gas flowrate in the stack to that in the SCC. The gas flowrate in the stack is simply the flowrate of the gas leaving the SCC plus air infiltrated and the gas released by the quenching procedure, all corrected for temperature change. It can be written as:

$$Q_{sec} = (Q_{stack} - Q_{leakage} - Q_{quench})\,(T_{sec}/T_{stack}) \qquad (1)$$

where Q_{sec} is the volumetric gas flowrate through the SCC evaluated at T_{sec}, the SCC exit temperature. The terms Q_{stack}, $Q_{leakage}$, and Q_{quench} are the volumetric flowrate through the stack, flowrate due to air inleakage between the SCC and the stack, and flowrate due to evaporated quench water, respectively, all corrected to T_{stack}, the stack temperature. In this case, all the flowrates are in actual m^3/s (or acfm), and all temperatures are in degrees Kelvin (or degrees Rankine). This equation is reasonably rigorous. It is simply a mass balance on the gas phase. If additional gas streams are identified, they can readily be incorporated although equation 1 lists the most common ones.

If the SCC temperature remains constant (at the minimum trial burn temperature, for instance), the leakage and evaporated quench water flows can be assumed, with little loss of accuracy, to be approximately proportional to the flue gas flowrate at the stack. Equation 1 can be reduced to:

$$\frac{Q_{sec1}}{Q_{sec2}} = \frac{Q_{stack1}}{Q_{stack2}} = \frac{V_{stack1}}{V_{stack2}} = \frac{\tau_2}{\tau_1} \qquad (2)$$

where V is velocity, τ is residence time, and 1 and 2 refer to different test conditions. In other words, the combustion gas flowrate is approximately proportional to the stack gas flowrate and velocity, and these are inversely proportional to the residence time. Once again, the assumptions incorporated in equation 2 are those which are frequently used in the calculations

associated with a trial burn. Equation 2 can be used with a reasonable degree of reliability in most cases.

Next, the residence time must be related to waste destruction. This is a far more difficult and dangerous step in the derivation. Nevertheless, an approximation must be made if some means of interpolating the data is to be used. For this type of analysis, the DE (destruction efficiency) is approximated by a first-order reaction according to the formula:

$$\left(1-\frac{DE}{100\%}\right)=\exp\left[-A\tau\exp\left(\frac{-E}{RT}\right)\right] \quad (3)$$

where A and E are kinetic rate constants, R is the universal gas constant, T is temperature, and τ is time. For a particular POHC at a constant temperature, taking the natural logarithm of both sides of equation 3 results in:

$$\ln\left(1-\frac{DE}{100\%}\right)=K\tau \quad (4)$$

where K is a constant consisting of the terms within the square brackets in equation 3 except for τ.

Equations 3 and 4 assume that the destruction of the small amount of POHC remaining in an incinerator which normally destroys more than 99.99 percent of the POHC will follow first-order reaction kinetics. This is a reasonable approximation for the very low concentrations of POHC in the gas phase that occur under these conditions and for which this approximation is intended. This assumption is supported by the results that have been obtained by the University of Dayton Research Institute in its work associated with development of the stability rankings given in Appendix D.

A reasonable way to ensure the DRE remains at 99.99 percent or above is to base the minimum allowable residence time (t_{min}) on the minimum observed DRE (DRE_{min}) and the residence time at the minimum-temperature trial burn point (T_{min}). For this analysis, it can be assumed that the minimum DRE corresponds to the minimum temperature. This assumption is a fallout of the assumption in equation 3, although this will not always be true as the mechanisms are more complex in actual operation.

In practice, the DE for a POHC is not measured. Rather, DRE is calculated from measurements of POHC emissions from the exhaust of the APCE. Although small, the APCE's contribution toward POHC removal will be the same from one test to the next. The further approximation can be made that the DRE is proportional to the DE. Without going through the derivation, equation 4 can be rewritten as:

$$\frac{\tau_{min}}{\tau_{Tmin}}=\frac{\ln\left(1-\frac{99.99\%}{100\%}\right)}{\ln\left(1-\frac{DRE_{min}}{100\%}\right)} \quad (5)$$

In other words, the logarithm of the penetration (1-DE) for each POHC is proportional to the residence time and the various gas flows as described in equation 2. Combining equations 5 and 2 reveals the following relationships:

$$Q_{stack\ max}=\frac{\ln\left(1-\frac{DRE_{min}}{100\%}\right)}{-9.21}\,Q_{stack}@T_{min} \quad (6)$$

or

$$V_{stack\ max}=\frac{\ln\left(1-\frac{DRE_{min}}{100\%}\right)}{-9.21}\,V_{stack}@T_{min} \quad (7)$$

where $Q_{stack\ max}$ is the maximum allowable gas volumetric flowrate at the stack, and $V_{stack\ max}$ is the maximum allowable gas velocity at the stack.

Thus, if this equation is used to interpolate the results of trial burns at two slightly different conditions, the permit limit for maximum flue gas flowrate measured at the stack ($Q_{stack\ max}$) should be either $Q_{stack\ max}$ evaluated from equation 6 or the maximum flue gas flowrate measured in the trial burn, whichever is lower. Similarly, the permit limit for maximum gas velocity measured at the stack ($V_{stack\ max}$) should be either $V_{stack\ max}$ evaluated from equation 7 or the maximum gas velocity measured in the trial burn, whichever is lower.

This approach should only be used when the permit writer is faced with results such that one combination of waste feeds results in one value of the gas flowrate, the second combination results in a different value, and the applicant cannot accept the lower value. Every effort should be made to avoid such a situation by planning the trial burn to achieve these conditions simultaneously through use of unregulated parameters such as excess air, as described earlier in this chapter. In all cases, this equation should never be used to extrapolate the data beyond that of a trial burn. For example, under no circumstances should this approach be used to allow a higher gas flowrate (and lower residence time) than measured in the trial burn. The equations are not sufficiently rigorous for

this purpose. They are given here as an interpolation tool.

To illustrate the use of this approach, consider a trial burn on a single chamber, liquid injection incinerator with two POHCs at two conditions. The first condition is at a full waste flow to achieve the maximum flue gas flowrate. The waste flow is reduced for the second condition to achieve the minimum temperature at a flue gas flowrate lower than the maximum. The measurements may be summarized as follows:

Run No.	Combustor Temperature, °C	Flue Gas Flowrate, m^3/s	DRE, percent POHC[1]	DRE, percent POHC[2]
1	1,200	20	99.999	99.998
2	1,000	17	99.997	99.996

The maximum allowable gas volumetric flowrate based on the DRE observed at the minimum temperature data point may be calculated from equation 6:

$$Q_{\text{stack max}} = \frac{\ln\left(1 - \frac{99.996\%}{100\%}\right)}{-9.21} 17\ \text{m}^3/\text{s} = 19\ \text{m}^3/\text{s}$$

Thus, if 1,000°C (1,830°F) is set as the minimum temperature limit, the minimum DRE measured at that temperature, 99.996 percent, is not enough to justify setting 20 m^3/s (700 cu ft/sec) (maximum measured) as the maximum flue gas flowrate. The flue gas flowrate limit should be set at 19 m^3/s (670 cfs). Even if $Q_{stack\ max}$ calculated by equation 6 were lower, 17 m^3/s (600 cfs) would be set as the limit because the incinerator already demonstrated compliance at the minimum temperature at that flowrate.

To illustrate how temperature and flue gas flowrates can be made to correspond so that the actual trial burn data can be used for setting the limits on these control parameters, consider the same example with the change that the tests be conducted to achieve the minimum temperature by increasing the air flow. The flue gas flowrate at condition 2 would be higher than 20 m^3/s (700 cu ft/sec). In this case, the maximum flue gas flowrate and the minimum temperature permit limits could be set from the same trial burn data point.

The maximum feed rate of each low heating value waste stream to each combustion chamber should be that demonstrated at the minimum temperature trial burn point. This is reasonable for a low heating value waste because an increase in waste feed leads to a decrease in temperature; thus, it is possible to minimize temperature and maximize waste feed rate at the same trial burn point. For a high- or medium-heating-value waste, the maximum feed rate should not be tied to the minimum temperature trial burn because 1) it may not correspond to the maximize feed rate and minimum temperature and 2) high heating value wastes are often used in place of auxiliary fuel. To limit the feed rate to that demonstrated at the minimum temperature trial burn point may severely limit the operator's ability to control temperature.

A low heating value waste is defined as one incapable of maintaining the incinerator temperature without the assistance of an auxiliary fuel or a high heating value waste. The exact value that defines this cutoff depends on the character of the waste. A waste whose LHV is less than approximately 11,600 kJ/kg (5,000 Btu/lb) will generally have difficulty supporting smooth combustion on its own. This very approximate cutoff is based on the requirement to maintain a typical rotary kiln at 871°C (1,600°F) at 100 percent excess air.

The limit on the maximum size of containerized waste to the PCC is designed to prevent depletion of the chamber oxygen from the sudden release of volatiles. This limit should not be tied to the minimum temperature trial burn point because volatile release is more rapid at higher temperatures. It should also not be tied to the highest temperature trial burn point because there is no proposed maximum temperature permit limit, and overcharging containerized waste to the PCC should cause CO excursions which are covered by other permit limits. Therefore, it is recommended that the limit on the maximum size of containerized waste to the PCC be set as the maximum demonstrated for any trial burn point.

In summary, the guidelines for setting permit limits for parameters related to waste destruction are as follows:

- Permit limits should only be set from trial burn data that show compliance with DRE, HCl, particulate, and CO performance standards.
- When applying the "universal" approach, every attempt should be made to achieve the worst-case values of all key parameters during the same test.
- When the minimum temperature and maximum combustion gas velocity cannot be achieved during the same test, the maximum flue gas flowrate measured at the stack should be $Q_{stack\ max}$ evaluated from equation 7 or the maximum flowrate measured in the trial burn, whichever is lower.
- The maximum feed rate of each low heating value waste stream to each combustion chamber should

be the feed rate of that stream at the minimum temperature trial burn point; the maximum feed rate of each medium- or high-heating-value waste stream should be the maximum feed rate of that stream for any trial burn point.

- The maximum size of containerized waste charged to the PCC should be the maximum demonstrated for any trial burn point.

3.6.2 Control Parameters Related to APCE Performance

Control parameters set from trial burn data that are related to APCE performance are listed in Table 3-3. These parameters pertain to specific particulate and acid gas collection devices. Control parameters that pertain to particulate control devices include:

- Maximum total ash feed rate to the incinerator system
- Minimum differential pressure across particulate Venturi scrubber
- Minimum kVA settings to ESP and kV to IWS
- Minimum pressure differential across FF
- Minimum particulate scrubber blowdown rate

The permit limits for APCE parameters relating to particulate collection devices should be set from the test performed at the worst-case conditions for the APCE parameters while the maximum amount of ash feed is being fed to the incinerator. For an incinerator burning solids, the maximum flue gas flowrate will entrain the maximum particulate. In that case, the test should also be performed at the maximum flue gas flowrate. The permit limits can then be set on the basis of this test.

In those cases where it is either impossible or impractical to achieve the maximum ash feed rate and flue gas flowrate and maintain the worst-case conditions for APCE performance. It is possible to use the results from several tests at similar (but not the same) values of the control parameters and arrive at a technically justified limit. It is important to note that this approach is intended only to verify that operating limits for different parameters, determined from two different test conditions, are mutually consistent. Under no circumstances should this approach be used to extrapolate values of any operating parameter beyond a level that has been tested. Two methods are given, one for a liquid injections and the second for a rotary kiln incinerator.

For a liquid injection, the particulate loading (at 7 percent O_2) can be approximated over a narrow range of operating conditions as being proportional to the ash feed rate and inversely proportional to the gas flowrate. The gas flowrate enters into this since a higher gas flowrate will tend to dilute the particulate. Note that the 7 percent oxygen correction does not influence the correction since the higher gas flowrate can be caused by a change in fuels or waste composition rather than by simple dilution. This generalization can only be made when comparing results of tests at similar, but not identical, conditions and it cannot be used to extrapolate the results beyond the conditions of any test. If extrapolation is attempted, assumptions on the interaction between the gas flowrate and oxygen correction, as well as numerous other factors invalidate the analysis. The above proportionality can be represented by the following equation:

$$\frac{PC_1}{PC_2} \leq \frac{\left(m_{ash}\right)_1 \times Q_2}{\left(m_{ash}\right)_2 \times Q_2}$$

where:

PC = the particulate concentration (mg/dscm) at each of the two conditions, corrected to 7 percent O_2

(m_{ash}) = the input rate of the ash to the incinerator at each of the two conditions

Q = flue gas flowrate at each of the test conditions

This equation can be reconstructed to compare the emissions at a given set of hypothetical conditions which are similar to a trial burn condition with the 180 mg/dscm limit specified by the regulations to yield equation 8.

$$\frac{PC_{limit}}{180\ mg/dscm} \leq \frac{\left(m_{ash}/Q_{stack}\right)_{limit}}{\left(m_{ash}/Q_{stack}\right)_{max\ ash,\ flue\ gas\ flow}} \quad (8)$$

In equation 8, the subscript "limit "denotes the trial burn at the conditions of the limit of performance of the APCE (minimum pressure drop, minimum KVA, or minimum blowdown rate) and the subscript "max ash, flue gas flow" denotes the trial burn at the conditions of maximum ash feed rate and maximum flue gas flow condition.

Equation 8 is presented here mainly for the purpose of illustration and to show how a similar equation is determined for a rotary kiln incinerator. Interpolation is rarely required to set conditions for a liquid injection incinerator. Because equation 8 is rarely used, no separate example of its use is given. The following

illustration for a rotary kiln incinerator can, however, readily be adapted to equation 8.

In summary, the permit limit for the maximum inorganic ash feed rate to a liquid injection incineration system should be set from the maximum flue gas flow rate test conditions whenever possible. If it is impossible to do so, limits for related control parameters can be based on the results of more than one test condition, although the test conditions used must be as similar as possible. If this is done, equation 8 should be used to determine if the "hybrid" conditions are internally consistent and will still satisfy the regulations.

A similar analysis can be done for rotary kiln incinerators. In this case, the particulate emissions can (over a narrow operating range) also be assumed proportional to the ash feed rate. However, for kilns, the particulate emissions are generally recognized to be proportional to the cube of the gas flowrate. This is based on particulate entrainment for kilns. Again, this is a rough approximation to assist in the evaluation of similar tests. This fact cannot be used as a predictive tool. By using these facts in an analogous way to the derivation of equation 8 one can generate equation 9 for rotary kiln incinerators.

$$\frac{PC_{limit}}{180\ mg/dscm} \leq \frac{\left(m_{ash}\, Q^3_{stack}\right)_{limit}}{\left(m_{ash}\, Q^3_{stack}\right)_{max\ ash,\ flue\ gas\ flow}} \quad (9)$$

If equation 9 is not satisfied, then the permit limit for maximum inorganic ash feed rate or the permit limit for maximum flue gas flowrate must be decreased by decreasing the value of the denominator until the equation is satisfied. A combination rotary kiln-liquid injection incinerator should be treated as a rotary kiln incinerator since most of the particle loading is expected to come from entrainment in the kiln.

The following illustrates the use of equation 9. Suppose a trial burn is conducted on a rotary kiln/afterburner incinerator at two test conditions. The first test is run at full waste and air flows to achieve the maximum flue gas flowrate and the maximum ash feed rate. The second test is run at reduced waste and the Venturi's throat is adjusted to achieve the minimum pressure drop:

Test	m_{ash},kg/s	Q_{stack},m^3/s	PC,mg/dscm	Venturi DP, cm H_2O
1	1.0	20	150	50
2	0.5	17	50	40

In this case, equation 9 becomes:

$$\frac{50\ mg/dscm}{180\ mg/dscm} \leq \frac{(0.5\ kg/s)\ (17\ m^3/s)^3}{(1.0\ kg/s)\ (20\ m^3/s)^3} = 0.28 \leq 0.31$$

Since equation 9 is satisfied, the maximum inorganic ash feed rate of 1.0 kg (2.2 lb)/s and the maximum flue gas flowrate of 20 m^3/s (700 cfs) can be taken from test condition 1 while the minimum pressure across the Venturi scrubber can be taken from test condition 2. If equation 9 were not used, then it would be necessary to pick these conditions at one or the other of the test conditions and set all appropriate parameters on that basis, thereby making the condition more restrictive.

The use of data from more than one test to set permit conditions should be avoided if at all possible. The following are a number of general observations which may prove useful when designing the trial burn so that one test condition can be used to set the conditions.

Whenever possible, the pressure drop across the Venturi scrubbers should be adjusted for a test by changing the throat size (if it is a variable throat Venturi) or, if that is not possible, by adjusting the liquid flow consistent with adequate performance. It should not be minimized by lowering the flue gas flowrate. This is especially important on rotary kiln incinerators as the flue gas flowrate has a cubed effect on the particulate emissions.

For systems with Venturi scrubbers, the goal of the trial burn should be to achieve a minimum pressure drop at the highest gas flow. For fabric filters, pressure drop can be decreased by increasing the cleaning frequency during the tests. In most cases, the particulate removal efficiency of a fabric filter increases as the cleaning frequency decreases, although at a penalty of reduced bag life. A higher than normal cleaning frequency during the trial burn will result in a more severe test of the system. To increase the life of the bags, a longer cleaning cycle may be desirable during normal operation. Allowing a longer cleaning cycle (within good operating practices) will not compromise particulate emission levels.

Acid gas collection devices must meet a performance standard of 99 percent HCl removal or a maximum of 1.8 kg (4 lb)/hr emissions. Permit parameters pertaining to acid gas collection devices include the following:

- Maximum total halide feed rate to the incinerator system
- Minimum water/liquor flowrate to the absorber
- Minimum pH to the absorber

Acid is removed from the gas by diffusing to and dissolving in a liquid of high surface area. For a given physical design of the absorber, the critical factors determining the removal efficiency are the L/G ratio and the solubility of the acid gas in the solution, which, except at low pH, is usually high. As acid gases dissolve and are removed in a scrubber solution, the pH of that solution decreases and results ultimately in a decrease in acid solubility and a decrease in acid removal efficiency.

Typically, this efficiency loss is countered by removal (blowdown) and replacement of a portion of the scrubber solution and by addition of caustic to maintain the pH. The most severe test of the system's capacity to remove acid from the gas occurs when the total halide feed rate is at a maximum, the pH of the scrubbing liquid is at a minimum, the flow of the scrubbing liquid is at a minimum, and the gas flow through the APCE is at a maximum. These conditions will result in a minimum L/G ratio, the highest acid gas loading, and the most acidic scrubbant. Thus, the permit limits for maximum total halide feed rate to the incinerator system, minimum L/G ratio, and minimum pH to the absorber should all be set from the same trial burn data point.

In summary, the guidelines for setting permit limits for parameters related to APCE performance are as follows:

- Permit limits for minimum differential pressure across particulate Venturi scrubbers, minimum kVA settings to ESP kV to IWS, and minimum blowdown rate for particulate scrubbers should be set at the trial burn data point with the maximum total ash feed rate to the incinerator system and the maximum flue gas flowrate at the stack. If these limits are set from a data point other than the maximum ash, maximum flue gas data point, the maximum ash feed rate and/or the maximum flue gas feed rate limit should be reduced, if necessary, to satisfy equation 9 for rotary kiln incinerators. The permit limit for minimum differential pressure across a FF is set from manufacturer specifications for new bags.
- Permit limits for minimum L/G ratio and minimum pH to the absorber should be set from the trial burn data point at the maximum total halides feed rate to the incinerator system.

3.6.3 Control Parameters Independent of Trial Burn Data

Control parameters which are independent of trial burn data are listed in Table 3-3. Permit limits for these parameters should be set independent of trial burn data and based on manufacturer recommendations.

3.7 Determining Operating Envelope

Permit limits are set on parameters such as temperature and flue gas flowrate, which are reliable indicators of incinerator performance. To meet these limits, the incinerator operator must maintain the system within an implied operating envelope of control variables such as waste, fuel, and air flowrates. With the exception of waste feed rates, it is not necessary or desirable to directly limit these control variables. However, the permit writer, and especially the permit applicant, should have a clear understanding of the operating limits imposed by a proposed set of permit conditions. This is particularly important in the trial burn planning stage when the permit applicant has the opportunity to examine the consequences of the permit conditions resulting from the trial burn plan and to modify the plan accordingly. Before the trial burn is approved, the permit writer and applicant should agree on the set of permit conditions that will result from the planned trial burn if it is successful.

Energy and mass balance procedures such as those described in Appendix E can be used to estimate the envelope of operating conditions resulting from a set of permit conditions. An example of use of energy and mass balance calculations for this purpose is presented in Chapter 4. It is recommended that, for flexibility in the permit conditions, these kinds of calculations be performed by the permit applicant.

CHAPTER 4
Example Test Case

The purpose of this chapter is to illustrate the previous guidelines for setting permit conditions for a typical incinerator facility. The example test case was developed using a hypothetical scenario intended to cover typical permit objectives and trial burn approach, data reporting requirements, and trial burn data evaluation. Although the facility design is based somewhat upon real systems and trial burn results are intended to represent actual data, any resemblance to an actual site is unintentional.

4.1 Site Description

The example incinerator is an industrial rotary kiln system that processes a wide variety of hazardous waste streams. The incinerator, shown schematically in Figure 4-1, consists of two combustion chambers followed by APCE. The PCC is a rotary kiln. The SCC is an afterburner. The kiln can receive the following wastes:

- Solids (either bulk or containerized) through a ram feed system at the front end of the kiln
- Sludge through a lance at the side of the kiln near the front end
- Liquid organic and aqueous wastes through two liquid injection units in the front end of the kiln

Kiln ash drops down into a water bath (sump), is conveyed up an inclined conveyor, and dropped into an ash hopper. Blowdown from the sump goes to the wastewater handling system. This wastewater system should be designed to meet all of the requirements of the National Pollutant Discharge Elimination System which was formulated in response to the Clean Water Act. (Wastewater treatment is not a subject covered in this handbook or example test case.) The primary combustion gases exiting the kiln are directed through the SCC. The SCC contains a waste burner with two liquid injection nozzles used to fire high heating value liquid organic waste. Natural gas is used as an auxiliary fuel to regulate the desired combustion temperature in each chamber.

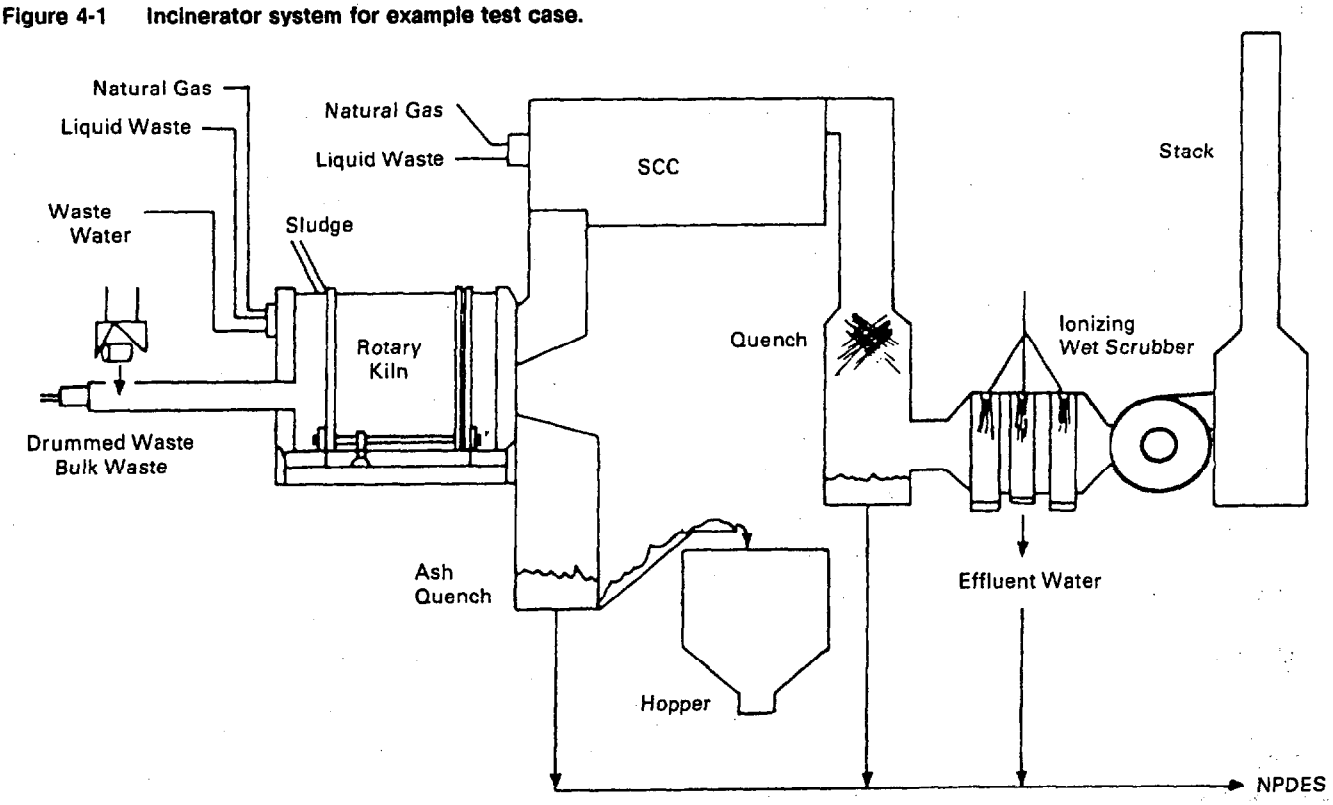
Stack gases leaving the SCC pass through a quench section and a three-stage IWS before being exhausted to the atmosphere via the induced draft (ID) fan and stack. The IWS consists of three stages in series, with twin parallel chambers in each stage. The first stage is a prescrubber (nonionizing). The following two stages are IWSs. The scrubber system serves for both particulate and acid gas removal. Scrubber liquor is pumped through separate headers to each of the three scrubber stages. The caustic flowrate along with makeup process water is regulated to maintain a pH of approximately 6.5 to 7.0. Effluents from the quench and all three scrubber stages are combined and flow to the wastewater system. Key incinerator design information is summarized in Table 4-1.

4.2 Structuring of the Trial Burn

In this example case, the facility is dedicated to the incineration of onsite-generated process wastes. Individual waste streams to be treated have typically consistent properties. That is, the physical and chemical characteristics of each waste stream do not change appreciably on a daily basis. Under this scenario, a multiple point permit approach (see Section 3.5) may be appropriate. The assumption for this example case, however, is that the applicant seeks a single set of easily enforceable (universal) permit conditions that: 1) are consistent with the daily operating requirements of the facility, 2) incorporate sufficient flexibility to satisfy anticipated requirements, and 3) are compatible with the safe and economic operation of each system component. Specifically, the applicant desires a permit that will:

- Allow burning of any waste in any combination consistent with the equipment design and intended operation
- Allow burning of any waste at feed rates established by storage and process limitations and consistent with the design capacity of the incinerator
- Require the minimum auxiliary heat input, power consumption, and material (water, caustic) usage
- Require the minimum number of trial burn test conditions

Figure 4-1 Incinerator system for example test case.



- Not impose unnecessary operational constraints and not impose extensive monitoring requirements

To structure a trial burn test matrix that will accomplish these objectives, four questions need to be answered:

- What waste streams, feed rates, and POHCs should be selected for testing?
- What should be the operational settings of thermal treatment parameters?
- What should be the operational settings of the APCE?
- How many test conditions will accomplish the objectives?

The following sections summarize the rationale for selection of trial burn test conditions, discuss the test matrix, and define the resulting permit conditions anticipated from this example test case.

4.2.1 Waste Selection and Feed Rates

The first task in selecting trial burn test conditions is to examine the individual waste streams and their disposal requirements to determine the waste types and quantities that should be burned during the trial burn. It is necessary to duplicate the most severe conditions likely to occur during actual operation and to identify those Appendix VIII (or other) compounds that will be designated as the POHCs. As illustrated in Figure 4-1, this facility incinerates three major waste stream types:

- Solids - containerized and bulk
- Sludge
- Liquid wastes

Table 4-2 lists the eight waste streams that will be burned at this facility and gives their major physical characteristics and composition. Note the three waste stream types listed above as well as their heating value--high or low. High heating value wastes are generally those which will support stable combustion on their own, typically greater than 11,500 kJ/kg (5,000 Btu/lb) LHV.

The solid wastes that will be burned by this facility consist of two streams identified as S1 and S2. Of these two, the "drummed waste," S1, is the larger stream. This waste makes the most severe demands on the incinerator's ability to meet DRE, HCl, and particulate standards because it has high concentrations of POHCs, it contains difficult-to-burn Appendix VIII constitutents and has high chlorine and ash contents. It contains 2.7 percent chlorinated organics consisting of carbon tetrachloride and trichlorobenzene, which are potential POHCs, that have a combined maximum feed rate of 30.6 kg (67.5 lb)/hr. The solids waste stream, S2, is only about half the size of the drummed waste stream, and the only potential POHC in it is toluene at 0.5 kg (1.1 lb)/hr. The applicant is requesting a permit to burn up to 27

Table 4-1. Example Incinerator Test Case: Summary Design Information

Parameter	Units	Primary Combustion Chamber	Secondary Combustion Chamber	Combined System
Incinerator type	-	Rotary Kiln	Afterburner	-
Inside dimensions (diameter x length)	m (ft)	3.4 x 6.7 (11 x 22)	3.6 x 7.5 (11.9 x 24.6)	-
Cross-sectional area	m^2 (sq ft)	8.8 (95)	10.3 (111)	-
Volume[1]	m^3 (cu ft)	59 (2,090)	78 (2,750)	-
Heat capacity	kJ/hr (Btu/hr)	72×10^6 (68×10^6)	36×10^6 (34×10^6)	108×10^6 (102×10^6)
Refractory thickness[1]	cm (in)	15 (6)	15 (6)	-
Refractory conductivity	kJ/s-m-°C (Btu-in/hr-sq ft-°F)	0.00144 (10)	0.00144 (10)	-
Refractory surface area[1]	m^2 (sq ft)	88 (950)	106 (1,140)	-
Cooled surface area	m^2 (sq ft)	0 (0)	0 (0)	-
Waste feed system	-	Ram feed for drums and bulk solids; sludge lance; liquid injection for organic and aqueous	Liquid injection for organic	-
Installation date	year	1981	1975	-
ID fan capacity	Normal m^3/min (dscf/min)	-	-	570 (20,000)
Maximum quench inlet temperature[1]	°C (°F)	-	-	1,090 (2,000)
Maximum scrubber inlet temperature[1]	°C (°F)	-	-	96 (205)
HCl removal capacity[1]	kg/min (lb/hr)	-	-	3.18 (300)
Quench water supply capacity[1]	L/s (gpm)	-	-	19 (300)
Quench water temperature[1]	°C (°F)	-	-	4-38 (40-100)

[1] Needed for energy and mass balance calculations.

kg/min (3,600 lb/hr) of solids, which can be met by burning any combination of S1 and S2. Clearly, the most severe case would be to burn only S1 for the test. If this is possible, a successful test will allow the operator maximum operating flexibility. If the system cannot burn only drummed solid waste, at least one test should be performed at a combined feed of S1 and S2 of 27 kg/min (3,600 lb/hr) with S1 accounting for as much as possible of this value. The permit condition would then specify the maximum total amount of solid waste and maximum drummed waste to be burned.

As shown in Table 4-2, the largest liquid wastes fed to the system is L1, the contaminated wastewater stream. The high concentration of water in this stream is likely to tax the ability of the kiln to maintain temperature and prevent quenching of the solid and liquid wastes. The large quantity of water also results in the largest gas release per unit of waste and, hence, the lowest gas residence time for a given combustion setting. Thus, L1 is a good stream to vary to establish the liquid waste feed rate limit during the trial burn.

The third category of waste to be considered is the sludge waste, SL. This waste will not sustain combustion on its own. It should be included in the test program because it represents a separate waste stream for which a feed rate limit must be determined and because it will tend to quench the high heating value solid wastes in the kiln. That this waste contains a potential POHC, chlorobenzene, adds weight to including it in at least some of the tests during the trial burn.

There are four high heating value liquid organic wastes. These are fed either to the kiln or to the SCC, and neither of these has a major advantage or disadvantage as a candidate for the trial burn. Below

Table 4-2. Example Incinerator Test Case: Major Physical and Chemical Characteristics of Onsite-Generated Wastes

Waste Type/ Category	Site Waste ID	EPA Waste ID Code	Waste Description	Location	High Heating Value, kJ/kg (Btu/lb)	Moisture, % wt.	Ash, % wt.	TOCl, % wt.	Carbon, % wt.	Hydrogen, % wt.	Oxygen, % wt.	RCRA App. VIII Compounds	Typ. Conc., % wt.	Disposal Requirements, kg/s (lb/hr)
Solids	S1	F005	Drummed waste	Kiln	20,900 (9,000)	4	45	2.2	36	9	3.8	Carbon tetrachloride Trichlorobenzene	1.1 1.6	0.31 (2,500)
Solids	S2	F005	Trash and bulk solids	Kiln	20,600 (8,900)	20	39	0	28	11	2	Toluene	0.1	0.14 (1,100)
Low Heating Value Liquids	L1		Organic contaminated wastewater	Kiln	Nil	98.67	0.07	0.2	0.05	0.01	1	Chloroform Toluene	0.14 0.02	0.51 (4,000)
High Heating Value Liquids	L2	F002	Liquid organic waste	Kiln o rSCC	32,700 (14,100)	15	1	15	50	16	3	Carbon tetrachloride Tetrachloroethylene	6.8 10	0.032 (250)
High Heating Value Liquids	L3	F005	Liquid organic waste	Kiln or SCC	35,460 (15,300)	2	2	0	78	10	8	Phenol Toluene	26 16	0.0063 (50)
High Heating Value Liquids	L4	K016	Liquid organic waste	Kiln or SCC	31,500 (13,600)	2	0.8	26	52.2	15	4	Bis(2-chloro)ethylether Carbon tetrachloride Trichloroethylene Trichlorobenzene	1 18 6 5	0.096 (750)
High Heating Value Liquids	L5	[1]	Liquid organic waste	Kiln or SCC	34,600 (14,900)	10	3	5	48	20	14	None	NA	0.0063 (50)
Sludge	SL	K085	Sludge	Kiln	6,200 (2,700)	70	14	0.01	10	3	2.99	Chlorobenzene	0.03	0.15 (1,200)

[1] Not a RCRA waste.

are the requirements for the liquid organic wastes that must be satisfied during the trial burn:

1. Ensure that the maximum total organic chloride is fired so that the maximum HCl loading is put on the scrubber.
2. Ensure that sufficient levels of POHCs are fired so that 99.99 percent DRE is detected.

It is possible to satisfy these conditions by firing the amounts of each of the L2 through L5 streams at the rates specified in Table 4-2. These are the average firing rates anticipated during normal operation; however, in this case, the applicant chose to meet the 8.4 kg/min (1,100 lb/hr) combined disposal requirements for these four streams by burning 2.28 kg/min (300 lb/hr) of the L2 waste in the kiln and 6 kg/min (800 lb/hr) of the L4 waste in the SCC.

The next step in the process is selection of the POHCs which will be burned during the trial burn. Since the guidance for this selection is still (as of this writing) not finalized, the following three POHCs will be arbitrarily chosen for the purpose of this example:

1. Trichloroethylene (TCE)
2. Perchloroethylene (PCE)
3. Trichlorobenzene (TCB)

Please see the final guidance on POHC selection or contact the OSW for further information on the selection process.

4.2.2 Trial Burn Operating Conditions

When the individual waste streams and feed rates are selected, the temperatures and excess oxygen levels are the primary operating conditions that need to be established for these combustion chambers. Temperature settings have an impact on the amount of auxiliary fuels required because the permit imposes limits on the maximum waste feed rate in each chamber. However, for this sample case, the applicant has the option of controlling temperature in the SCC by waste feed only because the waste (L4) has a heating value significantly greater than 9,300 kJ/kg (4,000 Btu/lb) and can be used as the primary fuel. Thus, by selecting the appropriate L4 feed rate, the use of auxiliary fuel can be minimized, and limits on waste feed rate can be increased. In spite of this option, the applicant's objective is to obtain a permit for chamber outlet temperatures sufficiently low to maximize operational flexibility. These target temperatures are approximately 800°C (1,470°F) for the kiln and 950°C (1,750°F) for the SCC exit planes.

The excess oxygen of about 11 percent was determined to be sufficiently high to permit operation close to the maximum gas flowrate for the system yet still within the ability of the ID fan to maintain draft in the kiln and design pressure drop in the APCE.

Table 4-3 summarizes the three test conditions selected for the trial burn. All tests will be performed with the same wastes and feed rates. These feed rates were selected to reflect maximum anticipated loading to the incinerator and maximum chloride and ash handling by the APCE. Waste feed rates are also within the design waste handling capacity of the incinerator system. The kiln and SCC temperatures are reduced progressively from the first test to the third test. The natural gas fuel to both chambers is used to control the temperature so that maximum waste feed can be maintained at relatively constant rates. Energy and mass balance calculations, as described in Appendix C, can be used to estimate the natural gas feed rates necessary to achieve the target temperatures at 11 percent excess oxygen for the selected waste feed rates. These calculations also determine the flue gas flowrate for each operating condition. The "worst-case" test conditions are investigated during the third test when temperatures to both chambers are lowered to target levels selected by the applicant.

If the incinerator satisfies the RCRA performance standards for DRE, HCl, particulate emissions, and CO emissions at these test conditions, it will have shown compliance under the following permit conditions for the combustion chambers:

- Minimum Temperatures
  - Kiln: 800°C (1,470°F)
  - SCC: 950°C (1,750°F)
- Maximum Waste Feed Rates
  - Solid waste (drummed and/or bulk): 27 kg/min (3,600 lb/hr) for 170-L (45-gal) drum size
  - Sludge to kiln: 9 kg/min (1,200 lb/hr)
  - Wastewater to kiln: 30.6 kg/min (4,000 lb/hr)
  - Organic liquid waste to kiln: 2.28 kg/min (300 lb/hr)
  - Organic liquid waste to SCC: 6 kg/min (800 lb/hr)
- Total Ash and Chlorine Feed Rate
  - Ash: 1.38 kg/min (1,800 lb/hr)
  - Chlorine (Cl^-): 2.58 kg/min (340 lb/hr)
- Maximum Gas Flowrate: 598 actual m^3/min (21,000 acfm) at stack conditions (71°C, 160°F)
- RCRA Listed Compounds: Thermal stability class equal to or lower than the tested POHC (based on $TSLoO_2$) in each waste stream

In addition to these limits, the facility would still have to meet the CO emission limits, maintain negative pressure in the kiln, and operate the liquid waste burner in the SCC according to burner design

Table 4-3. Example Incinerator Test Case: Trial Burn Test Matrix (Target Settings)

Test No.	Kiln Waste Feed, kg/min (lb/hr) Drummed Waste[1] S1	Sludge SL	Wastewater L1	High Btu L2	SCC Waste Feed, kg/min (lb/hr) High Btu L4	Total Ash Feed, kg/min (lb/hr)	Total Cl Feed, kg/min (lb/hr)	Temperature, °C (°F) PCC	SCC	Average Excess O_2, %
1	27 (3,600)	9 (1,200)	30.6 (4,000)	2.28 (300)	6 (800)	13.8 (1,800)	2.58 (340)	900 (1,650)	1,040 (1,900)	11.0
2	27 (3,600)	9 (1,200)	30.6 (4,000)	2.28 (300)	6 (800)	13.8 (1,800)	2.58 (340)	800 (1,470)	980 (1,800)	11.0
3	27 (3,600)	9 (1,200)	30.6 (4,000)	2.28 (300)	6 (800)	13.8 (1,800)	2.58 (340)	800 (1,470)	950 (1,750)	11.0

[1] Drummed waste feedrate corresponds to 1 drum approximately every 6 minutes.

Table 4-3 (continued). IWS Water Flowrate

Test No.	Estimated Gas Use, kJ/s (MBtu/hr) Kiln	SCC	Gas Flow to IWS[1], m^3/min (cfm) @STP[2]	@Actual	Quench Gas Outlet Temp., °C (°F)	Water Flow, L/min (gpm) Quench	IWS Stage 1	2	3	Total	L/G, L/m^3 (gal/ft^3)	IWS Voltage Settings, kV	IWS Inlet pH	Scrubber Blowdown Rate, L/min (gpm)
1	1,520 (5.26)	3,780 (12.9)	510 (18,000)	614 (21,700)	80 (176)	910 (240)	320 (85)	140 (38)	140 (38)	600 (161)	1.0 (0.0074)	30	7.0	15 (4.1)
2	0	3,517 (12.0)	510 (18,000)	614 (21,700)	80 (176)	887 (234)	320 (85)	140 (38)	140 (38)	600 (161)	1.0 (0.0074)	30	7.0	15 (4.1)
3	0	2,740 (9.5)	490 (17,000)	589 (20,400)	79 (174)	915 (242)	320 (85)	140 (38)	140 (38)	600 (161)	1.0 (0.0074)	30	7.0	15 (4.1)

[1] Assumed the same as stack flowrate @ STP.
[2] STP = 20°C (68°F) and 1 atmosphere.

specifications pertaining to atomization pressures, viscosity of the waste, and turndown.

4.2.3 Operating Conditions: APCE

The APCE trial burn test conditions are selected by the applicant, taking into consideration the ability of the APCE to achieve RCRA compliance with particulate and HCl emissions and its feasibility to maintain these operating conditions during all post-permit incineration activities.

The operating conditions of the prescrubber and the two IWSs will be maintained at relatively constant rates between test conditions. The critical scrubber operating parameters that will be reflected in the permit are listed in Table 4-3. The total IWS water flowrate is targeted for 650 L/min (160 gpm) for an L/G of 1 L/m^3 (0.0074 gal/cu ft) with an inlet pH of 7.0. The kV setting for the two-stage IWS is targeted for 30 kV, and the total scrubber blowdown at 15 L/min (4.1 gpm).

4.3 Trial Burn Test Results

The trial burn test consisted of three replicate runs at the same target test condition but at each of three (somewhat different, acutal) test conditions. Performance standards for DRE, HCl, and particulate emissions were passed at all test conditions. Time-weighted averages for CO stack gas levels were below the limit values. The process conditions for each run are summarized in Tables 4-4 through 4-6. The performance results are summarized in Tables 4-7 through 4-9. Further supporting data are included in Appendix G. An example strip-chart recording for combustion temperatures is also included in Appendix G along with example logs of CEM data for CO and oxygen and an example plot of corrected CO readings.

4.4 Determining Limits on Control Parameters

The results of the trial burn must now be converted to a set of limits on all the parameters listed in Table 2-1. As discussed earlier, the universal permitting strategy will be followed as described in Section 3.6. Under this strategy, one value of each parameter (e.g., temperature, gas flowrate, and pressures), including allowances for variability, applies to all modes of incinerator operation. The results are a readily enforceable set of conditions that have an adequate level of operating flexibility.

Table 4-4. Example Incinerator Test Case: Summary of Process Operation Results[1] - Test Condition 1

Parameter	Units	Run No. 1-1	1-2	1-3
Test date	-	May 12, 1987	May 12, 1987	May 13, 1987
Combustion gas flowrate	Actual m^3/min (acfm)	931 (31,800)	956 (33,300)	845 (31,300)
PCC temperature				
Mean	°C (°F)	910 (1,670)	916 (1,680)	916 (1,680)
Maximum	°C (°F)	962 (1,763)	968 (1,774)	969 (1,776)
Minimum	°C (°F)	850 (1,562)	860 (1,580)	850 (1,562)
SCC temperature				
Mean	°C (°F)	1,049 (1,920)	1,038 (1,900)	1,032 (1,890)
Maximum	°C (°F)	1,118 (2,045)	1,115 (2,039)	1,113 (2,035)
Minimum	°C (°F)	1,022 (1,872)	1,020 (1,868)	1,019 (1,866)
PCC pressure	mm H_2O (in H_2O)	-1.6 (-0.10)	-2.6 (-0.10)	-2.5 (-0.10)
SCC pressure	mm H_2O (in H_2O)	-8.6 (-0.34)	-8.4 (-0.33)	-7.6 (-0.30)
Quench inlet temperature	-	NA	NA	NA
Quench outlet temperature[2]	°C (°F)	79 (174)	79 (172)	77 (171)
Heat input rate	kJ/hr (Btu/hr)	74 x 10^6 (70 x 10^6)	72 x 10^6 (68 x 10^6)	69 x 10^6 (66 x 10^6)
Quench water flowrate	L/min (gpm)	852 (225)	912 (241)	965 (255)
IWS inlet pH	-	6.3	6.7	6.8
IWS outlet pH	-	2.9	4.7	3.9
1st stage IWS water flowrate	L/min (gpm)	321 (84.9)	322 (85.1)	322 (85.0)
2nd stage IWS[3] water flowrate	L/min (gpm)	142 (37.5)	142 (37.5)	142 (37.5)
3rd stage IWS[4] water flowrate	L/min (gpm)	142 (37.5)	142 (37.5)	142 (37.5)
IWS Unit 1A - DC Current	mA	33.8	21.8	14.2
IWS Unit 1A - DC Voltage	kV	30.0	30.5	31.0
IWS Unit 1B - DC Current	mA	21.1	16.5	10.7
IWS Unit 1B - DC Voltage	kV	31.1	30.6	31.8
IWS Unit 2A - DC Current	mA	94.2	126.1	94.4
IWS Unit 2A - DC Voltage	kV	28.2	27.8	27.7
IWS Unit 2B - DC Current	mA	105.4	116.2	81.7
IWS Unit 2B - DC Voltage	kV	28.8	29.0	28.5
Stack height	m (ft)	18.3 (60)	18.3 (60)	18.3 (60)
Stack exit velocity[3]	m/s (fps)	12.5 (41.0)	12.7 (41.8)	11.8 (38.9)
Stack temperature[3]	°C (°F)	71 (159)	72 (161)	71 (160)
Stack excess O_2[4]	%	10.85	10.58	10.68

[1] Average of readings taken during each run.
[2] Approximate IWS inlet temperature.
[3] Average of readings from two simultaneous MM5 trains.
[4] Orsat analysis.

Table 4-5. Example Incinerator Test Case: Summary of Process Operation Results[1] - Test Condition 2

Parameter	Units	Run No. 2-1	2-2	2-3
Test date	-	May 13, 1987	May 14, 1987	May 15, 1987
Combustion gas flowrate	Actual m^3/min (acfm)	915 (33,2800)	914 (31,200)	888 (31,400)
PCC temperature				
Mean	°C (°F)	816 (1,500)	821 (1,510)	804 (1,480)
Maximum	°C (°F)	866 (1,591)	872 (1,602)	854 (1,569)
Minimum	°C (°F)	780 (1,436)	781 (1,438)	779 (1,434)
SCC temperature				
Mean	°C (°F)	1,010 (1,850)	982 (1,800)	954 (1,750)
Maximum	°C (°F)	1,060 (1,940)	1,020 (1,868)	999 (1,830)
Minimum	°C (°F)	980 (1,796)	940 (1,724)	915 (1,679)
PCC pressure	mm H_2O (in H_2O)	-2.0 (-0.08)	-2.0 (-0.08)	-2.0 (-0.08)
SCC pressure	mm H_2O (in H_2O)	-8.9 (-0.35)	-8.9 (-0.35)	-8.9 (-0.35)
Quench inlet temperature	-	NA	NA	NA
Quench outlet temperature[2]	°C (°F)	78 (172)	80 (176)	82 (180)
Heat input rate	kJ/hr (Btu/hr)	67 x 10^6 (63 x 10^6)	68 x 10^6 (64 x 10^6)	70 x 10^6 (67 x 10^6)
Quench water flowrate	L/min (gpm)	927 (245)	893 (236)	840 (222)
IWS inlet pH	-	6.7	7.5	7.1
IWS outlet pH	-	2.9	3.1	2.9
1st stage IWS water flowrate	L/min (gpm)	322 (85.1)	322 (85.1)	321 (84.8)
2nd stage IWS[3] water flowrate	L/min (gpm)	142 (37.5)	142 (37.5)	142 (37.5)
3rd stage IWS[4] water flowrate	L/min (gpm)	142 (37.5)	142 (37.5)	142 (37.5)
IWS Unit 1A - DC Current	mA	23.1	14.6	31.8
IWS Unit 1A - DC Voltage	kV	29.5	30.0	30.4
IWS Unit 1B - DC Current	mA	16.4	9.7	18.5
IWS Unit 1B - DC Voltage	kV	31.1	30.8	30.5
IWS Unit 2A - DC Current	mA	63.3	106.0	114.1
IWS Unit 2A - DC Voltage	kV	29.0	29.3	28.7
IWS Unit 2B - DC Current	mA	74.4	111.7	96.5
IWS Unit 2B - DC Voltage	kV	29.2	29.0	28.9
Stack height	m (ft)	18.3 (60)	18.3 (60)	18.3 (60)
Stack exit velocity[5]	m/s (fps)	12.5 (41.1)	12.3 (40.5)	12.0 (39.4)
Stack temperature[33]	°C (°F)	71 (159)	72 (161)	71 (160)
Stack excess O_2[4]	%	11.59	11.72	10.14

[1] Average of readings taken during each run.
[2] Approximate IWS inlet temperature.
[3] Average of readings from two simultaneous MM5 trains.
[4] Orsat analysis.

Table 4-6. Example Incinerator Test Case: Summary of Process Operation Results[1] - Test Condition 3

Parameter	Units	Run No. 3-1	3-2	3-3
Test date	-	May 15, 1987	May 16, 1987	May 16, 1987
Combustion gas flowrate	Actual m^3/min (acfm)	878 (29,400)	862 (30,400)	869 (30,700)
PCC temperature				
Mean	°C (°F)	793 (1,460)	802 (1,475)	804 (1,480)
Maximum	°C (°F)	840 (1,514)	860 (1,580)	856 (1,573)
Minimum	°C (°F)	760 (1,400)	750 (1,382)	744 (1,372)
SCC temperature				
Mean	°C (°F)	971 (1,780)	954 (1,750)	949 (1,740)
Maximum	°C (°F)	1,020 (1,868)	1,024 (1,875)	1,018 (1,865)
Minimum	°C (°F)	960 (1,760)	954 (1,750)	949 (1,740)
PCC pressure	mm H_2O (in H_2O)	-2.0 (-0.08)	-2.6 (-0.10)	-2.6 (-0.10)
SCC pressure	mm H_2O (in H_2O)	-8.1 (-0.32)	-8.4 (-0.33)	-8.6 (-0.34)
Quench inlet temperature	-	NA	NA	NA
Quench outlet temperature[2]	°C (°F)	81 (177)	79 (175)	77 (171)
Heat input rate	kJ/hr (Btu/hr)	62 x 10^6 (59 x 10^6)	61 x 10^6 (58 x 10^6)	63 x 10^6 (60 x 10^6)
Quench water flowrate	L/min (gpm)	871 (230)	916 (242)	958 (253)
IWS pH	-	6.9	7.0	7.3
IWS pH	-	3.3	4.1	3.7
Prescrubber water flowrate	L/min (gpm)	322 (85.1)	321 (84.9)	322 (85.1)
2nd stage IWS[3] water flowrate	L/min (gpm)	142 (37.5)	142 (37.5)	142 (37.5)
3rd stage IWS[4] water flowrate	L/min (gpm)	142 (37.5)	142 (37.6)	142 (37.5)
IWS Unit 2A - DC Current	mA	32.8	23.2	14.5
IWS Unit 2A - DC Voltage	kV	29.0	29.5	28.7
IWS Unit 2B - DC Current	mA	21.3	17.4	8.1
IWS Unit 2B - DC Voltage	kV	29.5	29.5	29.3
IWS Unit 3A - DC Current	mA	129.8	124.2	75.4
IWS Unit 3A - DC Voltage	kV	25.0	27.1	26.5
IWS Unit 3B - DC Current	mA	112.5	103.6	66.5
IWS Unit 3B - DC Voltage	kV	24.0	27.0	26.8
Stack height	m (ft)	18.3 (60)	18.3 (60)	18.3 (60)
Stack exit velocity[3]	m/s (fps)	11.6 (38.1)	11.8 (38.9)	12.0 (39.2)
Stack temperature[3]	°C (°F)	72 (161)	72 (161)	71 (160)
Stack excess O_2[4]	%	10.68	11.19	10.58

[1] Average of readings taken during each run.
[2] Approximate IWS inlet temperature.
[5] Average of readings from two simultaneous MM5 trains.
[6] Orsat analysis.

Table 4-7. Example Incinerator Test Case: Summary of Emission Performance Results - Test Condition 1

Parameter	Units	Run No. 1-1	1-2	1-3
Test date	-	May 12, 1987	May 12, 1987	May 13, 1987
DRE - Trichloroethylene	%	99.9960	99.9980	99.9990
DRE - Tetrachloroethylene	%	99.9990	99.9970	99.9991
DRE - Trichlorobenzene	%	99.9950	99.9998	99.9992
Particulate matter[1]	mg/Normal m^3 (gr/dscf)	80.2 (0.0350)	65.5 (0.0286)	32.8 (0.0143)
HCl emissions	kg/hr (lb/hr)	0.560 (1.24)	0.831 (1.83)	1.06 (2.33)
Cl removal efficiency	%	99.64	99.45	99.31
Stack gas flowrate[2]	Actual m^3/min (acfm)	875 30,900	892 31,500	830 29,300
Stack gas flowrate[2]	Normal m^3/min (acfm)	507 17,900	515 18,200	481 17,000
Oxygen[3]	%	10.55	10.60	10.81
Carbon monoxide[1,3]	ppm	62.0	29.9	52.2

[1] Corrected to 7% O_2.
[2] Average of readings from two simultaneous MM5 trains.
[3] Concentrations in stack gas from facility *in situ* monitor. Oxygen monitor used to correct CO readings.

Table 4-8. Example Incinerator Test Case: Summary of Emission Performance Results - Test Condition 2

Parameter	Units	Run No. 2-1	2-2	2-3
Test date	-	May 13, 1987	May 14, 1987	May 15, 1987
DRE - Trichloroethylene	%	99.9993	99.9992	99.9960
DRE - Tetrachloroethylene	%	99.9992	99.9950	99.9980
DRE - Trichlorobenzene	%	99.9930	99.9960	99.9991
Particulate matter[1]	mg/Normal m^3 (gr/dscf)	101.6 (0.0444)	87.5 (0.0383)	112.1 (0.0490)
HCl emissions	kg/hr (lb/hr)	0.217 (0.478)	1.39 (3.07)	0.319 (0.704)
Cl removal efficiency	%	99.86	99.11	99.80
Stack gas flowrate[2]	Actual m^3/min (acfm)	878 29,400	864 30,500	841 29,700
Stack gas flowrate[2]	Normal m^3/min (acfm)	518 18,300	510 18,000	496 17,500
Oxygen[3]	%	11.55	11.39	10.43
Carbon monoxide[1,3]	ppm	56.3	80.1	76.5

[1] Corrected to 7% O_2.
[2] Average of readings from two simultaneous MM5 trains.
[3] Concentrations in stack gas from facility in situ monitor. Oxygen monitor used to correct CO readings.

Table 4-9. Example Incinerator Test Case: Summary of Emission Performance Results - Test Condition 3

Parameter	Units	Run No. 3-1	3-2	3-3
Test date	-	May 15, 1987	May 16, 1987	May 16, 1987
DRE - Trichloroethylene	%	99.9990	99.9950	99.9970
DRE - Tetrachloroethylene	%	99.9994	99.9980	99.9980
DRE - Trichlorobenzene	%	99.9950	99.9950	99.9993
Particulate matter[1]	mg/Normal m^3 (gr/dscf)	74.4 (0.0325)	55.3 (0.0242)	96.4 (0.0421)
HCl emissions	kg/hr (lb/hr)	1.61 (3.54)	0.702 (1.55)	1.55 (3.42)
Cl removal efficiency	%	98.93	99.53	99.02
Stack gas flowrate[2]	Actual m^3/min (acfm)	813 28,700	830 29,300	838 29,600
Stack gas flowrate[2]	Normal m^3/min (acfm)	484 17,100	493 17,400	498 17,600
Oxygen[3]	%	10.76	11.34	10.70
Carbon monoxide[1,3]	ppm	63.9	86.3	90.0

[1] Corrected to 7% O_2.
[2] Average of readings from two simultaneous MM5 trains.
[3] Concentrations in stack gas from facility in situ monitor. Oxygen monitor used to correct CO readings.

The universal strategy sets the values for the control parameters in the following order:

1. Control parameters from trial burn data that are related to waste destruction
2. Control parameters from trial burn data that are related to APCE performance
3. Control parameters that are independent of trial burn data

The results of the trial burn for the test case have been summarized in Tables 4-4 through 4-9 and in Appendix G. The guidelines of Chapter 2 may now be used to set control parameter limits based on these data. The trial burn was performed at three test conditions (or nominal operating points) with three runs performed at each test condition. Following the guidelines of Chapter 2, operating conditions of the three runs were averaged to yield a composite set of conditions for each test. The composite results, which are summarized in Table 4-10, show that the incinerator was in compliance with performance standards for each run of all three test conditions. The permit conditions chosen are summarized in Table 4-11 and are discussed in detail in the following sections.

4.4.1 Control Parameters Related to Waste Destruction

The control parameters related to waste destruction are listed in Table 3-2. The values of the parameters as they are to be specified in the permit are shown in Table 4-11. Following the recommended practice, the group A parameters listed below are the first to be set.

- Minimum temperature at the kiln and SCC exits
- Maximum CO emissions
- Maximum flue gas flowrate at the stack
- Maximum pressure in the kiln and SCC
- Maximum feed rates:
  - of each waste stream to each combustion chamber
  - of combined waste streams to all combustion chambers
  - per container, maximum size of containerized waste

As shown in Table 4-6, the mean kiln temperature for each of the three runs under these test conditions ranged from 793 to 804°C (1,460 to 1,480°F). The SCC temperature ranged from 949 C to 971°C (1,740 to 1780°F). The variation of the temperatures for all the runs is not given here; it is, however, given for run 1-1 in Appendix G, Table G-4 and Figure G-1. Table G-4 gives the per minute output from the

Table 4-10. Average Trial Burn Results At Three Test Conditions

Test Condition	Permit Target	Test No. 1	2	3
PCC exit temperature, °C	800	914	814	800
SCC exit temperature, °C	950	1,040	932	958
Stack exit velocity, m/s @ 72°C	12.3	12.3	12.3	11.8
m/s @ STP	10.4	10.4	10.4	10.0
DRE - Trichloroethylene, %	99.99	99.998	99.998	99.997
DRE - Tetrachloroethylene, %	99.99	99.998	99.997	99.998
DRE - Trichlorobenzene, %	99.99	99.998	99.996	99.996
Cl removal efficiency, %	99	99.47	99.59	99.16
Carbon monoxide[1], ppm	100	48.0	71.0	80.1
Feed rates, kg/min				
Drummed waste (S1)	27	27	29	27
Sludge (SL)	9	8.4	7.8	7.8
PCC organic waste (L2)	2.3	2.2	2.3	2.3
SCC organic waste (L4)	6.0	5.9	6.0	6.0
Wastewater (L1)	31	30	31	29
Total PCC waste	69	73	73	69
Total SCC waste	6	5.9	6	6
Total inorganic ash	13.8	13.8	14.4	13.8
Total halides	2.3	2.5	2.6	2.5
APCE inlet temperature, °C	80	78	80	79
Voltage to IWS, kV	30	29.6	29.7	27.7
Total electrical power to IWSs, kVA	7.0	7.04	6.63	6.44
IWS blowdown rate, L/min	15	17	20	15
Particulate concentration, mg/dscm	180	59.5	100.4	75.4
IWS water flowrate, L/min	650	606	606	606
pH to IWS	7.0	6.6	7.1	7.1

[*] Corrected to 7% O_2.

temperature data logger; and Figure G-1 is the graphical representation.

Table 4-10 summarizes the mean operating conditions during each of the successful tests. Note that all these values are given in metric units; however, permit conditions should normally be reported in the units in which the monitoring equipment is calibrated. For temperature, the mean is simply the average of the mean temperatures at which the kiln and SCC operated during each of the three runs at each condition, e.g., the mean of the time-averaged temperatures for each of the three runs. The lowest kiln temperature was 800°C (1,470°F) during test 3, while the lowest mean SCC temperature was 932°C (1,710°F) during test 2. The minimum temperature permit condition could be based on either test 2 or test 3. It is recommended that the SCC and PCC minimum temperatures not be taken from different tests. While in this case the differences are inconsequential, they are interrelated, and a temperature for each based on the results of different tests could result in incompatible limits. Table 4-12 summarizes the pertinent results of the tests for making the decision.

The following calculation can be used to estimate whether test 2 or 3 have significantly lower SCC gas residence times. To do this, the gas flowrate (in this case represented by the gas velocity at the stack at standard conditions) is converted to the respective temperatures of the SCC. For example:

$$10.4 \times (932 + 273) / 293 = 42.8$$

The gas velocities are proportional to the actual gas volumetric flowrate; hence, they are the inverse of the residence time in the SCC. Thus, we can say that test 3 was run at a slightly longer residence time than test 2. Because in this case test 2 shows the shorter residence time by a trivial amount and lower SCC temperature, it should be used to set the limit on temperature; however, the two conditions are so slightly different that either could be used with little or no risk.

The next control parameter that needs to be set is the CO emissions. As indicated in Section 2.1.2, the EPA is presently developing guidelines for these emissions. The CO for the nine runs performed varied between 29.9 to 90.0 ppm, corrected to 7 percent oxygen. As a result, under the present guidelines, the limit should be set at 90 ppm, the highest measured during test number 3. Under the new guidelines, the

Table 4-11. Summary of Permit Limits for Incinerator Example Test Case

Parameter	Target	Limit	Test Condition	Justification
PCC waste cutoff temperature, °C	800	800	3	Minimum measured
SCC waste cutoff temperature, °C	950	960	3	Minimum measured
Maximum stack velocity, m/s	12.3	12.3	1,2	Equation 7
Maximum feed rates, kg/min				
PCC solid waste (S1 & S2)	27	288	2	Maximum measured
PCC sludge (SL)	9	7.8		Minimum temperature condition
PCC organic liquid (L2-L5)	2.28	2.34	2	Maximum measured
SCC organic liquid (L2-L5)	6	6	2,3	Maximum measured
PCC wastewater (L1)	30	28.8	3	Minimum temperature condition
Total PCC waste	69	73.2	2	Maximum measured
Total SCC waste	6	6	2,3	Maximum measured
Total inorganic ash	22.8	14.4	2	Maximum stack velocity condition
Total halides	2.28	2.64	2	Maximum stack velocity condition
Maximum size waste drum, m^3	0.17	0.17	1,2,3	Only trial burn setting
Minimum IWS voltage, kV	30	29.7	2	Maximum stack velocity condition
Minimum scrubber blowdown, L/min	15	15	3	Equation 9
Minimum scrubber water flow, L/min	650	606	2	Maximum stack velocity condition
Minimum pH to scrubber	7.0	7.1	2	Maximum stack velocity condition
Maximum CO, ppm (1-hr average)	-	100	-	Per CO guidelines
Maximum kiln cutoff pressure	-	Atmospheric	-	Manufacturer specification
Maximum heat input rate, kJ/hr	-	63×10^6	-	Maximum measured
Maximum SCC waste viscosity, cp	-	100	-	Manufacturer specification
Maximum SCC waste turndown ratio	-	8:1	-	Manufacturer specification
Minimum SCC waste burner pressure, N/m^2	-	310,000	-	Manufacturer specification
Minimum SCC waste HHV, kJ/kg	-	11,600	-	Manufacturer specification
Maximum APCE inlet temperature, °C	80	80	2	Maximum measured

Table 4-12 Data Used for Setting Temperature Limit

	Test 2	Test 3
PCC temperature, °C	814	800
SCC temperature, °C	932	958
Combustion gas velocity, m/s		
At stack conditions	12.3	11.8
At STP	10.4	10.0
At SCC temperature	42.8	42.0

limit should be set at 100 ppm, because 100 ppm CO is generally considered to be the range for proper operation of the incinerator which would minimize the risk of excessive PIC formation and POHC emissions.

The next operating parameter that needs to be set is the maximum flue gas velocity or flowrate. As discussed in Section 2.1.3, flowrate should be measured as close to the exit of the SCC as possible; however, in most cases, the gas velocity at the inlet to the stack is an adequate indicator of combustion gas velocity. It was used in this case and found to be adequate. By the careful selection of the test conditions, the maximum combustion gas flowrate (by whatever measurement method decided on) should be specified from the same test as was the temperature, whenever possible. In this case, the maximum gas flowrate when corrected to SCC conditions was very slightly lower in test 3 than in test 1 or 2. It was the same during test 1 and 2. If the results of test 2 are used to specify the maximum combustion gas flowrate, all the criteria are satisfied, i.e., maximum measured during a test and chosen from the same test as the minimum SCC temperature.

For illustration, however, assume that the results require interpolation of data and that equation 7 of Section 3.6.1 will be used to implement the universal strategy. If the temperature and combustion gas flowrate limit were set on the basis of test 3 instead of test 2, the maximum gas velocity that would be allowed is 11.8 m/s (38.7 fps). This limit could be unduly restrictive; for example, when a high heat value waste is burned, the temperature will increase above the minimum, (which by itself is acceptable), but the gas velocity would also increase above the 11.8-m/s (38.7-fps) maximum and trigger a waste cutoff. Under these very narrow circumstances, it is possible to use equation 7 of Section 3.6.1 to determine whether the higher gas velocity of tests 1 and 2 can still achieve the DRE under the lower

temperature of test 3. It is worth repeating that in the example case, the exercise is trivial since the difference between the two sets of conditions is negligible. It is presented here for illustration.

The residence time (or gas flowrate) that is required to achieve 99.99 percent DRE at the lower temperature conditions can be estimated from equation 7 of Section 3.6.1. As the trichlorobenzene had the lowest average DRE of 99.996 percent at this minimum temperature test condition, its results can be used for the purpose. By equation 7, for this compound, then,

$$V_{\text{stack max}} = \frac{\ln\left(1 - \frac{99.996\%}{100\%}\right)}{-9.21} 11.8 \text{ m/s} = 13.0 \text{ m/s}$$

The value of 13.0 m/s (42.6 fps) is greater than the 12.3 m/s (40.3 fps) that was measured at the higher temperatures; hence, the maximum gas velocity in the stack can safely be set at 12.3 m/s (40.3 fps). Had the value calculated by equation 7 been less than 12.3 m/s (40.3 fps) (the highest velocity measured), the lower, calculated velocity would have been used. However, the applicant can design the test in most cases to achieve minimum temperature and maximum gas flowrates by the addition of water to the PCC or by the use of waste blending. Although this example was used to demonstrate the universal approach, the permit conditions could be set using a multiple point permitting strategy, i.e., different temperatures and velocities for different combinations of waste feeds.

The next parameter to be set is the maximum pressure in the kiln and SCC. During the tests, both the kiln and SCC pressures were constant during each run. As Tables 4-4 through 4-6 show, the pressure differences among runs were modest as well. Although not shown in the results, no indications of puffing were observed during the trial burns. As a result, following the guidelines in Section 2.1.4, the minimum operating pressure set-point for both the kiln and the SCC is atmospheric pressure, with the caveat that the SCC pressure must be lower than that in the PCC at all times.

According to the guidelines of Chapters 2 and 3, the maximum feed rates of low heating value wastes should be taken from the minimum temperature test condition. The wastewater (with no heating value) and the high-moisture sludge (with a heating value of 6,200 kJ/kg [2,700 Btu/lb]) may be classified as low heating value wastes. The permit limits for the maximum feed rates for these waste streams could be taken from either test 2 or 3. In this case, it was taken from test condition 2 for consistency with the temperature selection. From Table 4-10, the permit limit for maximum sludge feed rate should be set at 7.8 kg/min (1,030 lb/hr), and the permit limit for maximum wastewater feed rate should be set at 28.8 kg/min (3,800 lb/hr).

The maximum feed rates of medium- and high-heating value waste streams should be taken from the test condition at which each individual feed rate is maximized. Thus, from Table 4-10, the permit limits for maximum feed rates should be 28.8 kg/min (3,800 lb/hr) for the solid waste, 2.3 kg/min (300 lb/hr) for the L2 liquid waste, and 6 kg/min (790 lb/hr) for the L4 liquid waste. All these feed rates meet or exceed the permit limit targets.

The permit limit for the combined feed rates of all wastes to each combustion chamber should be taken from the test condition at which that value is maximized for each chamber. In this case, the combined feed rate of all wastes to the kiln was maximized at 73.2 kg/min (9,660 lb/hr) in test condition 2, and the combined feed rate of all wastes to the SCC was maximized at 6 kg/min (790 lb/hr) in test condition 2. Those values should be taken as the permit limits.

Only one size of containerized waste was fired in the trial burn: 208-L (55-gal) drums. Thus, the permit limit for the maximum size of containerized waste fired to the kiln should be set at 208 L. This waste was fired at a rate of one drum every 6 minutes. This value should also be incorporated into the permit condition.

4.4.2 APCE-Related Parameters

Permit limits for parameters set from trial burn data that are related to APCE performance should be set according to the guidelines of Section 3.6.2. For this example test case, these parameters include:

- Maximum ash feed rate to the incinerator system
- Minimum kV settings to IWS
- Minimum particulate scrubber blowdown rate
- Maximum total chloride feed rate to the incinerator system
- Minimum L/G ratio to the absorber
- Minimum pH to the absorber
- Maximum APCE inlet gas temperature

The maximum ash feed rate should be taken from the maximum stack gas velocity data point that occurred at test conditions 1 and 2. The ash feed rate was highest at test condition 2 at 14.4 kg/min (1,890 lb/hr), which exceeds the permit limit target. This value should be set as the limit.

The minimum kV setting to the IWSs (taken as the sum of the electrical power to all scrubbers) was 27.7

kV, taken at test condition 3. However, because the ash feed rate at condition 2 is actually higher than the ash feed rate at test condition 3 and the stack velocity at that condition is also higher than that of test condition 3, the maximum setting of 29.7 KV measured at condition 2 should be set as the permit limit for minimum KV to the IWSs.

The minimum particulate scrubber blowdown rate of 15 L/min (4 gpm) was achieved at test condition 3. Because the maximum ash feed rate and maximum stack velocity were recorded at test condition 2, equation 9 must be satisfied to justify setting minimum blowdown from a nominal operating point other than test condition 2. From Table 4-10, the ash feed rate and stack velocity at test condition 2 were 14.4 kg/min (1,900 lb/hr) and 12.3 m/s (40.3 fps), respectively. At test condition 3, the ash feed rate was 13.8 kg/min (1,820 lb/hr), the stack velocity was 11.8 m/s (38.7 fps), and the particle concentration was 75.4 mg/dscm. Because velocity is equal to gas flowrate divided by cross-sectional area, equation 9 can be solved:

$$\frac{75.4\ \text{mg/dscm}}{180\ \text{mg/dscm}} \leq \frac{13.8\ \text{kg/min}\left(\frac{11.8\ \text{m/s}}{A_{stack}}\right)^3}{14.4\ \text{kg/min}\left(\frac{12.3\ \text{m/s}}{A_{stack}}\right)^3}$$

$$0.42 \leq 0.88$$

where the cross-sectional area of the stack (A_{stack}) cancels out. The equation is satisfied; so the minimum scrubber blowdown rate permit limit can be taken from test condition 3 at 15 L/min (4 gpm).

According to the guidelines of Section 3.6.2, the permit limits for maximum total halide feed rate, minimum water flowrate, and minimum pH to the absorber (in this case, the scrubber system) should all be set from the maximum flue gas flowrate, or stack velocity, operating condition. Extreme values of these parameters were not all achieved at the same test condition. However, in test condition 1 where the stack velocity was at a maximum, all values satisfied the permit limit targets. Thus, the permit limits should be taken from test condition 1 at 2.52 kg/min (332 lb/hr) maximum total halide feed rate, 606 L/min (160 gpm) minimum scrubber water flowrate, and 6.6 minimum pH to the scrubbers.

The maximum APCE inlet temperature (same as quench outlet temperature) was 80°C (176°F) during test 2. Therefore, the maximum APCE temperature will be set at 80°C (176°F) which is less than the manufacturers specification of 100°C (212°F).

4.4.3 Parameters Independent of Trial Burn Data

Permit parameters for the example test case that are independent of the trial burn include:

- Maximum total heat input capacity for each chamber
- Maximum viscosity of liquid waste to the SCC
- Maximum SCC liquid waste turndown
- Minimum SCC atomization fluid pressure
- Minimum SCC waste heating value (when no auxiliary fuel is fired)

The permit parameters listed above should be set according to the recommendations of the manufacturer. For this system, the kiln should be maintained at negative pressure; the maximum total heat input to the kiln is 20,000 kJ (19,000 Btu)/s; the maximum total heat input to the SCC is 11,700 kJ (11,000 Btu)/s; the maximum viscosity of liquid waste to the SCC is 100 cp; the maximum turndown for the liquid waste to the SCC is 8:1, which results in a liquid waste flowrate range of 0.06 to 0.45 kg/min (8 to 60 lb/hr) to each of the two waste burners; the minimum atomization fluid pressure for the liquid waste SCC is 310,000 N/m^2 (45 psig); and the minimum SCC waste heating value in the absence of auxiliary fuel is 11,600 kJ/kg (5,000 Btu/lb).

4.4.4 Summary of Operating Limits

The permit writer and especially the permit applicant should have a clear understanding of the interrelated effects of the operating limits imposed by a proposed set of permit conditions. This is particularly important during the trial burn planning stage when the permit applicant has the opportunity to examine the consequences of the permit conditions that would result from the trial burn and to modify the plan accordingly. Before agreeing to a set of limits, the operator is encouraged to perform energy and mass balance calculations such as those described in Appendix E to verify that the permit conditions are internally consistent. As an example, energy and mass balance calculations have been used to establish the operating envelope for the rotary kiln/SCC incinerator of the example test case to meet the following set of permit conditions as established by the trial burn:

- Minimum kiln temperature: 800°C (1,470°F)
- Minimum SCC temperature: 950°C (1,750°F)
- Maximum stack velocity: 12.3 m/s (40 fps)
- Maximum waste feed rates
  - Kiln solid waste: 27 kg/min (3,600 lb/hr)
  - Kiln sludge: 9 kg/min (1,200 lb/hr)
  - Kiln wastewater: 30 kg/min (4,000 lb/hr)
  - Kiln liquid organic waste: 2.28 kg/min (300 lb/hr)
  - SCC liquid organic waste: 6 kg/min (800 lb/hr)

- Maximum total halides feed rate: 2.28 kg/min (300 lb/hr)
- Maximum total ash feed rate: 13.8 kg/min (1,800 lb/hr)
- Minimum water flowrate to absorber: 650 L/min (170 gpm)
- Minimum pH to absorber: 7.0
- Minimum KV settings to IWSs: 30 KV
- Maximum size of containerized waste to PCC: 208 L (55 gal)

A complete operating envelope for this system would involve calculation of the interrelated effects of variations in those parameters that the operator can control, i.e., waste, fuel and air feed rates and variations in those parameters that the operator cannot control such as waste composition. While an energy and mass balance could be used to develop a complete operating envelope, a large number of calculations would be involved, and the resulting n-dimensional (where n is the number of variables) operating envelope would be difficult to present and interpret. For most systems, it is not necessary or desirable to investigate the effects of variations in all parameters simultaneously.

An energy and mass balance can be useful to the operator to achieve the following:

1. Predict operating conditions for new incinerators
2. Verify trial burn temperature and combustion gas velocity targets for existing facilities and specific trial burn feed compositions
3. Check that all feeds can be maximized in one test, and verify that temperatures and combustion gas velocity will be the same for any two tests to be used in obtaining one set of conditions.

To illustrate the value of energy and mass balance calculations, the operating envelope for the test example was developed for the following constraints:

- The feed rate of only one waste stream at a time was allowed to vary. All other waste feed rates were assumed to be constant at their permit limits.
- Waste compositions were assumed to be constant.
- The primary air flow was assumed to be constant at 480 kg/min (63,400 lb/hr).
- The SCC was assumed to operate at 20 percent local excess air.

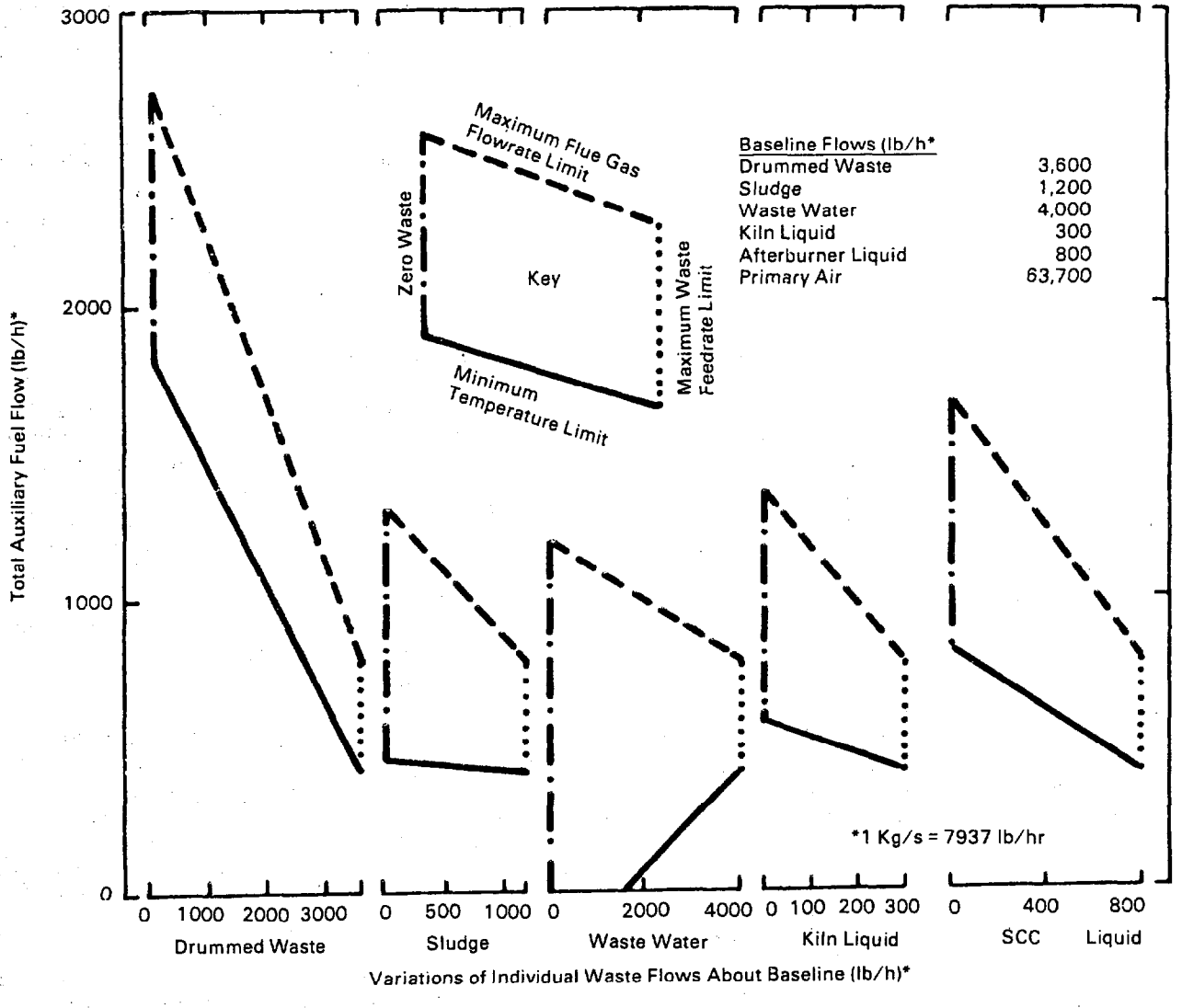
Under these constraints, the controlling permit limits were the combustion chamber exit temperatures, the waste feed rates, and the flue gas flowrate. Figure 4-2 shows the effect of varying the feed rate of each waste stream about the baseline on the total auxiliary fuel (combined natural gas flow to the kiln and the SCC) required to maintain operation within the permit limits. The solid lines in the figure represent the operating limit imposed by maintaining the kiln or the SCC at the minimum temperature, the dotted lines represent the maximum waste feed rate limit, the dashed lines represent the maximum flue gas flowrate limit, and the dash-dotted lines represent the physical limit of zero waste flow.

Allowing for fluctuations, it is most economical (i.e., it requires the least auxiliary fuel) to run as close to the minimum temperature line as possible. The liquid wastes and the drummed waste have sufficient heating values so that a reduction in waste flow must be offset by an increase in auxiliary fuel flow to maintain minimum temperature. Because the sludge heating value is barely sufficient to maintain the minimum kiln temperature, a reduction in sludge flow has little effect on the fuel flow required to maintain temperature. The wastewater has no heating value, so a reduction in wastewater flow reduces the auxiliary fuel requirement.

In all cases, as the auxiliary fuel flowrate is increased above the minimum temperature operating line, temperatures rise and the flue gas flowrate increases. The upper limit on auxiliary fuel flow is imposed by the maximum permitted flue gas flowrate. In many cases, this limit is academic because economics and equipment temperature limitations will prevent the operator from reaching these limits.

These conclusions are valid only under the constraints for which the operating envelope was developed. For instance, if primary air flow were allowed to vary, the maximum flue gas flowrate limit may become more important. If the waste compositions varied, the maximum halide and ash feed rates may become more restrictive than the maximum feed rate of each waste stream. Therefore, in developing an operating envelope, it is important to consider the system involved and set the constraints accordingly. Because the permit applicant best understands the system and how it is to be operated, it is recommended that calculations of this nature be performed by the permit applicant during the trial burn planning stage and prior to accepting permit conditions to ensure that all parameters required can, in fact, be achieved.

Figure 4-2. Operating envelope for example test case.



CHAPTER 5
Data Reporting

The review of relevant permit information is often complicated by the lack of uniformity in content and format of the data submitted. Required information may be either missing or buried in a trial burn report in an inappropriate location. Furthermore, redundant or irrelevant information in the report may also delay the review and permit writing process.

The following are typical problems that the permit reviewer/writer may encounter:

- It is not always clear which data are used to calculate the results.
- Treatment of analytical, sampling, and field blank corrections is not uniform.
- Not all relevant operating conditions are reported.
- Departures from standard sampling and analysis methods are not well documented.
- Some analytical results do not appear in the report.
- Quality assurance data are inadequate.
- Significant departures have been taken from the trial burn plan, which may have been written several months before the trial burn.

Clearly, there is a need for uniformity in kind, extent, and organization of the trial burn information so that the permit writer's task is facilitated. The entire permitting process would be speeded up, and soundly demonstrated technology to treat hazardous waste would be made available to serve the needs of the regulatory agency, the facility, and the public.

Reports of certain performance results and other information resulting from trial burns are mandated by the regulations. Other information is needed to support the performance results and indicate facility operations, while additional information is needed to ensure the integrity of the results and confirm that the protocol agreed upon was adhered to. In the past, because this assortment of test results and supporting data has been presented in a wide variety of formats and units, it has been difficult for the permit writer to rapidly assess or compare trial burn results.

There are several types of reporting needs. First, the permit writer needs the results of performance and operation tests during the trial burn itself. Second, design data are also required for engineering analysis in support of permit conditions. Finally, both design data and performance results are needed as input into the national data base for hazardous waste treatment, the HWCTDB, under development by the EPA and the Department of Energy (DOE). Trial burn data presented in a consistent format will facilitate entry of the results into the HWCTDB.

It is difficult and unnecessary to develop a single, uniform reporting format that will apply to all situations. However, the format given below should be applicable to most trial burns, and the applicant is urged to follow it as closely as is practical.

Example reporting forms to be followed as closely as is feasible are included in Appendix F. An example trial burn report format is provided in Section 5.2. To follow the example format and use the appended forms should alleviate many of the problems cited. In addition, an example trial burn report of a test case has been provided in Chapter 4 as a guide to using the format and forms.

5.1 Design Data Reporting

Basic design information is required in the permit application according to regulations in 40 CFR 270.62. To produce a complete, stand-alone document, the permit applicant should insert in the trial burn report a summary of the major design criteria of the incineration facility including basic design information and key operating parameters. Reviewers can then compare the test conditions with the original design criteria without reference to the original permit application. Furthermore, as discussed in Chapter 2, group D permit parameters reflect limits on operation based on equipment design information and manufacturer specifications. These design data should be made available to the permit writer for rapid evaluation of necessary permit limits. In some cases, additional design information can be requested for

computer modeling of the test results using the energy and mass balance model mentioned above. Following is an example of the design information that should be listed in a trial burn report:

- Type of incinerator (i.e., liquid injection, kiln)
- Linear dimensions of the incineration unit including the cross-sectional area of each combustion chamber
- Heat capacity of each combustion chamber
- Type(s) of waste feed systems

Additional design information should be provided for the following equipment:

- Liquid waste burner type(s) and capacity and design specifications for viscosity of feed, suspended solids, atomization requirements, turndown, and waste heating value
- Forced and induced draft fan capacities
- Auxiliary fuel type and capacity for each combustion chamber
- Design pressures and pressure drops for the combustion chambers and other gas handling equipment
- APCE
  - Maximum design and inlet temperature
  - Gas handling capacity
  - Pressure drop
  - Liquor (water) feed rate capacities
  - ESP or IWS electrical requirements
  - Other parameters which affect performance

A sample reporting format is shown in Appendix F. As noted, most of the summary design information is needed to support the energy and mass balance model and set permit limits for group C parameters.

Calculations of the design range of gaseous retention time in each combustion chamber may also be requested by the permit writer.

5.2 Trial Burn Result Reporting

The requirements for reporting various types of trial burn data are indicated in Tables 5-1 and 5-2. Several levels of requirements are shown:

a. Required by regulation
b. Recommended by this guidance handbook or by EPA policy
c. Needed for energy and mass balance model
d. Standard practice/highly recommended
e. Recommended
f. Optional

Data that are required by regulation certainly must be reported. Other information may be called for by EPA policy statements, and this, too, may be required by the permit writer on a case-by-case basis through use of 270.62(b)(3) or (b)(6)(x). Other information may not have been required in the past but is necessary for developing permit conditions or performing an energy and mass balance as discussed in this guidance handbook. In addition, a large volume of the trial burn report consists of information reported by standard practice or convention and should be reported. Some information designated as "recommended" may not have been typically reported in the past, but this type information is highly recommended to facilitate the review. Results that may have some value to the permit writer also are designated as "recommended." Finally, other results are optional in most situations and may be included for good documentation or in anticipation of future regulations.

In any event, "highly recommended," "recommended," and optional data to be reported must be agreed upon prior to the trial burn and included in the trial burn plan so that provisions can be made to acquire and report the data.

Reporting requirements and informational needs discussed in this handbook are based on EPA regulations, policy or practice. However, State or other regulatory agencies may have additional reporting requirements that are more stringent than the Federal requirements.

Regulations for hazardous waste incinerator permits are found in 40 CFR 270.62. Specific information currently required in the trial burn report is covered in 270.62(b)(6) to 270.62(b)(9) and is listed below:

- A quantitative analysis of the trial POHCs in the waste feed to the incinerator
- A quantitative analysis of the exhaust gas for the concentration and mass emissions of the trial POHCs, O_2, and HCl
- A quantitative analysis of the scrubber water (if any), ash residues, and other residues for estimating the fate of the trial POHCs
- A computation of DRE
- If the HCl emission rate exceeds 1.8 kg (4 lb)/hr of HCl, a computation of HCl removal efficiency
- A computation of particulate emissions
- An identification of sources of fugitive emissions and means of their control

Table 5-1. Trial-Burn Reporting Format and Requirements - Main Report

Recommended Report Organization	Specific Information	Reporting Requirements[1]										
		Incinerator Type		Air Pollution Control Equipment								
		LFI	RKI	Q	V	PT	IWS	ME	CY	DS	BH	ESP
Preliminary	Certification letter	R	R	-	-	-	-	-	-	-	-	-
Preface	Facility name/location	+ +	+ +	-	-	-	-	-	-	-	-	-
	Name of company performing testing	+ +	+ +	-	-	-	-	-	-	-	-	-
Table of contents/tables and figures	-	+	+	-	-	-	-	-	-	-	-	-
1.0 Summary of Test Results												
1.1 Process operation	Test dates	+ +,F[2]	+ +,F[2]	-	-	-	-	-	-	-	-	-
	Residence times	+	+	-	-	-	-	-	-	-	-	-
	Combustion temperatures	R,P	R,P	-	-	-	-	-	-	-	-	-
	High input (firing) rate	P	P	-	-	-	-	-	-	-	-	-
	Summary of APCE parameters	R,P	R,P	-	-	-	-	-	-	-	-	-
	Stack height	+	+	-	-	-	-	-	-	-	-	-
	Stack exit velocity	+ +	+ +	-	-	-	-	-	-	-	-	-
	Stack temperature	+	+	-	-	-	-	-	-	-	-	-
	Stack excess O_2	R	R	-	-	-	-	-	-	-	-	-
1.2 Emissions performance	Test dates	+ +,F[2]	+ +,F[2]	-	-	-	-	-	-	-	-	-
	DREs	R,P	R,P	-	-	-	-	-	-	-	-	-
	Particulate emissions	R,P	R,P	-	-	-	-	-	-	-	-	-
	HCl emissions	R,P	R,P	-	-	-	-	-	-	-	-	-
	Cl REs	R,P	R,P	-	-	-	-	-	-	-	-	-
	Stack gas flowrates	R,P	R,P	-	-	-	-	-	-	-	-	-
	O_2	R	R	-	-	-	-	-	-	-	-	-
	CO_2	+	+	-	-	-	-	-	-	-	-	-
	CO	R,P	R,P	-	-	-	-	-	-	-	-	-
1.3 Metals												
2.0 Introduction												
2.1 Background	Brief discussion of incinerator type	+	+	-	-	-	-	-	-	-	-	-
	Design data summary	M,F	M,F	M,F	-	M,F	-	-	-	-	-	-
	Objective for trial burn	+ +	+ +	-	-	-	-	-	-	-	-	-
	Planned test matrix and deviations	+ +	+ +	-	-	-	-	-	-	-	-	-
	Description of wastes/fuels	+ +	+ +	-	-	-	-	-	-	-	-	-
2.2 Non-standsard practices/events	Description of any unusual test methodologoies	+ +	+ +	-	-	-	-	-	-	-	-	-
	Discussion of any special problems encountered	+ +	+ +	-	-	-	-	-	-	-	-	-
3.0 Performance Results												
3.1 POHCs	Input rates	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
	Emission rates	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
	DREs	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
3.2 Chlorine	Input rates	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
	Emission rates	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
	REs	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
3.3 Particulate	Concentrations	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
4.0 Process Operating Conditions												
4.1 Process Overview	Brief description	+ +	+ +	-	-	-	-	-	-	-	-	-
	Process diagram	+ +	+ +	-	-	-	-	-	-	-	-	-
	Summary of process monitors	+ +	+ +	-	-	-	-	-	-	-	-	-

Table 5-1. Trial-Burn Reporting Format and Requirements - Main Report (continued)

Recommended Report Organization	Specific Information	Reporting Requirements[1]										
		Incinerator Type		Air Pollution Control Equipment								
		LFI	RKI	Q	V	PT	IWS	ME	CY	DS	BH	ESP
4.2 Incinerator Operating Conditions												
• Combustion temperature	PCC Temperature	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
	SCC Temperature	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
• Waste feed/auxiliary fuel data	Brief description/firing locations	+ +,P	+ +,P	-	-	-	-	-	-	-	-	-
	Feedrates	R,P,M	R,P,M	-	-	-	-	-	-	-	-	-
	Firing rates (heat release)	P	P	-	-	-	-	-	-	-	-	-
	Ash loading rates	P,F	P,F	-	-	-	-	-	-	-	-	-
• Waste burner data	PCC atomization/burner pressures	=	=	-	-	-	-	-	-	-	-	-
	SCC atomization/burner pressures	P,F	P,F	-	-	-	-	-	-	-	-	-
• Airflow data	Flow rates/velocities from MM5	+	+	-	-	-	-	-	-	-	-	-
	Flow rates/velocity indications from process monitors	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
	Blower data	+,M	+,M	-	-	-	-	-	-	-	-	-
	Draft measurements	R,P,F	R,P,F	-	-	-	-	-	-	-	-	-
• Residue generation rates	Bottom ash	-	M	-	-	-	-	-	-	-	-	-
	Fly ash	-	-	-	-	-	-	-	+	-	O	O
• Other operating	Scrubber mud/solid residue	-	-	-	-	O	-	-	-	+	-	-
	Kiln rotational speed	-	+ +	-	-	-	-	-	-	-	-	-
	Other conditions deemed important	O	O	-	-	-	-	-	-	-	-	-
4.3 APCE Operating Conditions												
• Wet process												
- Quench	Inlet temperature	-	-	P,F	-	-	-	-	-	-	-	-
	Exit temperature	-	-	+ +	-	-	-	-	-	-	-	-
	Water flowrate	-	-	+ +	-	-	-	-	-	-	-	-
- Venturi scrubber	Inlet temperature	-	-	-	P,F	-		-	-	-	-	-
	Pressure drop	-	-	-	P,F	-	-	-	-	-	-	-
	Water/liquor flowrate	-	-	-	+ +	-	-	-	-	-	-	-
- Packed tower scrubber (adsorber)	Inlet temperature	-	-	-	-	P,F	-	-	-	-	-	-
	Pressure drop	-	-	-	-	+ +	-	-	-	-	-	-
	Liquor flowrate	-	-	-	-	P,F	-	-	-	-	-	-
	Influent pH	-	-	-	-	P,F	-	-	-	-	-	-
- Ionized wet scrubber/wet ESP	Inlet temperature	-	-	-	-	-	P,F	-	-	-	-	-
	Voltage (AC, DC)	-	-	-	-	-	P,F	-	-	-	-	-
	Current (AC, DC)	-	-	-	-	-	P,F	-	-	-	-	-
	Sparking rate	-	-	-	-	-	+ +	-	-	-	-	-
	Water flowrate	-	-	-	-	-	+	-	-	-	-	-
- Mist eliminator	Pressure drop	-	-	-	-	-	-	+ +	-	-	-	-
• Dry processes		-	-	-	-	-						
- Cyclone	Pressure drop						-	-	+ +	-	-	-
- Dry scrubber	Reagent flowrate	-	-	-	-	-	-	-	-	+ +	-	-
	Atomizer rotational speed or nozzle pressure	-	-	-	-	-	-	-	-	+ +	-	-
	Inlet/exit temperatures	-	-	-	-	-	-	-	-	+ +	-	-
- Baghouse	Inlet temperature	-	-	-	-	-	-	-	-	-	P,F	-
	Pressure drop	-	-	-	-	-	-	-	-	-	P,F	-
- ESP	Inlet temperature	-	-	-	-	-	-	-	-	-	-	P,F
	Voltage	-	-	-	-	-	-	-	-	-	-	P,F
	Current	-	-	-	-	-	-	-	-	-	-	P,F
	Sparking rate	-	-	-	-	-	-	-	-	-	-	+ +

Table 5-1. Trial-Burn Reporting Format and Requirements - Main Report (continued)

Recommended Report Organization	Specific Information	Reporting Requirements[1]										
		Incinerator Type		Air Pollution Control Equipment								
		LFI	RKI	Q	V	PT	IWS	ME	CY	DS	BH	ESP
5.0 Sampling and Analysis Results												
5.1 Methods Description	Summary table	+ +	+ +	-	-	-	-	-	-	-	-	-
	Diagram indicating sampling locations	+ +	+ +	-	-	-	-	-	-	-	-	-
5.2 Waste Feed/Fuel Characteristics												-
• Physical characteristics	Moisture	+ +,M	+ +,M	-	-	-	-	-	-	-	-	-
	Ash	R,P,M	R,P,M	-	-	-	-	-	-	-	-	-
	Volatile matter	M	+ +[3],M	-	-	-	-	-	-	-	-	-
	HHV	R,P,M	R,P,M	-	-	-	-	-	-	-	-	-
	Specific gravity	R	R	-	-	-	-	-	-	-	-	-
	Viscosity	R[4],P[4]	R[4],P[4]	-	-	-	-	-	-	-	-	-
• Chemical characteristics	Chlorine	R,P	R,P	-	-	-	-	-	-	-	-	-
	POHCs	R,P	R,P	-	-	-	-	-	-	-	-	-
	Other Appendix VIII compounds	O	O	-	-	-	-	-	-	-	-	-
	Metals	O	O	-	-	-	-	-	-	-	-	-
	Fixed carbon	M	M	-	-	-	-	-	-	-	-	-
	Elemental analysis	M	M	-	-	-	-	-	-	-	-	-
	Heat capacity	M	M	-	-	-	-	-	-	-	-	-
	Heat of Vaporization	M	M	-	-	-	-	-	-	-	-	-
5.3 Stack Gas Concentration Data								•				
• Gases												
- CEMs	CO	R,P	R,P	-	-	-	-		-	-	-	-
	CO_2	R	R	-	-	-	-	-	-	-	-	-
	O_2	P	P	-	-	-	-	-	-	-	-	-
	SO_2	O	O	-	-	-	-	-	-	-	-	-
	NO_x	O	O	-	-	-	-	-	-	-	-	-
- Orsat	TUHC	+	+	-	-	-	-	-	-	-	-	-
	CO_2	+ +	+ +	-	-	-	-	-	-	-	-	-
	O_2	R	R	-	-	-	-	-	-	-	-	-
• POHCs	Volatiles, semivolatiles, other analytes	R,P	R,P	-	-	-	-	-	-	-	-	-
• Other	Moisture	R	R	-	-	-	-	-	-	-	-	-
	Chloride	R,P	R,P	-	-	-	-	-	-	-	-	-
	Particulate	R,P	R,P	-	-	-	-	-	-	-	-	-
	Metals	O	O	-	-	-	-	-	-	-	-	-
	PICs/other Appendix VII compounds	O	O	-	-	-	-	-	-	-	-	-
5.4 APCE Aqueous Streams	POHCs	-	-	R	R	R	R	-	-	-	-	-
	Chloride	-	-	+ +	+ +	+ +	+ +	-	-	-	-	-
	TDS	-	-	+	+ +	+ +	+	-	-	-	-	-
	pH	-	-	+	+ +	+ +	+	-	-	-	-	-
	Metals	-	-	O	O	O	O	-	-	-	-	-
5.5 Ash and APCE Residues	EP toxicity test results	-	+ +[5]	-	-	-	-	-	+	+	O	O
	POHCs	-	R	-	-	-	-	-	R	R	O	O
	Metals	-	O[5]	-	-	-	-	-	O	O	O	O

[1] Legend for reporting requirements:
R = required by current regulation or EPA policy
P = required by this permitting guidance
M = needed for energy and mass balance model
+ + = standard practice/highly recommended
O = optional
F = standard form available in Appendix B
- = not applicable
+ = recommended

[2] Standard forms available for all information in Process Operations Summary and Emissions Performance Summary

[3] Recommended for containerized solid waste

[4] Recommended for liquid waste fired in SCC

[5] Recommended for bottom ash

Table 5-2. Trial Burn Reporting Format and Requirements - Appended Information

Typical Appendix Format	Contents	Reporting Requirements[1]
Detailed S&A Results		
• POHCs	Concentration in each sample	R
	Sampling durations	R
	Trip and field blank values	R
	Averages	R
• Chloride	Concentration	R
	Impinger volumes	R
	Blank values	R
• Particulate	Filter weights	R
• All analytical test results	Laboratory reports/data	R
Raw Data Logs		
• Process data	Log sheets, strip charts	R
• CEM data	Strip charts, printouts	R
• Stack sampling data	Field data forms	R
Sample Traceability Records	Sample collection, treatment, and analysis log	R
QA Results	Surrogate recoveries	R
	Blind audit samples	R
S&A Methods	Summary of standard method	O
	Description of any deviations	R
	"Nonstandard" methods	R
Chromatograms[2]	Waste analysis	R
	Emissions analysis	R

[1] Legend for reporting requirements:
R = required by regulations or can be required due to EPA policy
O = optional

[2] In some cases, one set of chromatograms may be requested by the permit writer. This may be a complete set of all chromatography-based analyses or only chromatograms from selected samples. Routine submission of chromatograms is not recommended due to their bulk.

- A measurement of average, maximum, and minimum temperatures and combustion gas velocity
- A continuous measurement of CO in the exhaust gas
- Such other information as necessary to ensure that the trial burn determines compliance with the performance standards and to establish the operating conditions required to meet that performance standard
- A certification that the trial burn has been carried out in accordance with the approved trial burn plan and the results of all the determinations required [above]. This submission shall be made within 90 days of completion of the trial burn, or later if approved by the permitting authority
- All data collected during any trial burn, to be submitted following the completion of the trial burn
- All submissions required [above] must be certified on behalf of the applicant by the signature of a person authorized to sign a permit application or a report

The reporting requirements include a mixture of facility operation results, sampling and analysis results, and performance results. Certain quality assurance/quality control (QA/QC) results may also be required according to EPA policy. See reference 2 in Appendix A for specific guidance materials on QA/QC requirements.

Some information items listed in Table 5-1 may not be essential for developing incinerator permit conditions or conducting an energy and mass balance but, instead, may be required under other RCRA regulations or regulations in support of the NPDES or air quality permits. These items are included for completeness and to indicate the logical location in a trial burn report where the information may be presented. Some examples include chloride; total dissolved solids and metals in APCE aqueous streams; leachate extraction test results and metals in solid residues; and gases such as SO_2, NO_x, and TUHCs in the stack gas. The applicant may desire or be requested to include these items in the trial burn report to present a more complete picture of the total discharges of the facility in all media.

5.2.1 Suggested Report Format

The trial burn report should be structured in a format parallel to that for the trial burn plan to facilitate the review of the report and simplify the final report preparation. A useful technique is to use the same section numbers and identifiers in both documents. Assuming this parallelism, the remainder of this section will discuss the report format only.

The trial burn report provides several distinct types of information for which a recommended general outline is provided below; a detailed outline of specific information and requirements is provided in Tables 5-1 and 5-2 as an example format. The tables provide an overview of all information that might be required or otherwise included in trial burn reports, although no one incinerator would have all of the components covered in this matrix. This ordering of information represents a logical sequence of results that can easily be followed by the permit reviewer. It is for illustrative purposes; other organizational techniques could also be acceptable. However, it is important that all results needed for permitting be presented clearly, and unnecessary information should not be interspersed among them.

The preliminary information in the trial burn report must include certification required under 40 CFR 270.62(b)(7),(9) signed by a corporate officer or other authorized agent of the facility that the trial burn has been conducted according to the approved trial burn plan. It must also include a preface identifying the facility, location, and the name of the company(ies) that performed the trial burn testing and sample analysis.

Chapter 1 of the report gives a summary of the test results as well as of the facility information. It should include copies of Forms 1-4 of Appendix F for each test. The summary data for each run can be given in the appendix. The purpose of this section is to summarize all pertinent information required for establishing permit conditions. This should be a "stand-alone" section that provides the key performance results, operating conditions, design, and facility information needed for permitting. The section consists of several summary tables sufficient to explain the results. Appendix F gives examples of the summary forms needed.

The Introduction (Chapter 2) should primarily be text material summarizing the background of the facility and the type of waste(s) for which it was designed and should include a summary of trial burn objectives and the planned test matrix. Any deviations from the planned test matrix should be noted and explained. Also to be included here are brief descriptions of the types and sources of wastes and fuels to be normally burned at this facility as compared to the wastes burned during the test as well as any special wastes or spiking procedures used for the trial burn. The Introduction is also an appropriate location to describe any unusual (nonstandard) test methods used and any special problems encountered in testing including sampling and analysis problems such as breakthrough or loss of samples.

The remaining three sections should primarily contain detailed tables of results. Chapter 3, Performance Results, summarizes data involving the performance standards for POHCs, chlorine, particulate material, and any applicable metal limitations. This section, which is a more detailed version of material supplied in Chapter 2, provides the values used in calculating the results.

Chapter 4, Process Operating Conditions, summarizes all equipment operating conditions for the combustion chambers, APCE, and air/combustion gas moving equipment. A process diagram showing all the main components of equipment and process monitoring locations should be included under Section 4.1 of the trial burn report, Process Overview. An example of a process diagram is provided in Figure 5-1. Note that Figure 5-1 is given here for simplicity; however, a permit application should include a full piping and instrumentation diagram (P&ID). The process monitors may be summarized in a table referencing the locations indicated on the diagram. An example is provided in Table 5-3.

Section 5 in the outline, Sampling and Analysis Results, is the final section of the main report body. It should begin with a subsection on the sampling method used including a summary table of sample types, sampling points, sampling methods, frequency of sampling, sample preparation steps, and analytical methods. A diagram of sampling locations should also be included. Examples of the methods summary table and sampling point diagram are given in Table 5-4 and Figure 5-2, respectively. The analytical results may logically be organized into four areas: waste feed and fuel, stack gas, APCE aqueous streams, and ash and other solid residues.

General reporting requirements for trial burn data that are typically appended to the main report are indicated in Table 5-2. The appropriate regulatory agency will refine this list.

The appendices to the trial burn report are used primarily for reporting raw data and supporting logs. "Detailed S&A Results" can include data such as sample volumes, measured concentrations and weights, calibration curves, and response factors. "Raw Data Logs" may include sampling data forms and logs, logs of process data, strip-charts, and printouts from data loggers. "Example Calculations" should show precisely the processes by which final values were obtained for the performance results. "QA Results" is an important section showing surrogate recoveries, blind audit samples, and calibration data. "Sample Traceability Records" (or chain-of-custody logs) show the movement of each sample from collection to final analysis and any intermediate sample splitting, compositing, or treatment. "S&A Methods" may include complete method write-ups, or it may describe any deviations from referenced standard methods or any "nonstandard" methods used. Some permitting agencies request that "Chromatograms" be included

Figure 5-1. Example process diagram showing monitoring points.

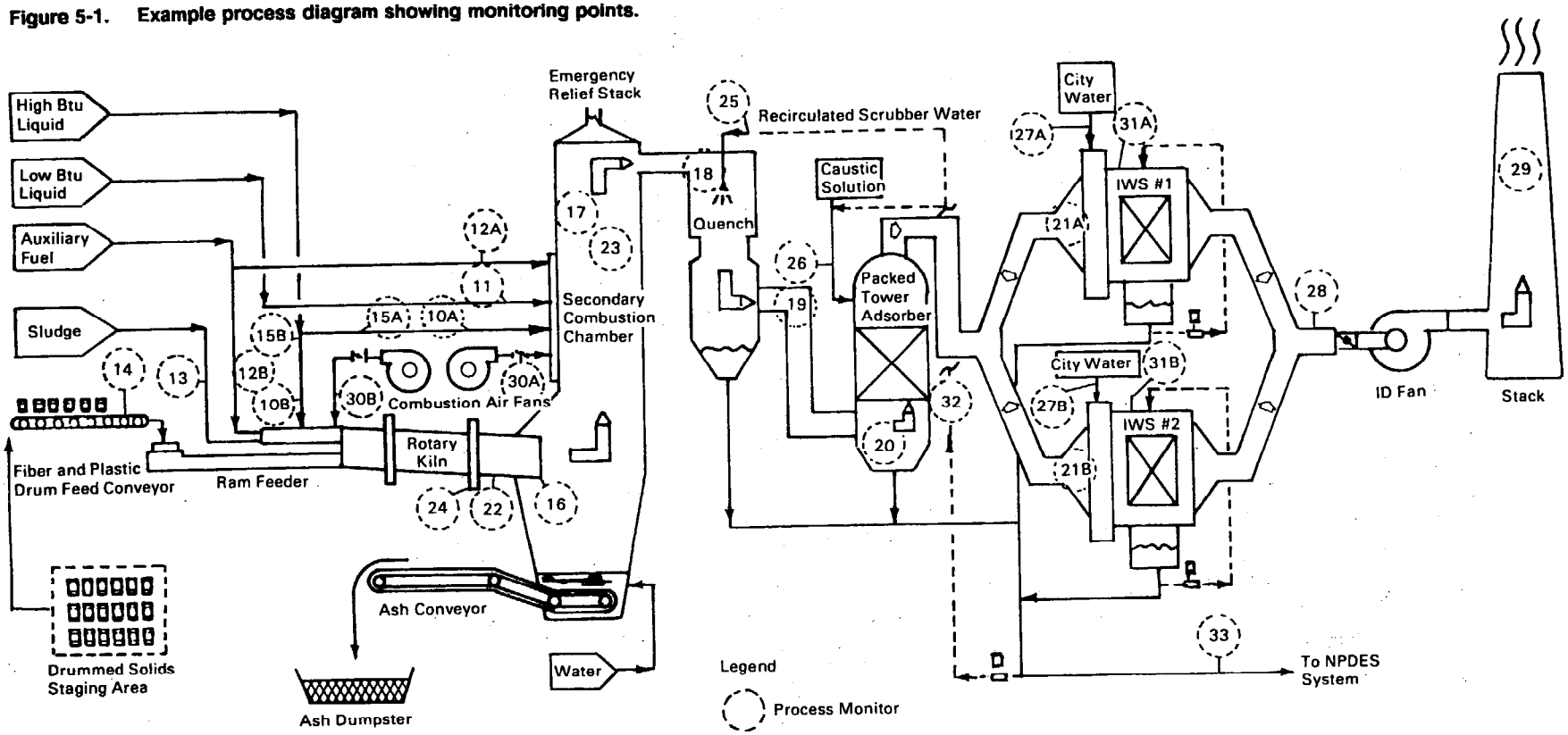


Table 5-3. Example Summary Table of Process Monitors

Parameter	Location of Monitor[1]	Type of Monitor	Operating Range	Units Recorded in Process Log
High-Btu liquid waste feed rate	10A - Feed line to nozzle on SCC 10B - Feed line to nozzle on PCC	Mass flowmeter	0-100	lb/min
Low-Btu liquid waste feed rate	11 - Feed line to injector on SCC	Mass flowmeter	0-100	lb/min
Auxiliary fuel flow	12A - Fuel oil line to SCC 12B - Fuel oil line to kiln	Mass flowmeter	0-100	lb/min
Sludge waste feed rate	13 - Feed line to injector on kiln	Mass flowmeter	0-100	lb/min
Drummed solid waste charge weight	14 - Automatic weigh scale at feed conveyor	Weigh scale	0-2,000	lb
Atomization steam pressure	15A - Waste burner in SCC 15B - Waste burner in kiln	Pressure transducer	0-100	psig
Rotary kiln temperature	16 - Kiln outlet	Type R thermocouple	2,650	°F
SCC temperature	17 - Secondary chamber outlet	Type R thermocouple	2,650	°F
Quench inlet temperature	18 - Quench inlet	Type J thermocouple	150-600	°F
Quench discharge temperature	19 - Quench outlet duct	Type J thermocouple	150-600	°F
Adsorber temperature	20 - Adsorber inlet	Type J thermocouple	150-600	°F
IWS inlet temperature	21A - Inlet duct to IWS No. 1 21B - Inlet duct to IWS No. 2	Type J thermocouple	150-600	°F
Rotary kiln pressure (draft)	22 - Rotary kiln chamber	Pressure transducer	-5 to 5	in H_2O
SCC pressure (draft)	23 - Secondary combustion chamber	Pressure transducer	-5 to 5	in H_2O
Rotary kiln speed	24 - Kiln rollers	Tachometer	0-1.0	rpm
Quench water flowrate	25 - Quench water line	Orifice meter	0-200	gpm
Caustic water flowrate	26 - Caustic water line to adsorber	Rotameter	0-50	gpm
IWS water flowrate	27A - IWS water line to unit No. 1 27B - IWS water line to unit No. 2	Orifice meter	0-50	gpm
Oxygen	28 - IWS outlet duct	Zirconium oxide fuel cell	0-25	percent
Carbon Monoxide	28 - IWS outlet duct	*In situ* NDIR	0-500	ppm
Combustion gas flowrate	29 - Stack	Resistance temperature flow detector	0-100,000	ACFM
Combustion air flowrate	30A - Air inlet duct to SCC 30B - Air inlet duct to kiln	Venturi meter	0-60,000	ACFM
IWS electrical readings	31A - Power lines to IWS electrodes for unit No. 1 31B - Power lines to IWS electrodes for unit No. 2	Voltmeter, Mill-ammeter	0-20 0-200	kV mA
Adsorber differential pressure	32 - Adsorber inlet and outlet ducts	Pressure transducer	0-20	in H_2O
Scrubber water blowdown rate	33 - Sewer line to NPDES system	Triangular weir	0-12	in H_2O

[1] Refer to Figure 4-1.

Table 5-4. *Example Summary Table of Sampling and Analysis Methods*

Sample	Sample Location[1]	Sample Frequency For Each Run	Sampling Method	Sample Size	Analytical Parameters	Preparation Method[2]	Analytical Method[2]
High-Btu liquid (organic waste)	1	One grab sample every 15 min omposited into one sample for each run	Tap (S004)	~100 mL per grab	SV POHC[3] Heating value Ash Viscosity Chlorine Elemental analysis	Solvent dilution NA NA NA NA	HRGC/MS[4] Calorimeter (D240-73) Ignition (D482-80) Viscometer (D-88-81) Organic halide (D808-81 and D4327-84) or (E442-81)
	1	One VOA vial every 15 minutes[5]	Tap (S004)	40 mL per vial	V POHC[6]	Dispersion/purge and trap	HRGC/MS
Low-Btu liquid (aqueous waste)	2	One grab sample every 15 min composited into one sample for each run	Tap (S004)	~100 mL per g	SV POHC Heating value Ash Viscosity Chlorine Elemental analysis	Solvent extraction NA NA NA NA	HRGC/MS4 Calorimeter (D240-73) Ignition (D482-80) Viscometer (D-88-81) Organic halide (D808-81 and D4327-84) or (E442-81)[7]
	2	One VOA vial every 15 min[5]	Tap (S004)	40 mL per vial	V POHC	Dispersion/ purge and trap	HRGC/MS
Auxiliary fuel (fuel oil)	3	One per run	Tap (S004)	250 mL	Heating value Ash Density	NA NA NA	Calorimeter Ignition (D482-80) Gravimetric
Sludge	4	One grab sample every 30 min composited into one sample for each run	Tap (S004)	~100 mL per grab	SV POHC Heating value Ash Viscosity Chlorine Elemental analysis	Solvent extraction NA NA NA NA	HRGC/MS Calorimeter (D240-73) Ignition (D482-80) Viscometer (D-88-81) Organic halide (D808-81 and D4327-84) or (E442-81)[7]
	4	One VOA vial[5] every 30 min	Tap (S004)	40 mL per vial	V POHC	Dispersion/ purge and trap	HRGC/MS
Drummed solid waste	5	One grab sample every other solid charge, composited at end of test. Each sample clearly identified.	Scoop (S007)	~250 g per grab	V POHC SV POHC Chlorine Elemental analysis Heating value Ash	Dispersion/ purge and trap Soxhlet extraction NA NA NA	HRGC/MS HRGC/MS Organic halide (D808-81 and D4327-84) or (E442-81)[7] Calorimeter (D2015-77) Ignition (D482-80)
Ininerator ash	6	One grab sample per run	Scoop (S007)	500 g	SV POHC	Solvent extraction	HRGC/MS
Caustic solution	7	One grab sample per run	Tap (S004)	500 g	Archive	NA	NA

Table 5-4. Example Summary Table of Sampling and Analysis Methods (continued)

Sample	Sample Location[1]	Sample Frequency For Each Run	Sampling Method	Sample Size	Analytical Parameters	Preparation Method[2]	Analytical Method[2]
Scrubber water blowdown	8	One grab sample every 30 min composited into one sample for each run	Dipper (S002)	4 L	SV POHC Specific conductivity	Solvent extraction NA	GC/MS[8] Conductivity meter
	8	One VOA vial every 30 min[5]	VOA vial filled from grab sample	40 mL per VOA	V POHC	Purge and trap	GC/MS
Stack gas	9	2-hr composite per run	MM5[9]	60-100 cu ft[10]	Particulate HCl	Desiccation NA	Gravimetric (EPA RM5) IC[12] (D4327-84)
					Moisture Temperature Velocity	NA NA NA	Gravimetric Thermocouple Pitot tube
	9	2-hr composite per run	MM5	60-100 cu ft[10]	SV POHC Moisture Temperature Velocity	Solvent extraction NA NA NA	HRGC/MS Gravimetric Thermocouple Pitot tube
	9	3-4 trap pairs per run	VOST (S012)[12]	20 L max. per trap pair	V POHC	Purge and trap	GC/MS
	9	One composite sample per run	EPA Ref. Method 3	~20 L	Oxygen, CO	NA	Orsar
	9	Continuous	NA	NA	CO	NA	NDIR continuous monitor, specific extracting or *in situ*
City water	10	Once pretest	Tap (S004)	NA	Ash, chloride	NA	Gravimetric, IC

NOTE: Sampling method numbers (e.g., S004) refer to methods published in *Sampling and Analysis Methods for Hazardous Waste Combustion*, December, 1983; analytical methods beginning with prefixes D and E refer to ASTM methods.

NA = not applicable.

[1] Refers to Figure 4-2; give P&ID reference number.

[2] Sample preparation and analytical methods reference the A. D. Little, EPA 600 and SW-846 methods.

[3] Semivolatile principal organic hazardous constituent.

[4] HRGC/MS = high resolution gas chromatography/mass spectroscopy.

[5] VOA = volatile organic analysis. All VOA vials from each run are composited just prior to analysis.

[6] Volatile principle organic hazardous constituent.

[7] E442-81 is used for samples with high (>0.1%) concentrations, and D808-81 and D4327-84 are used for samples with low concentrations.

[8] GC/MS = gas chromatography/mass spectroscopy.

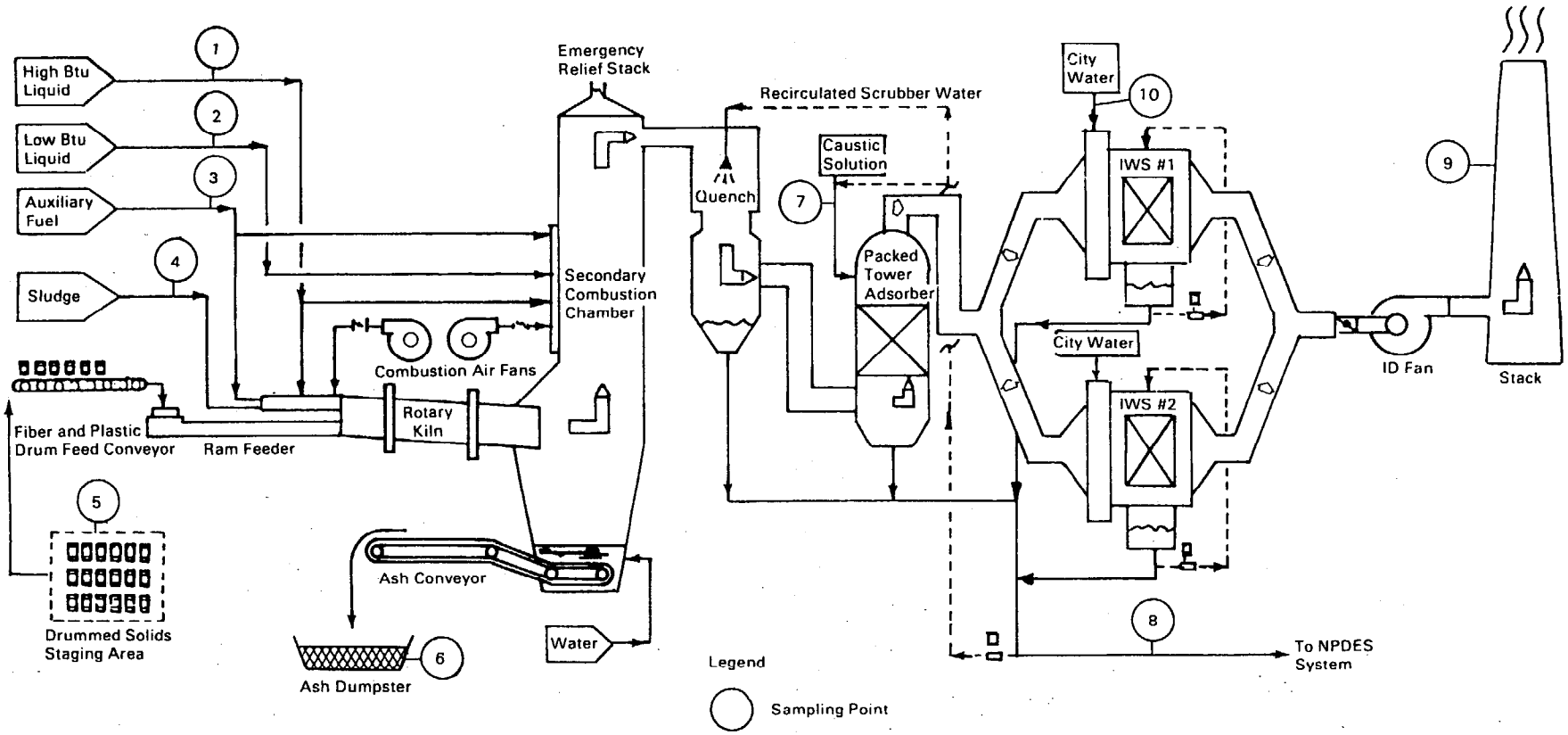
[9] MM5 = Modified Method 5 (EPA Reference Method 5, Modified), SW 846, Method 0010.

[10] Exact volume of gas sampled is dependent on isokinetic sampling rate.

[11] Ion chromatography.

[12] VOST = volatile organic sampling train.

Figure 5-2. Example of process diagram showing sampling locations.



for organic analysis of both the waste feed and stack emissions; however, this information can be voluminous and should not be included with every copy of the report.

5.2.2 Guidance for Reporting Process and Continuous Emissions Monitor (CEM) Data

Ideally, measurement of incinerator performance would be done on a real-time basis; however, a certain amount of time averaging must be used to evaluate and report trial burn data. Most of the trial burn data fall into two categories: data that must represent an average over the test period or portion of the test period and data that is recorded continuously or semicontinuously. Data that by necessity are an average include most of the analytical results, e.g., waste characterization results for a composited sample of waste feed as well as Modified Method 5 (MM5) or Volatile Organic Sampling Train (VOST) results for a sampling period of minutes to hours. Data taken continuously (or as continuously as practical) include both process and CEM data. This section discusses primarily the method by which continuously monitored data are processed and reported.

Process and CEM data needed for the trial burn are shown in Table 5-5. Sixteen parameters of this type are required for establishing permit conditions that fall into groups A, B, and C. Additional parameters needed to support the permitting process are also shown although others, not specified here, may be required at the discretion of the permit writer. Parameters that are related primarily to waste analysis (e.g., ash and halides input) are not included here. As discussed in Chapter 2, group A and B parameters are those which require continuous monitoring of process instrumentation and are tied to automatic waste feed cutoff. In addition, their status must be continuously monitored as described below. Specific RCRA requirements apply only to the group A parameters. Permitted operation requires continuous monitoring of combustion temperature, CO, waste feed rate, and a combustion gas velocity indicator (40 CFR 264.347(a)(1,2)) with automatic waste feed cutoff tied in if permit limits are exceeded (40 CFR 264.345(b,e)). The level of CO in the stack gas is the only parameter which by RCRA regulations specifically state must be continuously monitored during the trial burn (40 CFR 270.62(b)(6)(ix)). However, the incinerator should already have had continuous monitors installed for temperature, feed rate, and gas velocity to obtain approval for the trial burn because measurements of continuous operations should be taken with the same instruments used during the trial burn. Draft or pressure measurement, presumably on a continuous basis, is also required by RCRA to ensure that fugitive emissions are not released (40 CFR 264.345(d)). The RCRA regulations require reporting of the trial burn average, minimum, and maximum only for combustion temperature and gas velocity (40 CFR 270.62(b)(6)(viii)). A measurement of O_2 level in the stack gas is also required by RCRA (40 CFR 270.62(b)(6)(ii)). Continuous measurement is required per this guidance and other guidance material primarily to correct CO levels to a standard value of O_2. Based on this guidance, continuous monitoring and waste feed cutoff interlocks for important APCE parameters should also be required.

Table 5-5. Process and CEM Data Requirements

Permitting Level	Parameters
A	Combustion temperature for each chamber
A	CO level in stack gas
A	Indicator of combustion gas velocity
A	Pressure in PCC
A	Waste feed rate of each stream to each combustion chamber
A	Differential pressure across venturi scrubber
A	Differential pressure across FF
A	Absorber water flowrate and pH
B	Voltages and amperages for ESP or IWS
B	POHC and halides in waste
B	Size of containerized waste to PCC
B	Particle scrubber blowdown rate
C	Heat input rate for each combustion chamber
C	Burner turndown for LI chamber
C	Atomization pressure for LI chamber
C	APCE inlet gas temperature Oxygen level in stack gas Quench water flowrate Quench water temperature Auxiliary fuel feed rate PCC/SCC air flowrate

Group B and C parameters require maintenance of operating records. Parameters in group B require the use of trial burn data to establish permit conditions. Group C parameters, on the other hand, are set independently of trial burn conditions according to manufacturer specifications. Nevertheless, group C parameters must still be measured during the trial burn to demonstrate compliance with the permit limits that are based upon those specifications.

Some of the process and CEM data shown are needed for the energy and mass balance model, if it is to be used. Waste and auxiliary fuel feed rates are required for the model. Combustion gas velocity may be used as an alternative to design ID fan capacity; and measured APCE inlet temperature, quench water flowrate, and quench water temperature may be used instead of the design maximums. Finally, primary and secondary combustion air flow rates and ash generation rates, if available, need to be measured

during the trial burn and reported for use in the energy and mass balance.

Operating records must be used to report trial burn values for group C parameters and any other parameters needed for the energy and mass balance. The size of containerized waste to the PCC may be described in the text in Section 4.2 of the trial burn report. The maximum volume and mass used for each containerized waste must be reported along with the interval between charges. The particulate scrubber blowdown rate for each test run is based upon readings taken at regular intervals (1 hr or less).

The heat input rate for each chamber is reported for each test run. It is based on the heating value and average feed rate of each composited waste and fuel stream. Burner turndown should be reported for each burner using design maxima and the average feed rate of the waste. Atomization fluid pressure for each burner on the liquid injection chamber should also be reported. An average of readings taken at regular intervals (1 hr or less) is usually sufficient.

The APCE inlet gas temperatures do not normally vary significantly. To report an average of readings taken at regular intervals (minimum of 15 min) is sufficient. Averages of readings for the trial burn period need to be reported for quench water flowrate, pH, and temperature. Again, readings taken at regular intervals of at least 15 min are recommended. Primary and secondary combustion air flow rates, if available, should be reported with at least 15-min readings used for the average.

Power readings on the blowers along with calibration curves for conversion to flowrates should be reported if air flowrates are not available. The ash generation rate for each run involving solid waste should be reported. This rate is normally based upon the weight of all the ash collected during the test period. As an internal consistency check, it may be worthwhile to compare this value to the amount of ash fed to the incinerator as determined by the waste analysis and flowrate.

Example reporting forms for process and CEM data are located in Appendix F. The forms are divided into categories of combustion equipment, stack gas data, and APCE data.

Reporting Continuously Monitored Parameters

All the group A parameters (as defined in Chapter 2) must be monitored continuously during the trial burn as well as during subsequent operations. Using the recorded data for the trial burn test period, an average, maximum, and minimum must be reported for each parameter. For each run, reporting approaches will vary according to the instrumentation utilized. Some facilities may use strip-chart recorders for recording the data, and some will use computerized data loggers. Because data loggers often use strip-chart recorders as a backup, both types of information may be available. Continuous recording, which is available only through strip-chart recorders, is not necessarily required, although it is recommended that data be read in some manner at least every 15 sec and that a value be recorded at least every minute. Either strip-charts or data logger printouts for the trial burn period are normally included in an appendix to the trial burn report.

Averages, minimums, and maximums for each of the A and B parameters may be calculated using either strip-charts or data logger printouts. In some cases, both types of hard data may be used for a single parameter (e.g., maximum and minimum from strip-chart recording and time-weighted average from data logger printout). Each basic approach is described below.

Use of data loggers: Data loggers are normally equipped to provide a time-weighted average of readings taken within the interval between printing or recording. In general, during hazardous waste incineration, readings should be taken every minute. These frequent readings are needed as part of the continuous record unless strip-charts are also available. In addition, for the trial burn, it is useful to program the data logger to print out time-weighted averages for a longer period, typically 15 min. Following the trial burn, the 15-min averages corresponding to the sampling period may then be used to determine the average for each run; this is done by simply determining the arithmetic mean of all of the appropriate readings.

Some data loggers can be programmed to print out the minimum and maximum readings taken within the period between printing. If this approach is used to determine the minimum and maximum for each trial burn run, the printouts must be examined for all the sampling period. The lowest interval minimum and the highest interval maximum must then be reported. If the data logger does not record interval minimums and maximums, these must be read off the strip-chart, as explained below.

Use of Strip-charts: The use of strip-charts for determining minimums and maximums is relatively straightforward. The main problem is one of calibration. The strip-chart must be legible, and units of instrument readings and time must be clearly visible. The recording should be checked against the instrument gauge or read out at several values just before or during the trial burn. These instrument readings should be marked on the strip-chart paper. At the start and end of the trial burn run, the time should be marked on the x-axis of the paper as a cross-check. The date, operator initials, notes about run numbers, and other comments should also be recorded. Interruptions in sampling should be marked

on the strip-charts so that the nonsampling interval will not be included in determinations of the minimum, maximum, and average.

Special data-handling problems exist if the range of the strip-chart is exceeded for the maximum or minimum. Each exceeded time offscale and minimum or maximum value should be recorded. For example, if the kiln temperature spiked downward offscale every time a drum of chlorinated still bottoms was fired, the reported minimum temperature might be "<700°C for 16 min (24 exceeded ranges)." Of course, it is best to ensure that the strip-chart has a range wide enough to avoid such offscale readings for determining averages. While they may be used in some cases, offscale readings may limit the flexibility in permit limits for the facility. For example, in the case above, to report 700°C temperature for 16 min when the actual temperature was lower will result in a higher permit limit for temperature than if all values were recorded. Upward temperature spikes that go offscale, on the other hand, would not be allowed for establishing a permit limit.

Other approaches to using strip-chart data are available. Devices such as a planimeter can integrate under the trace. Computerized methods in which the recorder trace is optically or mechanically entered into a data base may also be applicable. The data base can then be used to calculate the time-weighted average, minimum, and maximum. The major concern with all these approaches is that the strip-chart must be appropriately calibrated and the device must account for instrument calibration factors and nonlinear responses. The approach to be used by the applicant should be specified in the trial burn plan and approved by the permit reviewer prior to the trial burn.

Special Problems

Most process instruments produce nearly instantaneous electrical signals that may be read off a gauge or processed in a data logging system. The CEMs, however, are generally not as responsive to changing conditions. Delays are caused by the gas stream physically moving through a sampling line, and instrumental delays are caused by a sensor that must adapt to changing gas composition. For a given gas, one type of instrument may be more responsive than another. For example, paramagnetic oxygen monitors respond more rapidly than do electrochemical types.

Combined delays for sample lines, conditioning systems, and instruments may range from several seconds to several minutes. The CEM system may be responsive in "tracking" a small change in concentration but not a large, sudden peak or dip. Delays such as these are important to consider for permit conditions involving time-delayed waste feed cutoff. This type of problem should be worked out as early as possible in the trial burn planning stage.

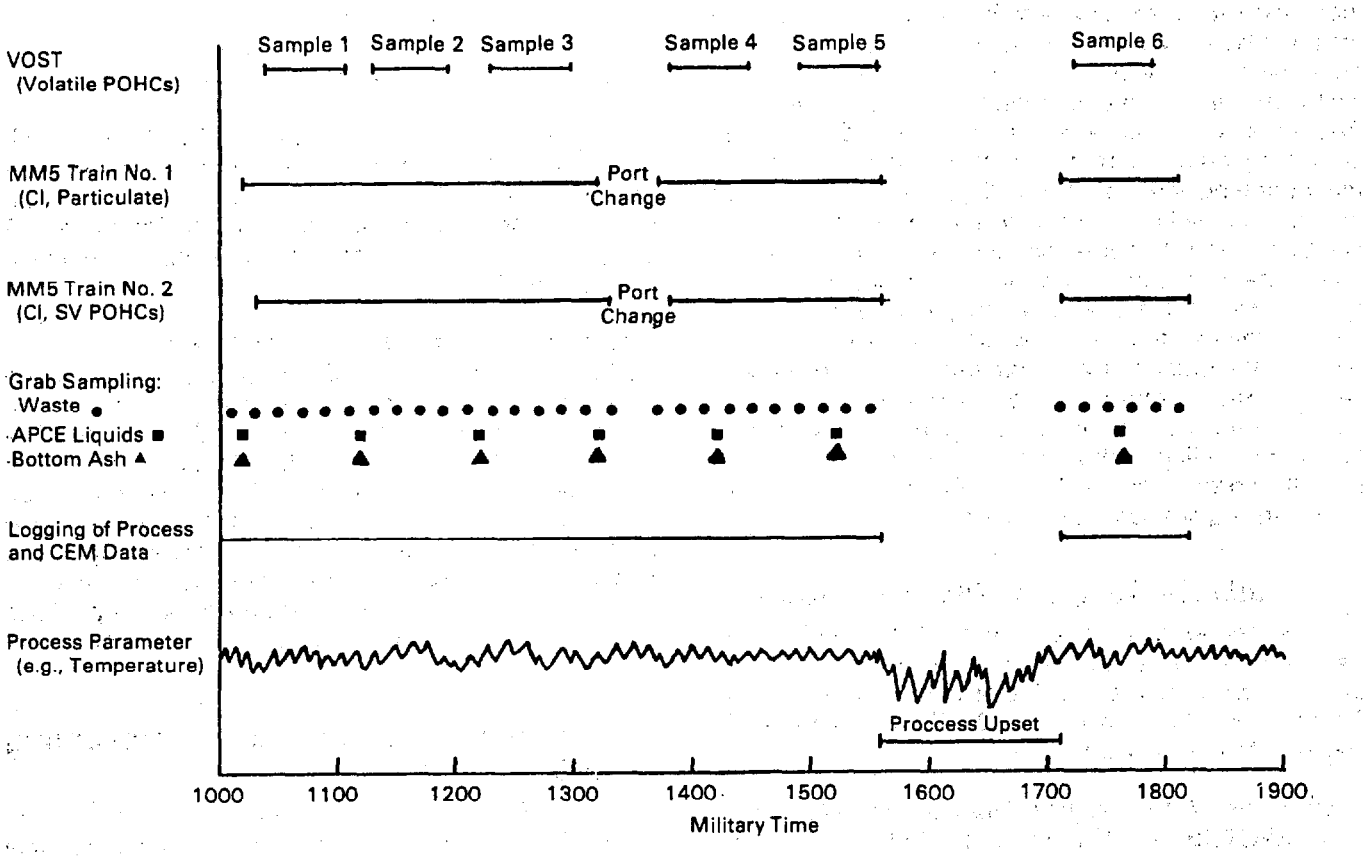
Another general data quality problem common to most trial burn tests involves the correlation of the performance results with the operating conditions. Different measurements span different time periods. The trial burn run can easily span 6 to 8 hr or longer as analytical detection limits often dictate actual sampling times. An additional problem may occur during the test when unavoidable variations in waste properties and other factors cause the unit to deviate from the planned conditions. Variations in process conditions outside the planned ranges can make correlating sampling results difficult. An example trial burn run timeline is shown in Figure 5-3 to illustrate these correlational problems.

Figure 5-3 shows how the various sampling and monitoring activities are coordinated during a typical trial burn run. Six 40-min VOST samples were taken during the run ("Slow VOST" at 0.5 L/min) for a total of 4 hours of volatile sampling. Two MM5 trains were used: one for particulate sampling and the other for semivolatile POHCs. Each train sampled for Cl^-. One train was started several minutes before the other. The total sampling time for MM5 was 6 hr with a port change midway to traverse the stack again at a 90° angle to the first traverse for isokinetic sampling.

Grab sampling was used for waste feed and scrubber liquids with compositing during or following the test. The waste feed was sampled at 12-min intervals and the scrubber liquid and bottom ash at 1-hr intervals. Grab sampling of liquids was briefly discontinued during the MM5 port changes for the best achievable correlation of POHC inlet and outlet measurement, but sampling of waste continued as solids retention time is normally greater than 30 min. The fourth VOST sample was also delayed until MM5 sampling continued. Logging of process and CEM data was continued during this interval.

Logging of process and CEM data must occur over the entire period of any sampling activity. This period of any concurrent sampling activity and logging becomes the formal trial burn period for that run. In the case illustrated in Figure 5-1, the trial burn run period is from 10:00 to 15:36 and from 17:06 to 18:12 for a total test time of 6.7 hr. The actual time required was 8.2 hr due to a 1.5-hr process upset when sampling and logging were discontinued because a process parameter deviated outside the planned trial burn range. It should be noted that sampling and logging of data may be discontinued only when a major process upset occurs that prevents proper waste incineration. In such a case, the run can only be considered a successful run if permit conditions can be written such that the conditions triggering the upset will not occur in subsequent operation. Otherwise, sampling must be continued during "upset" conditions, and the results of that run must

Figure 5-3. Example of trial burn test timeline.



be reported. The CEMs and logging of data must continue whenever hazardous waste is being fed to the incinerator.

It is necessary to report all minimum and maximum parameter values measured during a test to provide the data needed to set these limits. For example, if the temperature drops to a minimum during the trial burn and remains constant for a period, that period should be reported along with the minimum temperature. If there is more than one period of the same minimum temperature, the total time at this minimum value would be reported.

Processing and Reporting CO Data

The stack gas CO concentration is considered to be a real-time indicator of incinerator performance. Although CO levels cannot be directly related to DRE at high levels of DRE, on a site-specific basis, CO is a useful indicator of overall performance. Because of the interdependency of CO levels and incinerator monitoring, specific guidelines for CO are necessary. Separate guidance manuals on CO monitoring and on CO limits for hazardous waste incinerators are currently under development by EPA.

5.3 Operational Recordkeeping and Reporting

Recordkeeping requirements for permitted operation, although not part of trial burn reporting, are briefly mentioned here because of the close association between reporting trial burn data and establishing permit limits.

Operational logs constitute the major source of records for the facility. The exact format of the log is left to the facility because it includes important information for the operator (e.g., damper settings and tank level readings) that is not necessary for establishing permit conditions. The logs must, however, include all appropriate information needed to demonstrate compliance with permit limits. Units of measurement may be the same as the instruments record as long as they may be readily converted to units appropriate to the permit limits. Each instrument should be identified with a code number, manufacturer's name and model number, or other unique identifier. Detailed information, the operating principle, and calibration method for each instrument type are normally required in the permit application, and the log should reflect these information requirements.

In addition to operating logs for process data, logs that relate to waste characteristics are also essential for compliance with permit limits. Reporting forms for demonstrating compliance with the maximum permit limits on halides and inorganic ash are provided in Appendix F. It is also recommended that the permitting authority require that the facility record in the operating log the dates, times, and reasons for any permit violations or any automatic waste feed shutoff along with corrective actions taken, as well as any instances where the automatic waste shutoff system was not activated when parameters reached shutoff levels, the reasons, and corrective actions taken. The proposed amendments to the incinerator regulations include a requirement that such information be compiled into a report to be submitted to the permitting authority on a quarterly basis. The permit writer may wish to include this type of reporting requirement in the permit.

5.4 Available Computer Program Support

Two computer data bases are available that can be used by permit applicants to increase knowledge of incineration systems: 1) Hazardous Waste Control Technology Data Base and 2) Energy and Mass Balance Model Requirements.

Hazardous Waste Control Technology Data Base
The HWCTDB, which is jointly funded by the EPA's HWERL and the DOE through the Oak Ridge National Laboratory (ORNL), is a source of detailed information on thermal treatment technologies that may be useful in the permitting process. The HWCTDB is a compilation of data from regulations, guidance manuals, permit applications, and trial burn reports submitted to the EPA. The information is retrievable through a menu-driven system, and customized reports of summary information and itemized data listings can be obtained online.

Parameters in the data base have been grouped into five areas for ease of retrieval and selection:

1. General facility information
2. Design information
3. Waste characteristics
4. Operating conditions
5. Trial burn results

Within these parameters, HWCTDB provides information on the following:

- Existing thermal treatment facilities and their capabilities
- Trial burn and design data
- Heating values
- Waste components and concentrations
- DRE
- Permit status for existing, new, and research, development, and demonstration facilities

The data base is currently operated by ORNL, which has produced search forms that permit writers may use to access data on waste feed characteristics, capacity, incinerator design, and performance. A sample form for collecting trial burn data is included in Appendix F.

Energy and Mass Balance Calculation
To facilitate performance of energy and mass balance calculations for hazardous waste incinerators, a computer model has been developed under an EPA contract by EERC. The model is currently in draft form and is being reviewed by EPA. The model can assist the permit writer in evaluating incinerator trial burn and design data to develop consistent operating conditions. The use of this model is discussed in Appendices B and E of this handbook. A sample form for the engineering analysis data is also provided in Appendix E.

5.5 Recommended Forms for Presenting Data Summaries

Appendix F contains 12 forms which can be useful in presenting the information needed to evaluate a trial burn. While it is recognized that no one set of forms can include all variations of incinerator system designs, these should, if possible, be used as a guide. Use of the forms will help the permit writer identify key pieces of information quickly and facilitate the evaluation process. The forms in Appendix F fit into three categories:

1. Summary of the facility and target operating ranges
2. Summary of average operating conditions during each test condition of the trial burn. Note that a minimum of three runs at the same operating conditions constitute a test
3. Summary of the key parameters monitored and measured during each run

Table 5-6 lists the 12 forms in Appendix F and summarizes how they are used. The first two tables simply summarize the general facility information and the general design and operating information. Some operating information in Form 2 can be given as a range. The purpose of Form 2 is to summarize the facility's major attributes and to serve as a guide to the permit writer.

Table 5-6. Recommended Usage of Sample Forms in Trial Burn Report

Form No.	Title	No. of Copies	Purpose
1	Summary of Facility Information	1	To indicate the range of values that would be encountered during operation or to describe the facility
2	Summary of Design Information	1	To indicate the range of values that would be encountered during operation or to describe the facility
3	Description of Waste Streams	1	To indicate the range of values that would be encountered during operation or to describe the facility
4	Summary of Test Conditions (Waste Feed)	1 per test	To summarize the results of each test, i.e., average of the runs for that test condition[1]
5	Summary of Operating Parameter Values	1 per test	To summarize the results of each test, i.e., average of the runs for that test condition
		1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
6	Summary of System Performance	1 per test	To summarize the results of each test, i.e., average of the runs for that test condition
		1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
7	Method 5 and Particulate Results	1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
8a	Input Rates	1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
8b	Chloride Emissions	1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
9a	POHC Emissions (may be used for volatiles and semivolatiles or use Form 9c for semivolatiles separately)	1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
9b	POHC Input Rates	1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
9c	Semivolatile POHC Emissions (may be used in lieu of Form 9a for semivolatile emission results)	1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
10	Monitoring Data for Halides and Inorganic Ash and Operations	1 per run	To summarize the results of each run. The average of these data for each test constitute input to summary of the results of each test.
11	List of Samples	1 per test	As a QA/QC check on the samples taken during the test
12	Emergency Shutdown and Permit Compliance Record	1	Operation only

Note: Submit pages that have been copied on one side only to facilitate evaluation and review.
[1] If waste composition changes for each run, then Form 3 should be included to identify the actual composition of the wastes burned during each run.

Form 3 describes the waste streams that the facility will burn both during normal operation and during the trial burn. Different wastes may be burned during these two operations, for example, to fortify one or more waste streams with a specific POHC or to push the system to an extreme for the trial burn. Form 3 is used, therefore, to summarize the data for three different purposes. First, they can be used to summarize the ranges of waste types and composition that the facility will burn during normal operation. This summary, along with Forms 1 and 2, constitutes the overall facility summary. Second, Form 3 can be used to summarize the waste burned at each test condition. For this purpose, the forms present the summary of the runs constituting each complete test. Finally, Form 3 can be used to present the information on the wastes burned during each run. As can be seen, the averages of the information entered at this point form the input for the second purpose. This approach presents the information in a concise format which the permit writer can use to determine quickly how summary results were obtained.

Forms 4, 5, and 6 are used in a similar manner as Form 3. They can be used to present the operating

conditions of the incinerator during each run. It can also be used to summarize the mean operating conditions during each test. Once again, the same form is used to present data at two summary levels.

Forms 5 through 9 are intended to summarize some of the raw data on the performance of the incinerator. They would normally be presented in the appendix to introduce the raw data log for each run. Form 10 is only used if an emergency shutdown occurred during the trial burn. It is intended to document the occurrence and the conditions which caused it.

CHAPTER 6
Inspection and Maintenance Guidelines

A regular I&M program is critical to the successful operation of the incinerator facility. The primary objective of the I&M program is to ensure that major equipment is operated safely, reliably, and according to manufacturer operating specifications. Additionally, the I&M program addresses the calibration and maintenance of monitoring equipment used to establish the accuracy and reliability of process data that must demonstrate compliance with regulatory limits imposed in the operating permit.

Any hazardous waste incineration facility is required to adhere to an I&M program (40 CFR 264.347). The permit applicant must detail this program in the application. The information should address the specific I&M activities for major system components and monitoring instrumentation including the proposed I&M frequency. The permit writer relies on this information because I&M requirements are specific to the type of equipment, its intended operation, and the manufacturer. On the basis of this information and other recommended guidelines discussed below, the permit writer specifies the type of I&M program applicable to the facility under review.

Table 6-1 summarizes a recommended permit approach to the I&M program. Details of the I&M program and general guidelines are discussed in the following sections.

6.1 General Facility Equipment

Incineration equipment and APCE should be inspected daily or weekly to verify the operational status. This frequency implies an outside visual inspection of the equipment rather than a systematic component inspection. A detailed inspection of incinerator refractory, scrubber nozzles, or fabric collector bags, which would require a system shutdown, is recommended on a much less frequent schedule, as specified by the particular equipment manufacturer. Occasionally, a piece of equipment may indicate a potential problem. In this event, a detailed inspection of those equipment components is necessary to ward off potential noncompliance with RCRA performance specifications. Such problems are generally manifest through a variety of performance indicators.

Tables 6-2 and 6-3 list indicators of poor performance, the equipment problems generally associated with these indicators, and recommended maintenance and troubleshooting programs. If the facility cannot correct the problems by operational adjustment (within the limits of the operating permit), the equipment generally requires detailed inspection and possible repair. Appropriate troubleshooting and repairs should then be implemented to prevent possible safety risks or noncompliance with permit requirements. The inspection, maintenance, and troubleshooting practices recommended in Tables 6-2 and 6-3 require, in most cases, that the incinerator facility be shut down.

Operational and performance monitoring instrumentation such as liquid (pumpable) waste flowmeters, water flowmeters, pH meters, and CO, temperature and O_2 continuous recorders should also be subjected to a routine inspection and maintenance program. A visual inspection of this equipment should be carried out on a daily basis if possible. In the longer time frame, thermocouples should be inspected to determine whether the ceramic shields show signs of cracking or deterioration. Monitors for O_2 and CO should be inspected at clearly specified intervals for proper gas flowrate, vacuum pressures, and potentiometer settings. The gas conditioning systems that support this instrumentation should also be inspected to determine possible air inleakage and moisture dropout efficiency. Any supporting electronics hardware should also be inspected. The continuous monitoring response of this equipment also provides a continuous readout of instrument functionality.

The maintenance program for this equipment includes routine service and calibration activities. Service requirements are normally specified by the manufacturer, as they are specific to the type of instrumentation used. Response and calibration checks should be performed regularly. For gaseous analyzers for O_2 and CO (and others if required by regulations other than RCRA), calibration and response checks should be performed daily because these instruments are subject to drift and reduced sensitivity.

Table 6-1. Recommended Inspection and Maintenance Frequency

Equipment/Parameter	Inspection and Maintenenace Criteria	Inspection and Maintenance Frequency				
		Operation and Monitoring Equipment			Emergency Systems	
		Calibration	Inspection	Service	Alarms	Waste Cutoff
Incinerator equipment	Proper Operation	-	Daily	1	-	-
Waste feed/fuel systems	Proper Operation and Accuracy	2	Daily	1	Weekly	Weekly
PCC and SCC outlet gas temperature	Proper Operation and Accuracy	Monthly	Daily[3]	1	Weekly	Weekly
O_2 and CO monitors	Proper Operation and Accuracy	Daily	Daily[3]	1	Weekly	Weekly
Gas flow monitors						
• Direct gas velocity	Proper Operation and Accuracy	Monthly	Daily[3]	1	Weekly	Weekly
• Indirect fan amps	Accuracy	6 Months	Daily	-	Weekly	Weekly
Other incinerator monitoring equipment (flame scanners, air blowers, etc.)	Proper Operation	-	Daily	1	Weekly	Weekly
APCE	Proper Operation	-	Weekly	1	-	-
APCE support systems	Proper Operation	-	Daily	1	Weekly	Weekly
APCE performance instrumentation	Proper Operation and Accuracy	Weekly	Daily	1	Weekly	Weekly

[1] Equipment manufacturer's recommendation.
[2] Equipment manufacturer's recommendation or no less than monthly.
[2] Operators are also alerted immediately as to the functionality of the instruments because of the continuous monitoring response of this equipment.

Table 6-2. General Maintenance and Troubleshooting of Incinerator and Auxiliary Equipment

Equipment	Indicators	Problems	Recommended Maintenance and Troubleshooting
Incinerator refractory	Excessive temperature	• Loss of refractory, corrosion • Flame impingement	• Inspect and replace. Review refractory specifications. • Nozzle erosion. Inspect and replace.
Chamber pressure	Excessive pressure (high or low)	• Ash deposit, plugging • Excessive flowrate	• Inspect chamber, transition ducts, APCE indicators
Chamber excess O_2	Excessive O_2; unresponsive to firing rate	• Excessive air leakage • Obstructed fan dampers	• Inspect combustion air control system, fan and dampers
Liquid/slurry/sludge waste feed system	Excessive variations in O_2 and CO	• Variable waste concentration and heating value • Excessive feed rate • Feed line plugging	• Inspect seals and air fan dampers and control mechanism
	Excessive variations in waste feed pressure at the burner	• Feed line plugging • Excessive solids in the waste • Improper preheating of waste	• Inspect mixing tank and recirculation • Adjust feedrate • Inspect feed line screens, filter for deposits, plugs
		• Pump problems • Loss of atomization fluid (air-steam)	• Adjust temperature control for waste viscosity • Inspect waste pump operation • Inspect atomization air blower, steam supply
Solid feed mechanism	Excessive variation in O_2, temperature, CO, and/or pressure	• Feed conveyor problems • Feed ram cycle timer • Hydraulic feed system • Blockage of screw feeder	• Inspect solid feed system for timing, blockage and proper operation of components

Table 6-3. General Maintenance and Troubleshooting of Air Pollution Control Equipment

Equipment	Indicators	Problems	Recommended Maintenance and Troubleshooting
Quencher	Erratic outlet temperature	• Partially plugged nozzles • High variation in incinerator moisture feed • Low gas flowrate (<30 fps) • Water droplet impinging on thermocouple	• Inspect and replace plugged nozzles • Control moisture feed to incinerator • Increase gas flowrate to design range • Relocate thermocouple, replace defective nozzles
	Consistently high outlet temperature	• Plugged nozzles • Low water flowrate and high temperature • Excessive gas speed (>50 fps)	• Inspect and replace plugged nozzles • Calibrate water flowmeter; adjust to 50-80 percent of evaporation loss • Reduce gas flowrate
Venturi scrubber (conventional and IWS)	Erratic pressure differential	• Plugged nozzles • Adjustable throat diameter is too wide	• Inspect headers, flanges and nozzles • Reduce throat diameter and adjust liquid flowrate • Inspect throat regularly for deposits and wear
Absorption scrubber	Surging pressure differential (>10 %)	• Face velocity in excess of 12 fps • Plugged tray sections • Nonuniform scrubber liquor distribution • Leaking seals • Localized plugging of packing • Hole in the packing	• Inspect spray nozzles, water flowrate, weir bozes, seals, and downcomers for proper operation. • Inspect packing, adjust caustic concentration to 15-20 percent.
Fabric filter	Excessive pressure differential	• Excessive gas flowrate • Bag blinding (high dust loadings) • Leaking air lock or dampers • Faulty cleaning mechanism • Excessive dust accumulation in clean side of bags	• Reduce gas flowrate; check bleed air • Inspect cleaning mechanism; replace bags • Check proper temperature of gas to prevent condensation • Inspect proper removal of collected ash from hoppers
Electrostatic precipitator	Excessive sparking rate Intermittent smoke "puff"	• High moisture in gas • Excessive voltage and current settings • Improper sampling or cleaning frequency • Poor incinerator operation • Overload of ash hoppers	• Reduce moisture feedrate • Adjust setting assembly • Adjust rapping cycle • Inspect waste feed to incinerator • Inspect hopper for excessive deposits

6.2 Safety and Waste Cutoff Interlocks

The operating permit should also specify that all alarms, automatic waste cutoff systems, and emergency shutdown interlock systems be routinely checked to verify operational status. This I&M activity is particularly critical to the operation of the facility because the failure to interrupt waste feed during an operational upset could result in a dangerous situation. Therefore, and as required under 40 CFR 264.347(c), all automatic waste feed systems and associated alarms should be tested on at least a weekly basis. Checking at a lesser frequency, up to a monthly basis can be allowed if adequate and if more frequent testing can be shown to unduly upset operation.

APPENDIX A

Sources of Further Information

This document is part of the Hazardous Waste Incineration Guidance Series prepared by the EPA to assist both the applicant and the permit writer in the RCRA process leading to a final operating permit for hazardous waste incinerators.

Hazardous Waste Incineration Guidance Series

Volume I

Guidance Manual for Hazardous Waste Incinerator Permits. Mitre Corp. NTIS PB84-100577. July 1983. (Document is scheduled for revision.) Describes the overall incinerator permitting process, highlights the specific guidance provided by other manuals, and addresses permitting issues not covered in the other manuals such as treatment of data in lieu of trial burn. Thus, it can be viewed as a road map and a good summary of all permitting issues.

Volume II

Guidance on Setting Permit Conditions and Reporting Trial Burn Results. Provides guidance to the permit applicant on reporting trial burn data and to the permit writer on translating these data into meaningful and enforceable operating conditions for incinerators. Acurex Corp. 1989.

Volume III

Hazardous Waste Incineration Measurement Guidance Manual. Midwest Research Institute. 1988. (Draft under EPA review.) Addresses monitoring, sampling, and analytical instrumentation and the test methods required for trial burn testing and enforcement activities. Sampling and analysis methods for multimedia emission evaluations including quality assurance/quality control are also discussed.

Volume IV

Guidance on Metals and Hydrogen Chloride for Hazardous Waste Incinerators. Versar, 1989. (Draft under EPA review.) Specific guidance on limiting metals emissions from incinerators is provided. In particular, a risk assessment approach to setting limits on metal components inthe waste is employed. Guidance is also provided on doing risk-based checks on HCl emissions. (NOTE: Earlier title was: *Guidance for Permit Writers for Limiting Metal and HCl Emissions from Hazardous Waste Incinerators*.)

Volume V

Guidance on PIC Controls for Hazardous Waste Incineration. Midwest Research Institute. 1989. (Draft under EPA review). Details the specific permit requirements for CO and total hydrocarbon (THC) emissions from hazardous waste incinerators in the RCRA system. Emission limits for CO and THC and the rationale for their selection are discussed. (NOTE: Earlier title was: *Guidance on Carbon Monoxide Controls for Hazardous Waste Incineration*.)

Volume VI

Proposed Methods for Measurement of CO, O_2, THC, HCl and Metals at Hazardous Waste Incinerators. 1989. Presents a draft measurement method for the above parameters including performance specifications for continuous CO monitors.

Other Reference Documents

1. *Engineering Handbook for Hazardous Waste Incineration*. EPA Publication SW-889. September 1981.

2. *Practical Guide - Trial Burns for Hazardous Waste Incinerators*. Midwest Research Institute. EPA Publication No. 600/2-86-050. 1986

3. *Trial Burn Observation Guide*. Midwest Research Institute. 1988. (Draft under EPA review). Includes general guidance on preparation, on-site activities, and reporting aspects of observing a trial burn test.

4. *Background Information on Sampling and Analysis Methods Related to the Amendments to the Incinerator Regulations and to the Regulations on Boilers and Industrial Furnaces.* Midwest Research Institute. 1988. (Document under preparation.) Includes descriptions of recommended sampling and analysis methods.

APPENDIX B
Guidance For Incinerator Design Review

During the process of permitting a hazardous waste incinerator, the permit writer must make a number of engineering assessments. Before approving the trial burn, the permit writer must be assured that the design is adequate to protect human health and the environment. After the trial burn, the permit writer must be assured that the trial burn data are consistent and believable and that the data can be properly interpreted to establish a flexible set of permit conditions which are in compliance with performance standards. This appendix gives the permit writer background on incinerator design so that an application is reviewed to:

1. Ensure that there are no major design flaws of sufficient magnitude to render a trial burn unsafe
2. Ensure that the trial burn will generate sufficient verification information so that trial burn data may be properly interpreted and evaluated

In pursuit of the first objective, the permit writer should remember that the key phrase is "major design flaws." Incinerator design information available to the permit writer is not so universally applicable that a prior prediction of incinerator performance could be made with confidence; otherwise, there would be no need for trial burns. An example of a major design flaw would be an incinerator that is predicted to operate 200°C (390°F) lower than its design temperature but has inadequate auxiliary fuel provisions to make up the difference. An example of a minor design flaw is an incinerator that is predicted to operate 200°C (390°F) hotter than its design temperature.

The design review is most applicable to new incinerators which must be permitted before they can be built. For existing facilities, one can generally determine from observation of the unit or from operating data that it can attain specifications such as trial burn temperature and sufficient quench water flow to achieve the desired APCE temperatures.

The permit writer should perform the following steps for a design review:

1. Review the overall facility design and system schematics
2. Review thermal treatment equipment design
3. Estimate temperature and gas residence time and verify other control parameters for internal consistency
4. Review APCE design and estimate efficiency
5. Review measurement techniques and safety interlocks
6. Consider special wastes and similar systems

B.1 Overall Facility Design

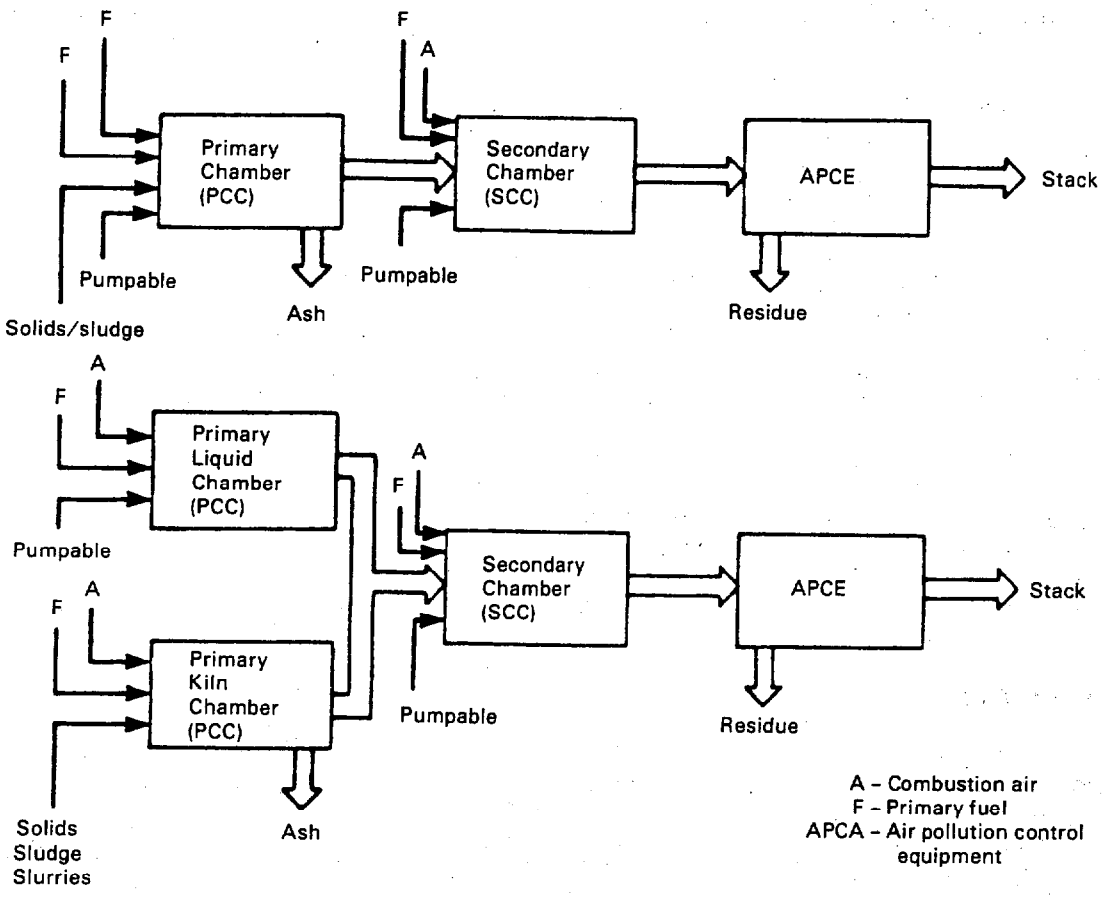
A schematic diagram of the incineration system should always be reviewed by the permit writer. All waste, fuel, air, water, and other input streams as well as the locations of all required measurement, should be labeled on the diagram. The permit writer should determine if all components of the system are being taken into account and that the permit parameters are being set and monitored with the proper measurements.

Figure B-1 provides layouts for typical incinerator facilities. For the most part, these facilities can be viewed as straight-through systems in which wastes are incinerated in single or multiple chambers with further thermal and flue gas treatment occurring downstream. The layout at the top of the figure shows a typical facility where the combustion gases leaving a PCC such as a rotary kiln or liquid injection chamber are further treated with a SCC, which is sometimes called an afterburner. Frequently, the SCC is fired with a liquid organic waste instead of fossil fuel. This practice is quite common as it results in significant cost reductions.

In most cases, flue gas scrubbing for particulate and acid control is required to meet current emission standards. It is important to point out that some facilities do not use afterburners nor APCE. For these units, operation is considerably simplified, but they are restricted to burn essentially ash-and halogen-free wastes to comply with RCRA standards for particulate and acid emissions.

Some commercial facilities use two PCC units, each designed to incinerate a category of wastes; for

Figure B-1 Incinerator equipment arrangements.



example, liquids in a liquid injection chamber and solids/sludges in a rotary kiln. These facilities are designed for maximum waste flexibility and operation. The combustion gases from both chambers are ducted to a common SCC unit for complete incineration of remaining combustible byproducts before scrubbing for particulate and acids takes place.

One other design variation, especially for large commercial incinerators, is heat recovery using waste heat steam generators or boilers. This equipment, which is always found upstream of APCE, is typically a "passive" device where no supplemental firing occurs. Therefore, it requires little or no consideration on the part of the permit writer in setting operating permit conditions. However, in the case where the boiler is supplementarily fired, the permit writer should consider its operation as a tertiary combustion chamber where further waste destruction occurs.

B.2 Incineration Equipment

There are a number of different types of incinerators and many design variations for each type. The permit writer should realize, therefore, that no single design review tool is universally applicable. Thus, it is important for the permit writer to know the basic principles of incineration to perform a "best-engineering" analysis of the design. Towards this aim, this section reviews the principal design features of thermal treatment equipment and specifically provides review guidance for design factors deemed most important to incinerator performance.

As mentioned, incineration of hazardous waste can be accomplished by several types of high-temperature combustion devices. Some of these have a rather long operating experience, other more recently developed types are not yet in widespread use, while still others are currently under research and development. By far the most common

incineration devices or PCC units are the liquid injection chamber, rotary kiln, and fixed hearth. The discussions below focus on these three principal designs that comprise well over 80 percent of the estimated 221 incinerator facilities already permitted or operating under interim status (1). The total thermal capacity of these units is projected at about 650 MW (2,200 x 10^6 Btu/hr) or 93 percent of total incinerator capacity. Table B-1 summarizes major design features, typical operating characteristics, suitable wastes, and other general information pertinent to these incinerator types. For the reader interested in obtaining additional information, Kiang and Metry (2) and Bonner, et al, (3) are recommended as guides. Other information can be obtained directly from incinerator manufacturers.

A section on fluidized bed combustor (FBC) incinerators is also presented below. These units, which represent less than 3 percent of the existing population, are not specifically treated in this permit guidance because of specific design and operating considerations and the inadequate data base on performance characteristics.

B.2.1 Liquid Injection Incinerators

As the name implies, a liquid injection incinerator is designed to burn liquid or pumpable hazardous wastes. The refractory chamber is typically cylindrical and is oriented for either down-firing or horizontal firing. The primary consideration in the selection of the firing orientation is the amount of inorganic ash in the waste and its chemical composition. Waste with a significant quantity of inorganic salts is typically treated in a down-fired system. At the high temperatures required for waste destruction, these salts are liquified; they may adhere to the refractory and form a slag. Removal of the molten slag in the down-fired liquid injection chamber is aided by gravity. However, in a horizontally-fired chamber, this gravity-assisted slag removal is not possible, and deposits of successive layers of ash often accumulate on the lower part of the chamber. Because these increased ash deposits can effectively reduce the available chamber volume, lower gas residence times and reduced gas mixing, increased maintenance, and reduced firing capacity can result. For example, for a 260-KW/m^3 (25,000-Btu/hr-cu ft) liquid injection chamber fired with liquid waste containing 5 percent alkaline salts and low-melting-point metal oxide ash, the accumulation of slag in the chamber could be as much as 15 percent of its volume for 100 hr of operation. For these cases, routine visual inspection combined with practical limits on ash content for horizontally-fired liquid incinerators should be considered by either the facility operator or the permit writer.

Liquid injection incinerators can be fired under positive (forced draft) or negative pressures (induced or balanced draft systems). Typically, positive-pressure chambers are used unless the facility is equipped with APCE. Because high-efficiency APCE often results in high pressure drops, a balanced draft (forced draft-plus-induced draft (FD plus ID)) system is often used. This configuration prevents the PCC unit from operating under excessive positive pressure to overcome flow restrictions in the APCE. To maintain the proper pressure in the chamber is important for equipment safety as well as for fugitive emission control considerations.

Pumpable liquid waste is injected into the chamber through atomizing burner nozzles. The liquid feed system should be properly designed to avoid feed line plugging, excessively variable feed composition, nozzle erosion, and poor atomization. A good, commonly used method of minimizing these problems is the use of waste recirculation at the tank and at the burner.

Other desirable designs include multiple burner arrangements which allow better waste distribution in the chamber, more efficient atomization, and improved turndown firing capability. Preferably, primary combustion air should be injected at each waste burner location to provide stable combustion with rapid droplet vaporization and burnout. Waste heating value is not critical when supplementary fuel (waste or fossil fuel) is available to maintain chamber temperature. For high-water-content waste, the feed rate should not be too high to prevent primary flame quenching, which can be manifest in increased CO and hydrocarbon emissions. The design and operating practices are also important for SCC units or afterburners because liquid wastes are also incinerated in these devices.

A key factor in the performance of liquid injection incinerators is atomization quality, which is defined by the droplet size distribution of the spray. The presence of large drops cannot be tolerated because if the residence time in the combustion zone is insufficient to ensure complete combustion, unburned material may exit the combustion chamber.

Nozzles are typically either internal or external atomizing and mechanical or twin fluid. The difference between an internal and external atomizing nozzle relates to the point in the nozzle where the fluid (waste or fuel) is atomized. While this difference is important in the design and selection of the nozzle, it is not important in the evaluation of a permit application. Mechanical or twin fluid atomizing nozzles are generally employed in liquid injection incinerators. One common type of mechanical atomizer is a simple pressure jet in which the liquid is forced through a constriction; atomization occurs because of the instability of the liquid film formed downstream of the constriction. Droplet size increases with increasing liquid flow and decreasing hole size. Another type of mechanical atomizer is the rotary cup in which a

Table B-1. Incineration Equipment

Equipment Type	Typical Design Features	Suitable Wastes	Other Considerations
Liquid Injection	• Refractory-lined furnace down- or horizontally-fired • Positive pressure or balance draft design • Heat input capacity of 0.37-38 MW(0.125-130 x 10^6 Btu/hr) • Typical L/D = 2 to 3:1 • Heat release rates of 100-370 KW/m^3 (10,000-35,000 Btu/hr-cu ft) • Operating temperatures of 980-1,650°C (1,800-3,000°F) • Gas residence times of 0.3-2 sec	• Primarily pumpable and atomizable liquid wastes • Low- and high-heating value wastes • Halogenated wastes • Organic vapor-laden waste gases	• Supplemental fuels are required for the initial refractory heat-up period and for incineration of LHV wastes • Typically operating with excess air from combustion blower • SCC not always necessary
Rotary Kiln	• Refractory-lined cylindrical rotating furnace mounted horizontally with a slight incline for passage of ash • Negative pressure in the kiln • Heat release rates of 160-470 KW/m^3 (15,000-45,000 Btu/hr-cu ft) • Operating temperatures of 650-1,260°C (1,200-2,300°F) for PCC; 800-1,600°C (1,470-2,800°F) for SCC • Gas residence times of 1-3 sec (in SCC) • L/D of 1:5 for kiln • Variable rotational speed typically in the range of 0.01-1 rpm • Solids retention time of 1-2 hr • Solids waste feed capacity 0.17-0.56 kg/s (1,300-4,000 lb/hr)	• Solid, liquid, and slurry wastes • Contaminated, bulk low- or high-heating value wastes • Suitable for gaseous wastes	• Supplemental fuel is required for the initial heat-up period and for incineration of low heating value wastes • Considerable retention time of solids is required • SCC is required with pyrolytic or excess air combustion
Fixed Hearth	• Single or multiple refractory chambers • Typical waste loading capacity 0.05-0.3 kg/s (400-2,400 lb/hr) • Heat capacity 0.9-5.3 MW (3-18 x 10^6 Btu/hr) • Underfire and overfire air injection designs available	• Primarily solids and sludges • Low- and high-heating value wastes • Halogenated wastes	• Supplemental fuel is required for the initial heat-up period and for incineration of LHV wastes • Typically used for treatment of small quantity of wastes • PCC can be operated with both excess or starved air

liquid jet is impinged on a spinning cup or disk. Centrifugal forces cause the resulting droplets to move radially outward, and the combustion air flow must be used to direct the droplets into a favorable path for combustion within the incinerator chamber. Rotary cup atomizers are used for sludges and slurries because they do not have narrow passages that can be plugged. In the twin fluid atomizer, a second fluid, either high-pressure steam or air, is forced at high pressure and velocity into a slower moving liquid jet, and atomization occurs because of the high shear between the two streams. These nozzles can produce extremely fine drops if sufficient atomization fluid is employed (4).

The permit writer should compare the liquid waste burner specifications with the quantity and properties of the waste to be burned to ensure the following:

- The burner is the appropriate size to handle the range of waste flows expected.
- The viscosity of the waste as fired is not too high.
- The particle size and quantity of solids in the waste are not too high.

B.2.2 Rotary Kiln Incinerators

Rotary kilns are refractory-lined cylindrical chambers positioned with a slight incline from the horizontal plane. The rotation of the kiln promotes the mixing of the solid waste and hot combustion gases and transports the ash down the length of the chamber to the ash hopper. Incinerator facilities utilizing rotary kilns provide the greatest flexibility for hazardous waste disposal. The kiln can accommodate a variety of solids, slurries, and sludge waste streams in containerized form such as fiber packs and drums or as bulk or shredded solids. In addition, the rotary kiln operates as a liquid injection unit because liquid wastes are also injected through atomized waste feed burners. Existing rotary kiln capacities range as high as 44 MW (150 x 10^6 Btu/hr), and larger commercial facilities are under construction. Chamber operating temperatures are typically below 1,090°C (2,000°F), with many units operating with exit gas temperatures as low as 650°C (1,200°F).

Several factors should be scrutinized when rotary kiln designs and trial burn data are reviewed. Waste devolatilization, ash retention time, and particulate entrainment have a strong influence on the

performance of rotary kilns and should be considered, or computed, as follows.

Waste Devolatilization
Wastes are generally fed to kilns in batches, often in disposable drums that cause cyclical transient behavior. When a batch first enters the kiln, it heats up, dries, and devolatilizes, consuming heat and cooling the kiln. Then the volatiles burn very quickly; the rate is limited only by turbulent mixing and the availability of oxygen. The rapid burning can cause a rapid increase in gas temperature and decrease in the excess air level. These transient effects of batch feeding become more pronounced with increasing charge size, volatile content, and kiln temperature. Kilns are generally run at high excess air levels (often 100 percent or more) to allow for these transients. After the volatiles are released and burned, the remainder of the heat content of the waste burns relatively slowly.

Ash Retention Time
Kiln ash retention time is inversely proportional to kiln slope and rotational speed and is directly proportional to the length-to-diameter ratio. It may be estimated according to the U.S. Bureau of Mines (1927) formula (5):

$$\theta = 0.19L \div NSD$$

where:

- θ = Ash retention time, min
- L = Kiln length, m
- D = Kiln diameter, m
- N = Kiln rotational speed, rpm
- S = Kiln slope, m/m

Particulate Entrainment
Particulate entrainment in a rotary kiln depends primarily on the size and density of the solids, the velocity and properties of the gas, and kiln design and operating conditions. The subject has been treated by Khodorov (1961) and by Li (1974) (6):

$$W = K_2\left(DFNS^{-1}\theta^{1/2}\right)^{1/2} \frac{U^4 \mu^{3/2} \rho}{d^{3/2} D^{3/4} D_s^3 n f(C_f)}$$

where:

- W = Entrainment rate, kg/s
- K_2 = Proportionality constant which varies with the roughness between the cylinder wall and feed solid
- D = Inside diameter of the cylinder, m
- F = Solid feed rate, kg/s
- N = Cylinder rotation speed, radians/s
- S = Cylinder slope, m/m
- θ = Dynamic angle of repose of the solid, radians
- U = Gas velocity, m/s
- μ = Gas viscosity, N s/m^2
- ρ = Gas density, kg/m^3
- d = Solid density, kg/m^3
- D_S = Diameter of the feed particles, m
- n = Solid particle size distribution parameter
- $f(C_f)$ = Modification parameter, which is a function of the concentration of entrainable fines in the solid

Incineration of bulk solids and containerized hazardous wastes requires special considerations. The complete burning of solid combustible material requires longer residence times than liquid and gas waste fuels. The length of time, which can be as long as 2 hr, depends on the rate of the mass transfer of the organic component in the solid waste to the gas stream. The rate of mass transfer, in turn, depends on temperature, the size of the solids, the volatile content of the waste, and the degree of mixing achieved. The rate of solid feed, the size of containerized solid waste, the solids loading in the kiln, and the retention time of ash in the kiln are all important considerations for achieving complete combustion of combustible material while retaining sufficient efficiency to destroy volatilized POHCs. Although current RCRA regulations do not address incinerator residue quality (i.e., the degree of complete combustion of the ash leaving the kiln), many States and local regulatory agencies require that the incinerator operate in a manner that avoids creating an ash disposal problem. This requirement imposes routine analyses of the residual ash, with further treatment if necessary, before landfill disposal.

Rotary kilns can operate with excess combustion air or under pyrolytic or oxygen-starved conditions. Typically, excess air is used, thus providing an oxidizing environment which is generally more protective of refractory material. Irrespective of excess air levels, the combustion gases generally pass through a SCC or afterburner to ensure complete combustion of measured organics leaving the kiln unit. For a rotary kiln burning a variety of bulk solids, secondary incineration of combustion byproducts is more critical to efficient destruction than a liquid injection incinerator. Typically, SCC chambers for rotary kiln systems are conservatively designed to provide high temperature and longer residence times. Also, most rotary kilns operate under negative pressure for control of fugitive emissions from waste feed areas and kiln end seals during ash removal. Air pollution control is inevitably required with this incineration system due to the nature of hazardous waste treated.

B.2.3 Multiple Hearth Incinerators
A multiple hearth incinerator typically consists of a series of flat hearths within a refractory shell. Sludge or solid waste is continuously fed through the roof onto the top hearth. Rotating arms cause the waste to drop from hearth to hearth until the remaining ash is discharged at the bottom of the furnace. Air is

preheated as it is used to cool the rotating arms. Additional heat is provided through auxiliary burners. Gas flows countercurrent to the waste and exits at the top of the furnace.

Existing multiple hearth incinerator designs have a heat input capacity of 0.9 to 5.3 MW (3 to 18 x 10^6 Btu/hr). Each chamber is typically equipped with oil or gas burners for startup and supplemental heat requirements. For larger incinerators with capacities greater than 93 kg (200 lb)/hr, solid waste feed and ash removal are automated with hydraulic-ram/hopper or cart-dumping systems.

As with rotary kiln incinerators, the factors of waste devolatilization, ash retention, and entrainment should be considered. Waste bed combustion on the primary chamber grate is typically accomplished at low temperature and with a minimum of underfire air to prevent formation of metallic salts and minimize particulate emissions. Solid waste-charging systems are designed so that volatiles from "fresh" waste pass through the flames in the flame port before entering the mixing chamber. The rate of ignition of unburned solid waste containing high concentrations of volatiles (including moisture) is maximized using small waste feed batches. This operation prevents flash volatilization, which carries the potential for flame quenching and smoke generation. Controlled waste charging also reduces the need for bed stoking required at times to enhance solid waste burnout.

Solids transport is determined by the rotational rate of the rabble arms and the location of the drop holes. Entrainment can occur as the waste drops from hearth to hearth if the opposing gas velocity is greater than the terminal velocity of the waste particles. Entrainment increases with increasing gas flow and with decreasing particle size and density.

B.2.4 Fluidized Bed Incinerators

Although fluidized bed incinerators or combustors (FBCs) represent a minor fraction of the existing waste incinerator population, several design and operating advantages of these units are likely to result in increased use of these equipment types in the thermal destruction of hazardous waste. The FBCs are typically simple, compact combustors that provide efficient destruction of a wide variety of wastes (i.e., solid, liquid, and gaseous) at low temperature. The main chamber consists of a bed of hot inert material which is fluidized with 0.76 to 2.4 m/s (2.5 to 8.0 fps) combustion air. Bed temperature is typically maintained in the range of 450 to 850°C (840 to 1,650°F). Waste incineration occurs in and above the bed (freeboard area) where temperatures can reach 980°C (1,800°F). The bed material can be selected to maximize retention of halogenated acids and metallic oxides, thus reducing the emission burden to the APCE. For several FBC designs, a high residence time of liquid and solid waste in the hot bed is achieved. Circulating bed combustors (CBCs) are designed for increased reentrainment of solids in the gas stream leaving the chamber. The solids are then captured in a downstream cyclonic hopper and reinjected into the PCC. This CBC design essentially extends the bed volume to the entire primary chamber in comparison with conventional FBC design.

Aside from temperature, the primary design factor to be considered is the gas velocity, which must be high enough to maintain bed fluidization but low enough to prevent bed attrition. It is constrained by the terminal velocity of the bed particles and is, therefore, a function of the particle size. Superficial velocities in the range of 1.5 to 3 m/s (5 to 10 fps) are common. Entrainment from a fluidized bed occurs when the terminal velocity of the waste (or bed) particles is less than the velocity of the gas in the freeboard space above the bed. Entrainment increases with increasing gas flow and with decreasing particle size and density.

B.3 Temperature and Gas Residence Time

Incinerators allow for the destruction of hazardous wastes by providing high temperature and sufficient time in an oxidizing environment for the waste to burn such that harmless or easily removed products such as O_2, H_2O, HCl, and ash remain. The permit writer should perform specific calculations to determine if the temperatures and gas residence times reported in the trial burn plan are reasonable and can be expected to be demonstrated in the trial burn.

B.3.1 Calculation Technique

This section presents a technique by which the permit writer can calculate the temperature and gas residence time in the combustion chamber of an incinerator using the waste feed and design data as presented in a permit application. It should be kept in mind that every incinerator is unique and that application of this generalized technique to a particular incinerator may be inaccurate. When possible, a detailed energy and mass balance (E&MB), as described in Appendix E, should be performed. An E&MB is capable of computing not only both temperature and residence time but also many operational parameters. It can, therefore, be used as a tool to verify information developed from the trial burn itself. Nevertheless, generalized correlations such as those presented in this section are useful to illustrate trends and to extrapolate data over a limited range.

Residence time and effluent flow in an incinerator largely depend on total air flow to the incinerator. A fair approximation of residence time can be made

using the ideal assumption that only air flows through the incinerator, resulting in equation 1:

$$\tau_{ideal} = 353VP \div m_{air}T \quad (1)$$

where:

τ_{ideal} = Ideal incinerator residence time, s
V = Volume of the combustion chamber, m^3
P = Pressure of the combustion chamber, atm
m_{air} = Total flow of all air including leaks into the combustion chamber, kg/s
T = Combustion chamber temperature, °K

This approximation can be made because most of the volumetric throughput in an incinerator is due to air and because combustion of most fuels and wastes produces about the same number of moles as it consumes.

When the waste has a high aqueous or moisture content or when a significant water stream is fed into the incinerator, equation 1 tends to overpredict residence time, and a correction factor must be applied. Figure B-2 shows the value of this correction factor as a function of the mass ratio of water to air flows to the incinerator, where the water flow includes the sum of all moisture content, aqueous content, or water in all streams input to the incinerator, and the air flow includes the sum of all air flows including leaks. For incinerators in series, residence time of the first unit would be calculated from all air and water flows into that unit alone, but residence time of each succeeding unit would be calculated from all air and water flows into that unit and all units upstream. Residence time can be converted into actual volumetric flow in actual cubic meters per second by equation 2:

$$\text{Volumetric flow} = V \div \tau \quad (2)$$

or to velocity (U) in m/s by equation 3:

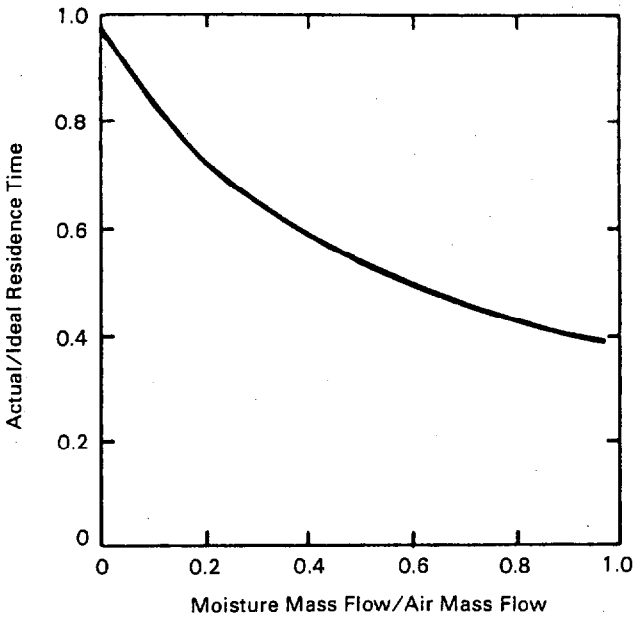
$$U = \text{Volumetric flow} \div \text{Cross-sectional area} \quad (3)$$

where cross-sectional area is in m^2

Temperature in an incinerator can be roughly correlated with the fractional heat loss and the ratio of total heat input to total mass input, as shown in Figure B-3. This correlation assumes that the heat capacity of a combustion mixture is independent of composition, which is a reasonably accurate assumption unless the mixture has a high water content. Figure B-4 shows the correction to the ideal temperature that must be applied to account for water content.

Fractional heat loss is the ratio of heat loss through the walls to total heat input to the incinerator. It is a function of temperature, size, shape, insulation, and

Figure B-2. Actual-to-ideal residence time ratio vs. moisture-to-air mass flow ratio.



heat input. Most hazardous waste incinerators are fairly well-insulated and have a fractional heat loss of less than 10 percent.

The total heat input to the system includes the sum of all chemical and sensible heat inputs as shown in equation 4:

$$\text{Total Heat Input} = \Sigma \text{ Chemical Heat Input} + \Sigma \text{ Sensible Heat Input} \quad (4)$$

The chemical heat input from a fuel/waste stream is the product of its mass flow and lower heating value (LHV) as calculated in equation 5:

$$\text{Chemical Heat Input} = m_{fuel/waste} \times LHV \quad (5)$$

Because only the higher heating value (HHV) of a fuel/waste is typically measured, the LHV may be approximated from equation 6:

$$LHV = HHV - [(1\text{-MOISTURE})HFAC + MOISTURE]\ 2{,}440 - Cl\ (1 - MOISTURE)\ 1{,}160 \quad (6)$$

where both LHV and HHV are in units of kJ/kg and where MOISTURE is the mass fraction of liquid water in the fuel/waste, Cl is the mass fraction of chlorine in the dry fuel/waste, the combustion water parameter (HFAC) is the ratio of the mass of water generated from the combustion of hydrogen in the fuel/waste to the mass of the dry fuel/waste and 2,440 kJ/kg (1,060 Btu/lb) is the heat of vaporization of water. The final term in equation 6 is not normally seen in the

classical definition of lower heating value, but is used to account for the fact that in most heating value measurements, the chlorine comes out in solution; 1,160 kJ/kg (500 Btu/lb) is the heat of solution of HCl. Figure B-5 shows the difference between higher and lower heating value as a function of MOISTURE and HFAC. For these calculations, all input streams containing liquid water should be considered fuel/waste streams; thus, a pure water stream from equation 6 would have a LHV of -2,440 kJ/kg (-1,060 Btu/lb). The value of the combustion water parameter is calculated from equation 7:

$$HFAC = \left(\frac{H}{1} - \frac{Cl}{35.5}\right)\frac{18}{2} \qquad (7)$$

where H and Cl are the mass fractions of H and Cl in the dry fuel/waste. Figure B-6 shows that HFAC increases sharply with H and decreases slightly with Cl. The sensible heat input of a stream is the product of the mass flow of the stream (m), the mean heat capacity of the stream, and the difference between the preheat temperature ($T_{preheat}$) and the reference temperature. Under most conditions, sensible heat may be approximated with reasonable accuracy from equation 8:

$$\text{Sensible Heat Input} = 1.01\ m\ (T_{preheat} - 298) \qquad (8)$$

where sensible heat is in units of kJ/kg and $T_{preheat}$ is in °K, and 1.01 kJ/kg is the heat capacity of air.

B.3.2 Example Test Case

This section describes an example application of the calculation technique discussed above. The example test case is for a rotary kiln/SCC incineration system that is shown schematically in Figure B-7. Control parameter inputs, which are summarized in Table B-2, were taken from design data supplied by the applicant for a representative operating point.

The rotary kiln has a volume of 160 m^3 (5,650 cu ft), an inside surface area of 320 m^2 (3,440 sq ft), and a 0.21-m (8.2-in) thick refractory covering with a conductivity of 8.2 x 10^{-4} kJ/s-m-°C (5.7 Btu in/hr-sq ft-°F). For the operating point of interest, the rotary kiln has three input streams: waste, steam used to atomize liquid waste, and air. The feed rates for the three streams are 1.05 kg/s (8,330 lb/hr) waste, 0.096 kg/s (760 lb/hr) steam, and 5.39 kg/s (42,800 lb/hr) air, including 0.067 kg/s (530 lb/hr) water vapor in the air. The preheat temperature is 450°K (350°F) for the steam, and 289°K (60°F) for both the waste and the air. The waste stream has an HHV of 7,690 kJ (3,310 Btu/lb), with 1.24 dry weight percent hydrogen, 5.83 dry weight percent chlorine, and 18.47 weight percent water.

Using the above data, the necessary normalized parameters for the rotary kiln may be calculated. To calculate the total heat input, chemical heat from the waste stream must be considered along with the sensible heats of all input streams. For this waste composition, the combustion water parameter HFAC is calculated from equation 7:

$$HFAC = \left(\frac{0.0124}{1} - \frac{0.0583}{35.5}\right)\frac{18}{2} = 0.0968$$

This value of HFAC, combined with a MOISTURE value of 0.1847 and a Cl value of 0.0583, can be used to obtain the LHV of the waste from equation 6:

LHV = 7,690 - [(1 - 0.1847) 0.0968 + 0.1847] 2,440
- 0.0583 (1 - 0.1847) 1,160
= 6,990 kJ/kg (3,006 Btu/lb)

Because the water stream is input in the vaporized form of steam, its LHV is 0. The chemical heat from the waste stream (and the total chemical heat in this case) is calculated from equation 5:

Chemical Heat Input = 1.05 x 6,990
= 7,340 kJ/s (25 x 10^6 Btu/hr)

The mass flows and preheat temperatures of each stream may be substituted in equation 8:

Sensible Heat Input = 5.39 x 1.01 (289 - 298)
= -49 kJ/s (-167,000 Btu/hr) for air,

= -9.5 kJ/s (-31,000 Btu/hr) for the waste, and

= +14.7 kJ/s (50,000 Btu/lb) for the steam,

amounting to a total sensible heat input of -43.8 kJ/s (-150,000 Btu/hr). The total heat input to the kiln may be calculated from equation 4:

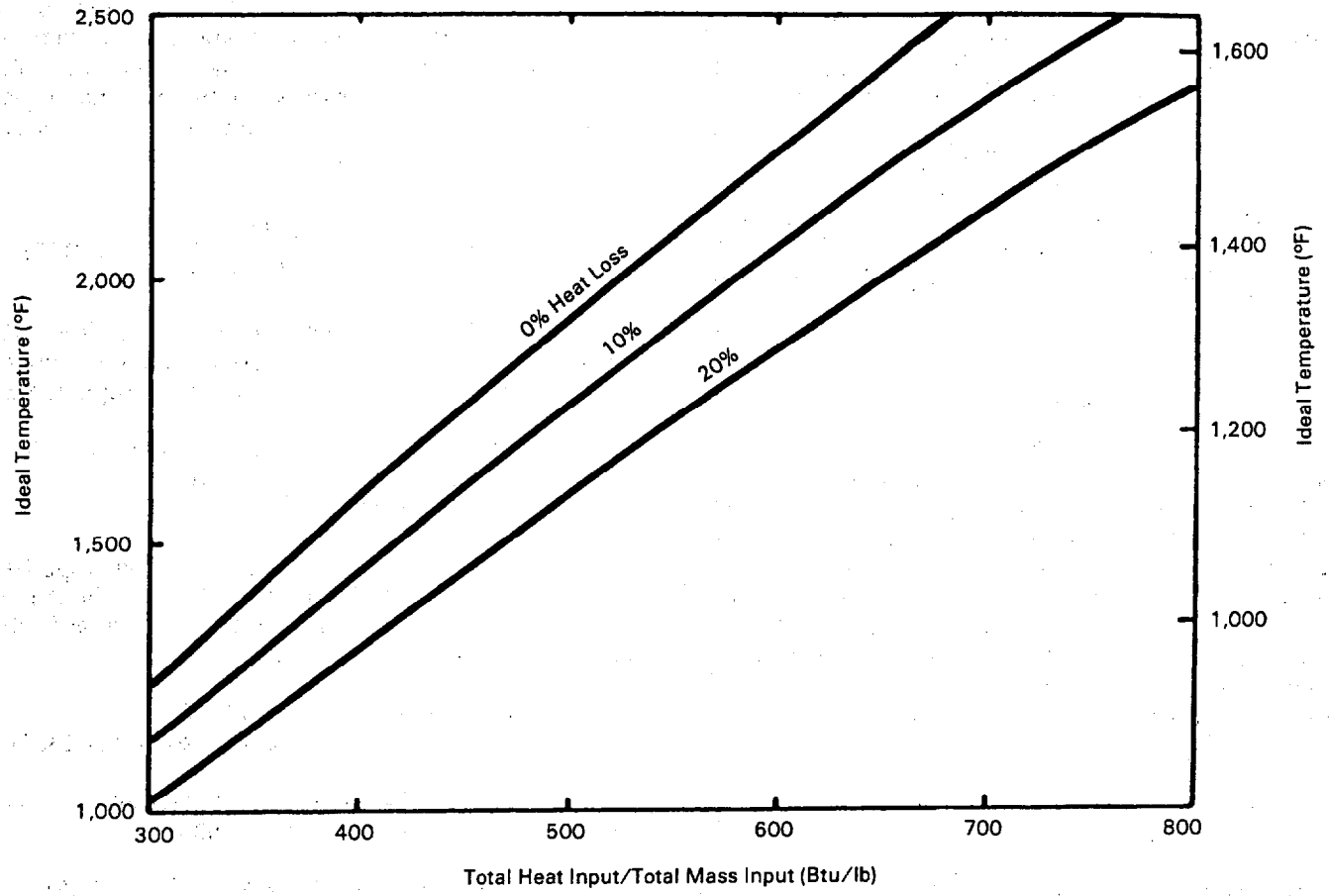
Total heat input = 7,340 - 43.8
= 7,300 kJ/s (24.9 x 10^6 Btu/hr)

Because the sum of all feed rates to the kiln is 6.54 kg/s (51,900 lb/hr),

Total heat input/total mass input
= 7,300 ÷ 6.54
= 1.120 kJ/kg (480 Btu/lb)

Assuming 10 percent heat loss from the kiln, e.g., the example test kiln is very long and, thus, is expected to have a high heat loss, the ideal kiln temperature may be estimated to be 1,200°K (1,700°F) from Figure B-3. This ideal temperature must be corrected to take into account the high heat capacity

Figure B-3. Ideal temperature vs. total heat input to total mass input ratio and fractional heat loss.



of the water in the combustion gas. All three input streams contain water: 0.19 kg/s (1540 lb/hr) in the waste, 0.067 kg/s (530 lb/hr) in the air, and 0.096 kg/s (760 lb/hr) of steam. Thus, there is a total of 0.35 kg/s (2,800 lb/hr) water input to the kiln, which is 5.4 percent of the total input mass flow. From Figure B-4, at an ideal temperature of 1200°K (1700°F) and 5.4 percent water, the actual temperature is predicted to be 34°K (61°F) lower than the ideal temperature, or 1,170°K (1,640°F).

The ideal residence time may be estimated from equation 1:

$$\tau_{ideal} = (353 \times 160 \times 1) \div (5.39 \times 1{,}170) = 9.0 \text{ s}$$

This may be corrected for water using Figure B-2. For $m_{moisture}/m_{air}$ of 0.35/5.39 = 0.065. The ratio of the actual to the ideal residence time is 0.88; thus the estimated actual residence time is 7.9 s. The volumetric flowrate may be calculated from equation 2:

Volumetric Flow = $160 \div 7.9$
= 20.3 m^3/s (43,000 acfm)

To carry out this analysis on the SCC, the procedure is the same except that the mass and energy carried over from the kiln must be considered. The total heat leaving the kiln is the heat entering the kiln minus the 10 percent heat loss which is 7,300 - 0.1 x 7,300 = 6,570 kJ/s (23.2 x 10^6 Btu/hr). However, 0.42 kg/s (3,370 Btu/hr) of ash is removed from this stream before it enters the SCC. From equation 8, the sensible heat of the ash being removed at 1,170 K is 370 kJ/s (1.26 x 10^6 Btu/hr), so that the net heat going from the kiln into the SCC is 6,200 kJ/s (21.2 x 10^6 Btu/hr).

The SCC has a volume of 113 m^3 (4,000 cu ft), and an inside surface area of 147 m^2 (1,580 sq ft). It has a refractory covering 0.21 m (8.2 in) thick with a conductivity of 5.05 x 10^{-4} kJ/s-m-°C (3.5 Btu in/hr-sq ft-°F). In addition to the carryover from the kiln, for the operating point of interest, the SCC has four other input streams: waste, auxiliary fuel, atomizing steam, and air. The feed rates for these streams are 0.26 kg/s (2,060 lb/hr) waste, 0.062 kg/s (490 lb/hr) fuel, 0.093 kg/s (738 lb/hr) steam, and 3.16 kg/s (25,100 lb/hr) air (including 0.04 kg/s [334 lb/hr] water vapor in the air). The preheat temperatures for all fresh streams are 289°K (60°F), except for the steam, which is preheated to 450°K (350°F). The waste stream has a HHV of 23,300

Figure B-4. Correction to ideal temperature vs. ideal temperature and water/total mass flow ratio.

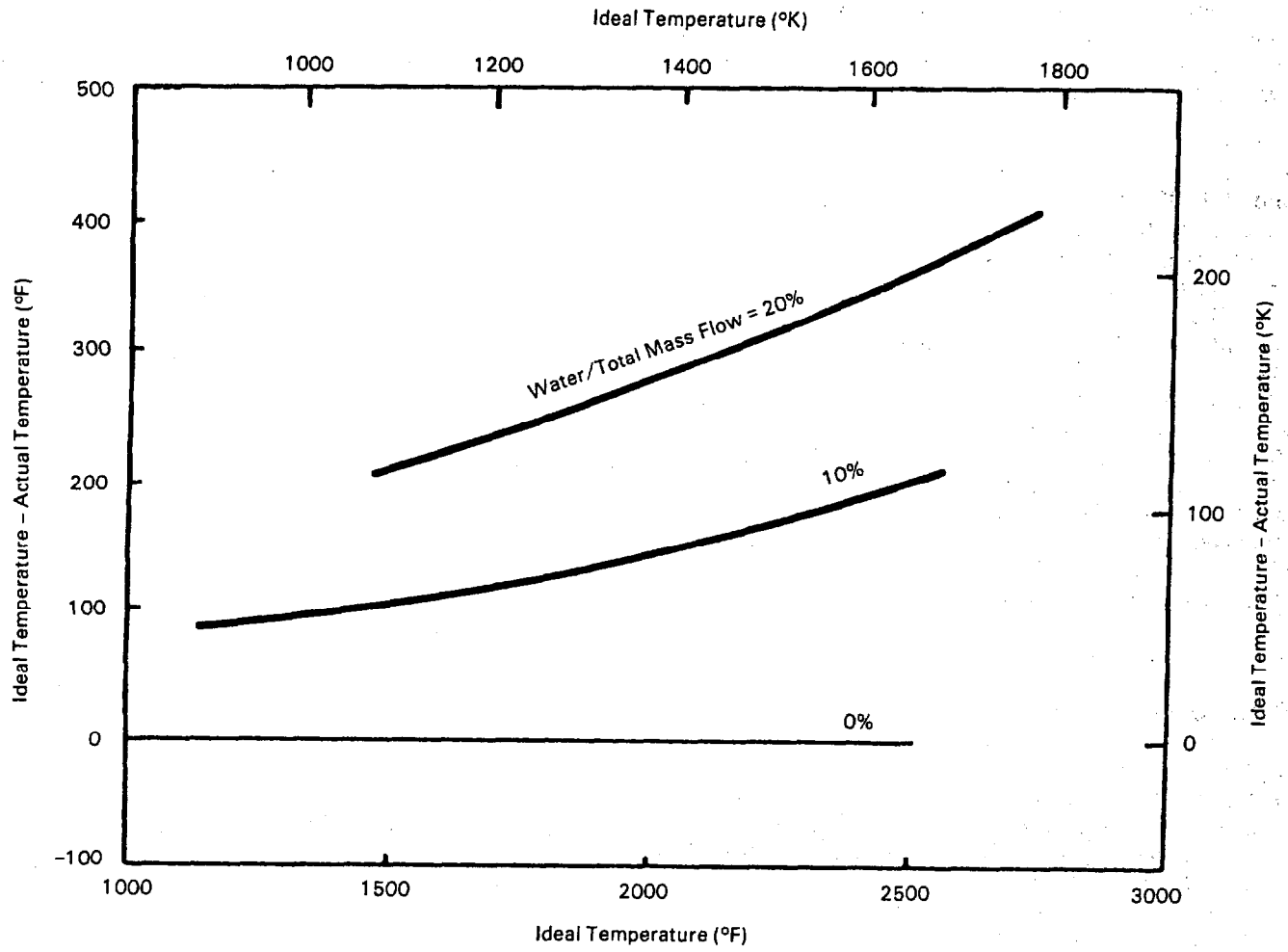


Figure B-5. Difference between higher and lower heat value vs. combustion water parameter and moisture in wet fuel/waste.

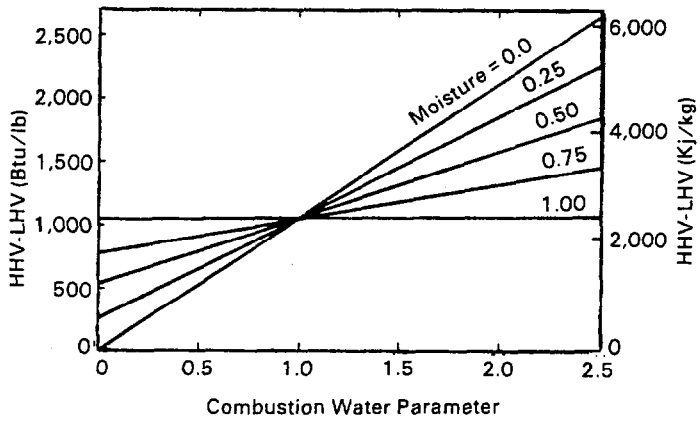
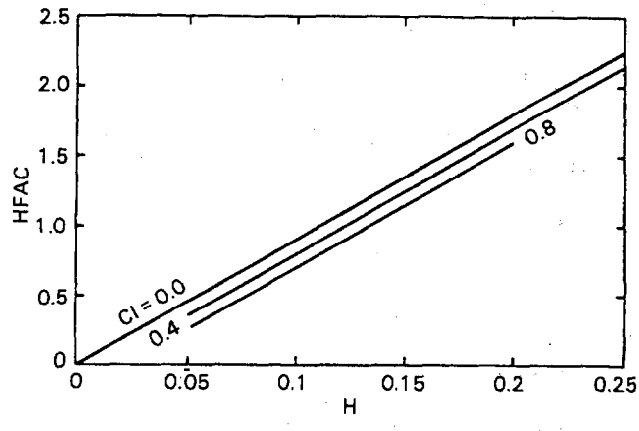


Figure B-6. Combustion water parameter vs. mass fraction H in dry fuel/waste and mass fraction Cl in dry fuel/waste.



kJ/kg (10,000 Btu/lb), with 5.86 dry weight percent hydrogen, 25.70 dry weight percent Cl, and no moisture. The fuel stream has a HHV of 44,000 kJ/kg (19,000 Btu/lb) with 12.65 dry weight percent hydrogen, and no moisture.

Following the same method as for the kiln input streams, HFAC is calculated as 0.4625 for the waste and 1.1388 for the fuel from equation 7. From equation 6, the LHVs are 21,900 kJ/kg (9,420 Btu/lb) for the waste and 41,200 kJ/kg (17,700 Btu/lb) for the fuel. From equation 5, the chemical heat inputs are 5,700 kJ/s (19.5 x 10^6 Btu/hr) for waste and 2,550 kJ/s (8.7 x 10^6 Btu/hr) for fuel for a total chemical heat input of 8,250 kJ/s (28.2 x 10^6 Btu/hr). From equation 8, the sensible heat of the fresh input streams is -2.36 kJ/s (-8,100 Btu/hr) for waste, -0.56 kJ/s (-1,910 Btu/lb) for fuel, +14.28 kJ/s (48,800 Btu/lb) for steam, and -28.72 kJ/s (-98,200 Btu/lb) for air. Thus, the total sensible heat input, including the carryover from the kiln, is 6,180 kJ/s (21.1 x 10^6 Btu/hr). From equation 4, the total heat input to the SCC is 14,400 kJ/s (49.2 x 10^6 Btu/hr). The total mass flow is 9.7 kg/s (77,000 lb/hr), so the total heat/total mass input is 1,480 kJ/kg (640 Btu/lb).

Because the SCC is much shorter than the kiln, a smaller fractional heat loss is expected. Thus, assuming 5 percent heat loss, the ideal afterburner temperature is estimated to be 1,520°K (2,280°F). The air, the steam, and the kiln effluent have a combined 0.48 kg/s (3,800 lb/hr) water, which is 4.9 percent of the total input mass flow. From Figure B-4, the temperature correction is 50°K (90°F), and the estimated actual temperature is 1,470°K (2,190°F).

The ideal residence time from equation 1 is 3.2 s (using the combined air flows to the kiln and the SCC), and the ratio of actual-to-ideal residence time is 0.89. Thus, the estimated actual residence time in the SCC is 2.8 s. The volumetric flow from equation 2 is 40.4 m^3/s (86,000 acfm).

Detailed energy and mass balance calculations were performed for this example using the computer program described in Appendix E. Results of the calculations and correlations were compared with the design calculations of the permit applicant in Table B-3. The program, the correlations, and the design calculations all showed excellent agreement in calculating temperatures and flows. Thus, it can be concluded that these correlations agree quite well with the energy and mass balance program on which they are based. It can also be concluded that this construction permit application is based on reasonable design calculations and that the manufacturer's claims concerning temperatures and flows are achievable.

The energy and mass balance program is the preferred method for performing these calculations. Although the correlations have been shown to be viable, to use them can be tedious. Errors can result from calculational mistakes, inaccurate graph readings, or poor assumptions (such as the assumed heat loss from each combustion chamber).

B.4 Air Pollution Control Equipment

The two kinds of pollutants that emerge from hazardous waste incinerators are gaseous pollutants and particulate pollutants. Because hazardous wastes are often highly chlorinated, the gaseous pollutant of greatest concern is HCl. Flyash comprises most of the particulate pollutants. Flyash particles emerging from incinerators typically have mass mean diameters of >10 μm. However, they have broad distributions; thus, there may be a significant fraction of particles in the submicron range. In addition, high concentrations of toxic heavy metals tend to be found in submicron particles. Therefore, APCE for incinerators burning metal-containing wastes should effectively remove small particles.

Hazardous waste incineration systems generally employ more than one type of pollution control device to remove both particles and gases effectively. The APCE must be properly designed, operated, and maintained to achieve design performance continuously under a variety of incinerator operating conditions. The permit writer must, therefore, review the proposed APCE design as presented in the permit application. It should be assessed for engineering soundness, and an estimate should be made whether the APCE can achieve the performance expected in the trial burn. Calculations should be made to verify many of the system and operating parameters to ensure their consistency and soundness.

Specifically, the APCE specifications should be reviewed to ensure the following:

- Sufficient quench water is available to cool the flue gas to the recommended APCE operating temperature.
- Sufficient fan capacity is available to handle the maximum expected gas flowrate.
- The system can meet the 180 mg/dscm particulate performance standard for the expected particle loading and size distribution.
- The system can meet the 99 percent Cl removal performance standard for the expected total Cl feed rate.

This section will present a brief description of most types of APCE and provide the permit writer with several tools to help verify expected system and operating parameters and performance.

Table B-2. Input Data for Energy and Mass Balance Example

	Feed rate (lb/h)	Preheat (°F)	Proximate analysis (as received) (percent)				Heating value (higher) as recvd) (Btu/lb)	Elemental analysis (dry percent)						
			Fixed carbon	Volatiles	Ash	Moisture		C	H	N	S	Ash	O	Cl
Primary waste	8,330	60	4.42	23.12	53.99	18.47	3,310	22.85	1.24	0.0	3.86	66.23	0.0	5.83
Primary fuel	0	—	—	—	—	—	—	—	—	—	—	—	—	—
Secondary waste	2,060	60	0.0	100.0	0.0	0.0	10,000	55.18	5.87	0.0	1.86	0.0	11.39	25.71
Secondary fuel	490	60	0.0	100.0	0.0	0.0	19,000	87.35	12.65	0.0	0.0	0.0	0.0	0.0
Primary air	42,800	60												
Secondary air	25,100	60												
Secondary water	738	350												
Primary water	760	350												
Ash dropout	3,370													

Design Specifications		Primary	Secondary
Refractory thickness	(in)	8.2	8.2
Refractory conductivity	[(Btu)(in)/(h)(ft^2)(°F)]	5.7	3.5
Unit volume	(ft^3)	5,650	4,000
Refractory surface area	(ft^2)	3,440	1,580
Cooled surface area	(ft^2)	0	0

B.4.1 Wet Systems

Wet APCE is predominant among existing incinerators. Typical equipment that is used includes quench chambers, scrubbers, and wet ESPs. Most systems are designed for particulate control. The capture of HCl also occurs because of the solubility of the acid in water. The control efficiency for HCl can be enhanced by adding a caustic solution to the scrubbing water. Caustics such as NaOH or $NaCO_3$ are also used to control the pH of water recirculated to the wet scrubber. Control of pH requires 1.10 kg of NaOH or 1.46 kg of $CaCO_3$ per kg HCl. Figure B-8 presents a layout of a typical wet control system.

Quench Chambers

The quencher often precedes the scrubber equipment. Its function is to reduce the temperature of the hot gases leaving the thermal equipment units and to increase the humidity of the gases to the saturation point. This action reduces water evaporation in the downstream scrubbing equipment and alleviates the potential problems associated with particle generation in caustic scrubbers. Also, the quencher facilitates particulate scrubbing by initiating particulate agglomeration as well as protecting the downstream equipment from high-temperature damage. Because particulate scrubbing occurs in the quencher, these units are also called spray scrubbers. Designed as integral parts of a venturi scrubber, some quenchers are located at the inlet of the scrubber converging section.

A constant gas temperature at the quencher outlet often signifies proper operation of the unit. This temperature is typically maintained close to the saturation temperature of the gas, 82 to 93°C (180 to 200°F). Often, the quench water is recirculated from the sump back to the inlet to minimize water use. However, even in closed loop systems, some amount of water makeup is required to replace the amount lost through evaporation. Optimum operation would use only makeup water (about 50 to 80 percent of evaporative loss) to minimize reentrainment of particulate back into the gas stream. Quench water requirements to achieve saturation temperature can be calculated as follows:

Table B-3. Comparison of EER Energy and Mass Balance Results with Permit Application Design Calculations

	EER Energy and Mass Balance		Permit Application Design
	Program	Correlations	Calculations
Rotary kiln temp. (°F)	1,623	1,640	1,600
Flow (acfm)	41,821	43,000	41,922
SCC temp. (°F)	2,218	2,190	2,200
Flow (acfm)	85,742	86,000	84,668

$$M_W = \frac{18\left(\bar{P}_{H_2O}\right)}{MW_{DG}\left(P - \bar{P}_{H_2O}\right)}\left(M_{DG}\right) \qquad (9)$$

where:

M_W = Quench water feed rate which yields saturation (lb/hr).

$\bar{P}_{H_2O}$ = Vapor pressure of moisture (psia) (function of inlet gas temperature).

MW_{DG} = Dry gas molecular weight.

$\bar{P}$ = Absolute pressure (psia).

M_G = Dry gas mass flowrate (lb/hr).

Up to this quench feed water rate, both sensible and evaporate cooling occur. Any additional quench feed water cools through sensible heat transfer. Generally, for quench/venturi scrubber applications, only 80 percent of the evaporate water loss (FW) is recommended for the quench chamber with a gas temperature slightly above saturation (e.g., 93°C [200°F]). The total water vapor mass flowrate leaving the quench is:

Figure B-7. Schematic of incinerator for energy and mass balance example.

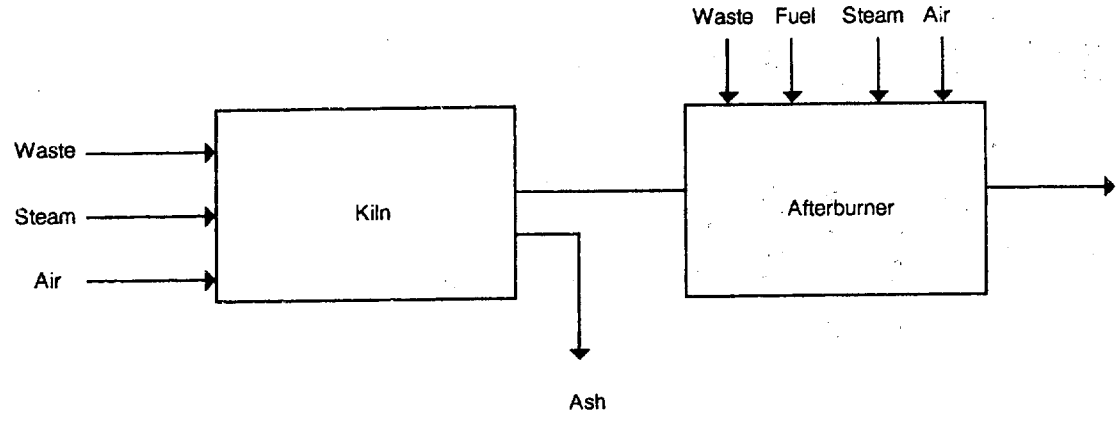
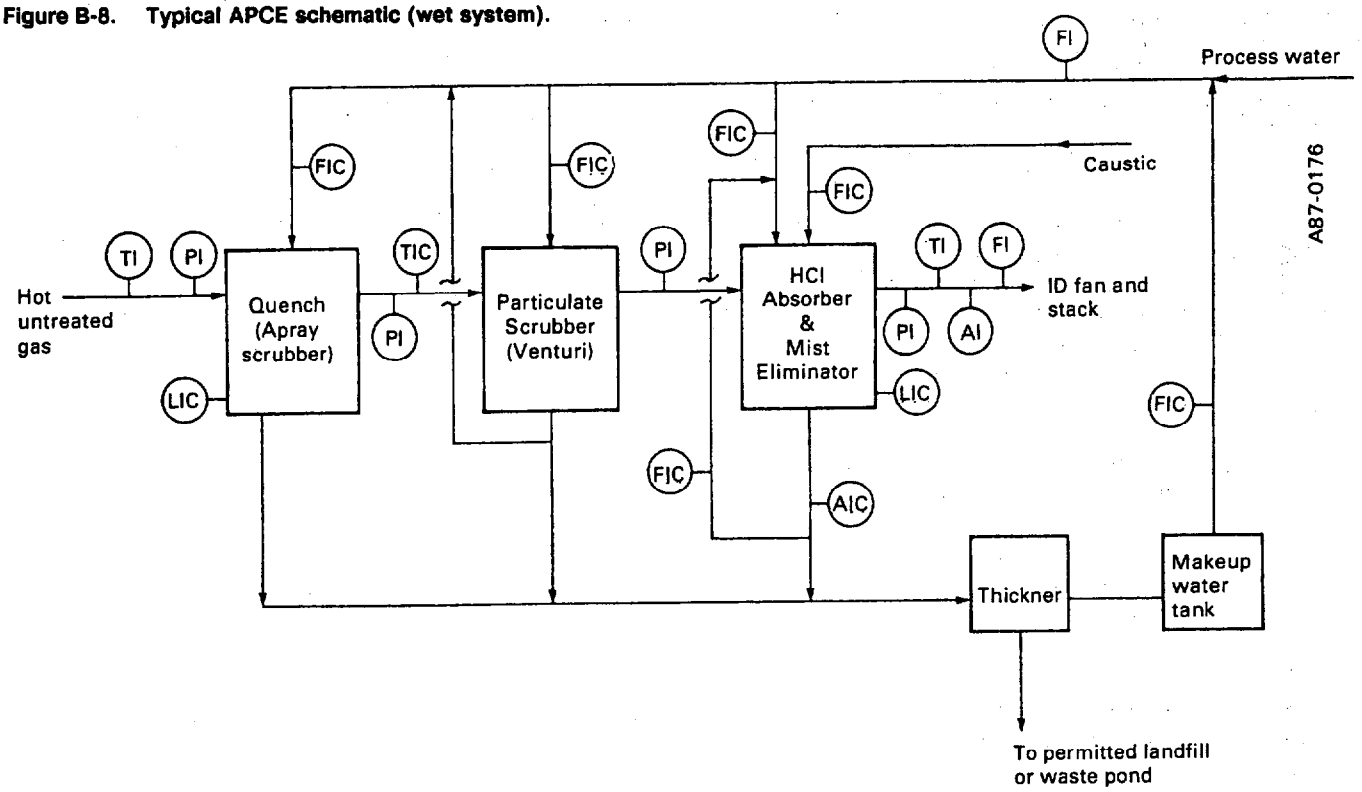


Figure B-8. Typical APCE schematic (wet system).



TIC - Temperature indicator controller
LIC - Level indicator controller
FIC - Flow indicator controller
PI - Pressure indicator
FI - Flow Indicator
AIC - Analysis (pH) indicator controller
AI - Analysis (O_2, FO, CO_2) indicator

$$F_{H_2O(out)} = M_W + F_{H_2O(in)} \quad (10)$$

where:

$F_{H_2O(in)}$ = Mass flowrate of water vapor in entering gas, (lb/hr).

A regimented maintenance program for the quencher should be followed to ensure that effective water spray (unobstructed nozzles) is retained.

Several types of wet scrubbers are used in industry. Despite their low mechanical efficiency, the adjustable and fixed throat venturi scrubbers are most commonly used for incinerator applications because of their high particulate collection efficiency. Other scrubber devices include packed bed (vertical and horizontal), tray or plate, impingement, entrainment, mechanically aided, and ionized scrubbers. They remove gaseous pollutants through the mechanism of absorption. Alkaline scrubbing solutions are often used to increase the rate of mass transfer and to neutralize acids.

Packed-Bed Scrubbers

Absorption removal efficiency for packed-bed scrubbers can be described by the number of transfer units attained by a device. Efficiency increases with increasing number of transfer units. The number of transfer units can be found from:

$$N_{TU} = Z \div H_{TU} \quad (11)$$

where:

N_{TU} = Number of transfer units
Z = Scrubber length (m)
H_{TU} = Height of a transfer unit (m)

The number of transfer units increases, and, thus, efficiency increases with increasing scrubber length. The height of a transfer unit is generally determined empirically for different packed-tower configurations. The height of a transfer unit generally decreases, and, thus, efficiency increases with increasing L/G ratio, packing interfacial area, and gas diffusivity.

Venturi Scrubbers

Venturi scrubbers atomize water into small droplets and then use the droplets to collect particles. Efficiency generally increases with increasing L/G ratio, throat velocity, and particle size. Particle

collection efficiency in a venturi scrubber can be estimated using the equation of Calvert (1972) (7):

$$\text{Efficiency} = 1 - \exp[(QL/QG) \times UG \times F(Kp)] \quad (12)$$

where:

QL = Liquid flowrate (m^3/s)
QG = Gas flow velocity (m^3/s)
UG = Gas throat velocity (m/s)
Kp = Inertial impaction parameter (a function of particle size)

This equation and Figure 2-3 show that scrubber efficiency is a function of the pressure drop across the venturi, which can be estimated using the following empirical equation (8):

$$\Delta P = \frac{V_T^2 \rho_G A_T^{0.133} L^{0.78}}{1{,}270} \quad (13)$$

where:

ΔP = Pressure drop in H_2O
V_T = Throat velocity (fps)
ρ_G = Gas density (lb/cu ft)
A_T = Area of throat (sq ft)
L = L/G ratio (gal/1,000 cfm)

For a fixed gas flowrate and throat area, control of ΔP inherently controls the amount of liquid or L/G ratio required. Typically, the higher the ΔP, the greater the efficiency. Some scrubbers at existing incinerators operate with ΔP as high as 2.0 m H_2O (80 in W.C.) or higher. Venturi scrubber operation is optimum when the ΔP is maintained relatively constant (<5 percent variation in ΔP), which can be achieved by proper setting of the liquid flow and adjustment of the throat when allowable. Routine maintenance of the nozzles and visual inspection of the critical parts of a scrubber (e.g., throat) are important for the equipment to maintain design performance.

Scrubbers in general can also be used for acid emission control by adding caustic solution to the spray water. Although venturi scrubbers can be used to absorb HCl, the most commonly used absorbers are the packed, tray, or spray towers. Good absorption efficiency is primarily a function of L/G distribution, alkaline concentration of scrubbing solution, gas, water temperature, and gas residence time (face velocity). For packed-bed scrubbers, the packing depth (Z) is defined as follows (3):

$$Z = 4.6\,ACFS \div Kga\,P$$

where the constant 4.6 is determined by the natural logarithm of the scrubbing efficiency (e.g., ln 100/1 for 99 percent efficiency), ACFS is the actual cu ft/s of the flue gas, P is the total pressure, and Kga is the absorbing capacity of the scrubbing solution as shown in Table B-4. From these data, it is evident that when excessive Cl_2 is anticipated, a caustic solution is necessary to absorb the free chlorine, whereas HCl can effectively be scrubbed with water because of its high solubility.

Table B-4. Typical Values of Kga (B-3)

Gas	Scrubbing Solution	Kga, (lb/mole)/(in-H_2O-cu ft-sec)
Cl_2	NaOH	1.4×10^{-5}
HCl	H_2O	1.1×10^{-5}
SO_2	NaOH	4.8×10^{-6}
SO_2	H_2O	2.2×10^{-7}
Cl_2	H_2O	9.5×10^{-8}

The packing material and tray and plate arrangement also provide the mechanism for particulate collection utilizing the hydraulic energy of the liquid and mass transfer of the solids from the gas into the scrubbing liquid. As in the quencher and venturi, the scrubbing water or liquor is recirculated. This process requires careful monitoring of the solids and pH level of the scrubbing solution to maintain equipment design performance. Relatively constant pressure drop across these units is also indicative of good operation. Because localized plugging may occur in these units, routine maintenance and inspection are necessary.

All scrubbers are equipped with separators or demisters. These are passive units which are designed to trap water droplets entrained with the flue gas prior to the stack. Although important for system design evaluation, this equipment requires little or no consideration in the operating permit once its design has demonstrated compliance with the particulate emission standard.

Additional wet particulate control devices are electrically-induced systems such as the IWSs and wet ESPs. These units compensate for the lower kinetic energy of high-pressure-drop systems by ionizing the gas stream. Performance of these units is strictly a function of secondary voltage and electrical current, gas flowrate, and scrubber water flowrate. Ionized wet scrubbers combine the principle of electrostatic particle charging with packed-bed scrubbing technology. A constant DC voltage is applied in the ionizing section. Because wetted positively charged plates are continuously flushed, the buildup of a resistive layer is prevented. The flue gas leaving the ionizing section is further scrubbed in a packed-bed. The efficiency of IWSs is relatively insensitive to particulate resistivity, but control of constant voltage and packed-bed scrubbing water flowrate is required.

B.4.2 Dry Systems

The most commonly used dry particulate collection systems are mechanical collectors, ESPs, and FFs. Although these alternative control devices are currently less popular than their counterpart wet systems for complete emission control, these alternative control devices may be the systems of choice for future incinerator facilities because they require reduced residue handling and disposal requirements. Several of these technologies are currently used in combination with wet technologies.

Mechanical Collectors

Mechanical collectors remove particles through the forces of inertia and gravity. Cyclones are the most common type of mechanical collectors. In a cyclone, the air flow impinges tangentially onto the inner wall of a cylinder. Particles strike the cylinder wall and then slide down into a hopper, where they are removed. The most important operating parameters are particle size, gas flowrate, and cyclone design geometry. Cyclone efficiency can be estimated using the equation of Lapple (1951) (9):

$$\text{Efficiency} = \frac{1}{1+\left(K_\mu / V_\rho\right)/d_p^2} \qquad (14)$$

where:

- K = Cyclone geometry factor (m)
- μ = Gas viscosity (kg/m-s)
- V = Inlet gas velocity (m/s)
- ρ = Particle density (kg/m3)
- d_p = Particle diameter (m)

Cyclones are not highly efficient (e.g., <90 percent control), but they are inexpensive, and, thus, are often used as methods of pretreatment before other APCE.

Electrostatic Precipitators

Electrostatic precipitators remove particles by charging them and then collecting them on oppositely charged plates. Plates are periodically rapped to remove the collected particles. The ESPs are highly efficient, even for submicron particles. For example, typical ESP efficiency might exceed 99 percent for 5 mm particles, dip to 95 percent for 1 mm particles, and again increase to above 99 percent for 0.1 mm particles. Submicron particle collection efficiency is high because the mechanism of Brownian diffusion increases the ability of submicron particles to migrate to collection plates. Collection efficiency increases with increasing plate area and applied voltage and decreases with increasing gas flowrate. ESP efficiency can be predicted using the Deutsch equation:

$$\text{Efficiency} = 1 - \exp\left(\frac{-AW}{Q}\right) \qquad (15)$$

where:)

- A = Plate area (m^2)
- W = Particle drift velocity (m/s) (a function of applied voltage and particle size)
- Q = Gas flowrate (m^3/s)

Dry ESPs are much more efficient in capturing small size particles (<10 µm) than cyclones. Contrary to wet ESPs, however, the collection efficiency is also a function of particle resistivity, which, in turn, will vary with waste type burned as well as gas temperature and acid concentration in the flue gas.

Fabric Filters

Filters remove particles by collecting them on filter fibers or on previously collected particles. The most commonly used types are fabric filters (FFs), in which gas flows through parallel arrangements of filter bags. Bags are periodically cleaned by shaking or reversing the air flow. Well-maintained baghouses are highly efficient, but problems may arise if the gas stream has high moisture or acid content or if holes or cracks develop in the bags from manufacturing flaws or aging.

Efficiency increases with increasing pressure drop and decreases with increasing air-to-cloth ratio. Fabric filters often have collection efficiencies in excess of 99 percent, exclusive of water vapor and condensibles. The type of material used for the bags varies with such factors as temperature, humidity, and chemical characteristics of the dust and gases. Maximum gas temperature inlet is typically 260°C (500°F), although it varies according to the type of material. Steady pressure drop across the FF is indicative of good operation with the minimum ΔP defined by the manufacturer for operation with clean bags. Careful temperature control is necessary to minimize water vapor condensation, blinding, and corrosion.

Spray Drying Absorbers

Acid absorption can also be achieved in the gas phase using spray drying absorbers (SDAs). In this process, a solution, slurry, or paste containing an absorbent is atomized and injected into the flue gas. The amount of water injected is not sufficient to lower the temperature to the dew point, and the atomized material is transformed into a dry, free-flowing product. The chemical reaction between HCl and the caustic absorbent occurs in the gas phase in contrast to wet scrubbing devices. Thus, particulate control is necessary downstream of the dry scrubber to prevent the escape of the caustic and salts to the stack.

B.5 Measurement Techniques and Safety Interlocks

The measurement techniques should be reviewed to verify that appropriate QA/QC requirements are met as described in Reference 10. Special attention should be paid to critical measurements such as temperature and gas concentrations.

Thermocouple placements should be so marked that the temperatures that are being measured and reported are clearly indicated. Each thermocouple should be described in the application as to type, sheath or shielding material, sheath or shielding diameter, the proximity and visibility of any flames or cooled surfaces, and the typical condition of the thermocouple during operation, e.g., clean, blackened, or slagged. This information is important because the temperature a thermocouple measures is not truly the gas temperature but is an equilibrium temperature based on radiative and convective heat transfer between the thermocouple and its surroundings. When radiative heat transfer is significant, the thermocouple reading may be too high because radiative heat is transferred from the flame, or it may be too low because the radiative heat is transferred to cooled surfaces or incinerator walls. Radiation becomes more significant for high temperatures, large thermocouple sheaths, blackened thermocouple sheaths, and increased visibility of the flame or cooled surfaces. If these conditions change drastically from those of the trial burn because of change in operation, thermocouple deterioration, or thermocouple replacement, the permit limit temperature as measured by the thermocouple during the trial burn may no longer be the conservative level.

Thermocouple placement is discussed in the *Engineering Handbook for Hazardous Waste Incineration* (SW-889). Briefly, the thermocouple must be placed in the center of a turbulent zone of the gas stream exiting the combustion chamber. It is typically placed as close to the center of the gas flow as possible. Shielding must be provided to prevent direct impingement of radiation from the flame and from glowing portions of the wall onto the thermocouple housing.

Gas concentration measurements can be made on a wet or on a dry basis. Concentrations measured on a wet basis can be substantially lower than those measured on a dry basis, especially if the measurements are taken from the stack gas, which is typically saturated with water. The permit writer should be aware of the basis on which gas concentrations are reported and should take this into account in any calculations such as the energy and mass balance calculations described elsewhere in these appendices.

Automatic waste feed cutoff is required when permit limits for group A and group B parameters are exceeded. The permit writer should examine the schematic diagrams for the instrumentation and control systems to verify that the safety interlocks for waste feed cutoff are tied to the appropriate monitoring devices.

B.6 Special Wastes and Similar Systems

The guidelines for evaluating incinerator design and setting permit limits outlined in this handbook are not universally applicable. For example, a waste with a high content of toxic metals may warrant special consideration. Some toxic metals may vaporize in high-temperature incinerators and condense on the surface of fine particles. If the waste has a high concentration of toxic metals, the permit writer may want to set a maximum and a minimum combustion chamber temperature limit and may want the trial burn to meet fine particulate as well as total particulate emissions standards. Specific guidance on toxic metals from incinerators will be developed by the EPA (see Appendix A).

In evaluating incinerator designs, the permit writer should take into account the design and performance of similar incinerator systems. Such design and performance data may be accessed through the HWCTDB that is maintained at the ORNL.

B.7 References

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APPENDIX C

Time and Temperature Dependency of the Destruction Process

Incineration is a high-temperature oxidation reaction process governed by chemical reaction equilibrium and kinetics. The basic reaction equilibrium parameter is the equilibrium constant at constant pressure expressed mathematically as follows:

$$K_p = \frac{\pi P_{pi}\,\beta i}{\pi P_{ri}\,\alpha i} \qquad (1)$$

where,

$K_p(T) = \exp(-\Delta E/RT)$

Where P_{pi} and P_{ri} are the partial pressures of products and reactants, respectively, and αi and βi are the chemical reaction constants. The equilibrium constant K_p is an exponential function of temperature (T) and free energy (E) of each reaction component. In all practical combustion systems, the chemical reaction involves several intermediate reaction products that exist for a limited amount of time. This time dependency is taken into consideration by chemical reaction kinetics and is expressed as follows:

$$\frac{C_A}{C_0} = -A\Delta\tau\exp\left(-\frac{E}{RT}\right) \qquad (2)$$

where A and E are the organic compound Arrhenius rate constants (determined empirically using laboratory thermal decomposition devices), R is the universal gas constant, T and $\Delta\tau$ are temperature and time available at that temperature, C_A and C_0 are the concentrations of the compound at time τ, and $\tau = 0$, respectively.

These expressions indicate that temperature is the primary parameter in driving reactions to equilibrium and the predominant force of the reaction rate for all chemical compounds. High temperature is also necessary to provide the thermal energy to heat, vaporize, and devolatize organic compounds trapped in the waste feed. Heating, vaporization, and devolatilization are necessary first steps for combustion of fuels and destruction and oxidation of all toxic organic compounds. Thus, temperature in each thermal chamber is the primary control parameter needed to ensure high destruction efficiency (DE) of organics in hazardous waste incinerators. The temperature in each chamber should be controlled to the demonstrated minimum.

The kinetic rate expression suggests that for organics fed in the PCC, the DE ($1 - C_A/C_0$) is the result of a series of decomposition reactions in the PCC and downstream combustion chambers as illustrated by the following expression:

$$\frac{C_A}{C_0} = \prod_{i=1}^{n} \frac{C_i}{C_{i-1}} = -A\sum_{i=1}^{n}\exp\left(-\frac{E}{RT_i}\right)\Delta\tau_i \qquad (3)$$

where C_n is the concentration of the compound at the exit of the n^{th} combustion chamber.

Combustion temperature is dependent primarily on the total heat input (thermal duty), the mass throughput of the gas, and the composition of the reaction products. For relatively constant fractional heat loss through the combustion chamber walls, the temperature rise across a combustion chamber can be determined by the change in enthalpy as follows:

$$DT = \frac{Q}{m}C_p(T) \qquad (4)$$

where m is the mass throughput of the gas, $C_p(T)$ is the specific heat coefficient as a function of temperature, and Q is the net heat input determined on a low heating value basis available after heat loss. For high excess air combustion systems, as is the case for most incinerators, combustion air accounts for most of the gas throughput.

Solution of the kinetic rate expression (equation 2) for the temperature required for 99.99 percent DE is as follows:

$$T_{99.99} = 503E\,(\ln 0.109A\tau)^{-1}$$

This equation can be used to make approximate estimates of gas phase decomposition of the compound under well-mixed conditions. An empirical estimate of 2.6×10^{-6} s^{-1} can be used for this purpose if a better value is not available.

APPENDIX D

Designating Principal Organic Hazardous Constituents

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D.1 Background

The destruction efficiency (DE) of POHCs is dominated by the temperature, time, and fuel/air stoichiometry (excess air) experienced by the POHCs in the high temperature zones of incinerators. Calculations and experimental observations have shown that the emissions of undestroyed, residual POHCs are kinetically (reaction rate), not thermodynamically controlled [Tsang and Shaub (1982), Trenholm, et al (1984)]. Thus, determination of the exact time, temperature, and stoichiometry history of all the molecules in an incinerator is necessary to determine the absolute DE of a POHC. This type of information is, of course, not currently available. However, sufficient information is available to estimate the relative DE of potential POHCs.

Simple conceptual and more complex models suggest that the gas-phase residence time and temperature in the post-flame or thermal zones of incinerators control the relative emissions of most POHCs [Dellinger, et al (1986), Clark, et al (1984)]. The basic reason behind this is that all molecules entering the flame zone of an incinerator are essentially destroyed and only the small fraction escaping the flame zone may be emitted from the facility. Various flame zone "failure modes" exist which may cause residual POHCs to be emitted. Once in the post-flame zone, gas-phase thermal decomposition kinetics control the rate of POHC destruction and PIC formation and destruction.

If all POHCs in a given waste stream in a given incinerator are volatilized at nearly the same rate, they will experience the same post-flame gas-phase residence time, temperature, and stoichiometry history. This means that the gas-phase thermal stability of the POHCs (as determined under a standardized set of conditions) may be used to predict their relative incinerability. The temperature for 99% destruction at 2.0 seconds gas-phase residence time, [$T_{99}(2)(°C)$], is one method of ranking the thermal stability of POHCs. Other residence times or temperatures may be used to develop this ranking. However, laboratory data indicate that although absolute POHC DEs are dependent upon time and temperature, the relative DEs, i.e., incinerability ranking, are relatively insensitive to these parameters [Dellinger, et al (1984), Graham, et al (1986), Taylor and Dellinger (1988)]. On the other hand, stoichiometry has been shown to be a major variable in determining relative stability [Graham, et al (1986) Taylor and Dellinger (1988)].

Theoretical considerations suggest that oxygen-starved pathways through the incinerator are responsible for most POHC and PIC emissions. Even though the facility may be operating under nominally excess air conditions, poor mixing will result in oxygen-deficient pockets where the rate of POHC destruction is low and PIC formation is favored. Consequently, it is believed that gas-phase thermal stability under sub-stoichiometric oxygen conditions is an effective predictor of POHC relative incinerability.

A recent study compared the incinerability predictions of several proposed POHC ranking methods with results of 10 pilot- or full-scale test burns [Dellinger, et al (1986)]. The ranking methods included heat of combustion, autoignition temperature, ignition delay time, flame failure modes, theoretical flame mode kinetics, thermal stability of pure compounds under excess air conditions, thermal stability of mixtures under oxidative conditions, and the thermal stability of mixtures under oxygen-starved conditions. Correlations of the prediction of the rankings with field results were poor except for thermal stability of mixtures under oxygen-starved conditions. Although the laboratory data base used to predict full-scale POHC DREs was very limited, statistically significant correlations in 7 of 10 cases

were observed using this ranking approach. The results of this comparison along with theoretical considerations suggest that this type of thermal stability ranking should be used to replace the previously recommended heat of combustion index.

D.2 Construction of the Ranking

Tables D-1 and D-2 present the incinerability ranking of Appendix VIII organic compounds based on the gas-phase thermal stability under oxygen-starved conditions. This ranking is considered preliminary as actual experimental data has been generated on a limited number of compounds. The ranking is based on available experimental data generated predominantly at the University of Dayton Research Institute (UDRI), limited studies reported in the open literature, and theoretical considerations.

Currently, sixty-one compounds have been experimentally evaluated by UDRI under a consistent set of experimental conditions which was devised based on the previous discussion [Dellinger and Taylor (1987), Taylor and Dellinger (1987)]. These compounds, for which experimental data has been generated which is consistent with available literature data or theoretical consideration, are designated experimentally evaluated and are listed in **boldface**. Compounds which have not been experimentally studied by UDRI under these consistent test conditions, but for which experimental data exist within the open literature, are listed in italics. The remaining compounds were ranked based on limited experimental data on the actual compound, data on similar compounds, and/or reaction kinetic theory. For this latter group, which includes the majority of the ranking, sufficient data were not available to designate the compounds as experimentally evaluated. Thus, their ranking should be considered tentative and subject to change following experimental study.

The ranking was devised by assigning $T_{99}(2)$ values to each compound. For some compounds, initially identical values of $T_{99}(2)$ were assigned resulting in identical rankings. For example, there was no clearcut basis for predicting the relative stability of diphenyl amine, 1,1 dichloroethene, and fluoroacetic acid. Hence, the three compounds received a "tie" ranking as the 41st most stable compound. In other instances, the compounds that were initially assigned identical $T_{99}(2)$ values belonged to homologous series. In this case, the mechanisms of destruction were similar and relative reaction rates could be assigned. This was generally the case for polynuclear aromatics (PNAs); consequently, unique rankings could be assigned for most of these compounds. In general, it was not possible to further distinguish the initial ranking when the compounds in question decomposed by different mechanisms (i.e., "comparing apples and oranges"). In spite of these uncertainties, it is felt that the overall trend is correct. It is generally felt that the uncertainty in predicting $T_{99}(2)$ values, the accuracy of field test data, and the variation in the actual pollutant emissions from facility to facility does not justify a more precise, 1 to 1 ranking of the Appendix VIII organics.

The ranking includes all individually-listed organic compounds included on the current Appendix VIII list. Appendix VIII also lists many compounds by class (N.O.S.) We have generally not included a ranking of individual compounds only included in Appendix VIII as part of an N.O.S. listing. However, many compounds are listed individually and by class. When this occurs, our ranking includes the individually-listed compounds. Exceptions to this rule were made for 1,2,2-trichloro-1,1,2-trifluoroethane, dichlorofluoromethane, chlorodifluoromethane, ethyl chloride, 1,3,5-trichlorobenzene, and 1,2,3,5-tetrachlorobenzene. Experimental data were available for these compounds and they have been of interest as frequently selected POHCs or possible incineration surrogates. Sulfur hexafluoride has also been included in our ranking, although not on Appendix VIII, due to interest in its utility as an incineration surrogate [Taylor and Chadbourne (1987)].

Trace metal-containing compounds were not included in this ranking since the metal itself is a toxic moiety and is not destroyed in the incineration process.

The incinerability ranking will be updated and revised semi-annually as additional experimental data become available and it is possible to expand the list of experimentally evaluated compounds. It is recognized that there may be some errors in this initial ranking due to the lack of a complete data base. However, it is felt that this ranking is already significantly superior to that generated based on the heat of combustion index.

D.3 Using the Ranking

The ranking in Table D-1 is grouped by horizontal lines which separate compounds into nine thermal stability classes, i.e., very stable, moderately stable, fragile, etc. This grouping is generally based on natural divisions in the predicted stability or theory which suggest significantly different mechanistic pathways for the decomposition of compounds within different classes.

One may use the thermal stability ranking in the same manner as the previous heat of combustion index, i.e., selection of a group of POHCs for trial burn testing and only allow POHCs to be burned which are lower in the ranking than the most fragile POHC for which 99.99% DRE can be demonstrated. An alternative approach would be to only allow trial burn testing of experimentally evaluated POHCs, but allow incineration of all POHCs lower in the ranking than

the least stable POHC for which 99.99% DRE can be demonstrated.

Another alternative approach involves the use of the incinerability class divisions. In this approach, one can demonstrate 99.99% DRE of a group of experimentally evaluated POHCs within an incinerability class and receive approval to burn all other POHCs within and below that class. For example, if 99.99% DRE can be demonstrated for chloromethane, acetonitrile, and chlorobenzene, the facility would be allowed to burn any Appendix VIII compound. As a second example, if 99.99% DRE is demonstrated for hexachlorobutadiene, methyl ethyl ketone, and cresol, the facility would only be allowed to burn compounds ranked in class 3 or lower. Since the ranking is subject to semi-annual revision, it is suggested that the ranking which is current when the trial burn is approved be used throughout the permit process unless a change in POHC selection is mutually agreed upon by all interested parties. A summary of the ranking by classes is given in Table D-3.

It should be noted that reformation of a POHC from its own decomposition products or formation of the POHC as a PIC from another waste feed component is generally not included as a factor in this ranking. Significantly, laboratory studies have shown that both POHC reformation and PIC formation can affect observed DEs [Taylor and Dellinger (1988), Dellinger, et al (1988)]. In some instances, it is felt that the laboratory determination of $T_{99}(2)(°C)$ were unavoidably affected by POHC reformation, (e.g., formation of chloromethane from chlorine atom attack on methane). When it was judged that POHC reformation was inevitable from almost any waste, reformation was included in the thermal stability ranking. However, some deviation from the predicted ranking may be expected due to PIC formation. As additional studies concerning PICs are completed, guidelines for evaluating the role of PIC formation will be furnished.

The extensive testing conducted by UDRI has shown that the ranking of most of the compounds is relatively insensitive to composition of the waste mixture. However, a few notable exceptions have been observed in initial tests. This includes aniline derivatives and PNAs in general. Somewhat lesser variability has been observed for benzene, toluene, and pyridine, which were judged to be sufficiently constant to be included as experimentally evaluated compounds. Consequently, it is suggested that the waste composition be carefully considered before these compounds are selected as POHCs. Benzene, toluene, and PNAs are expected to be particularly prone to formation as PICs in full-scale incinerations and observed DREs may be significantly affected. Effects of PIC formation may be minimized by feeding the POHC at a sufficiently high concentration.

Finally, it should be noted that no rankings are given for PCBs which are listed as N.O.S. in Appendix VIII. An estimate of the stability of individual PCB congeners may be made by assuming that the congener is slightly less stable than the chlorinated benzene corresponding to the least chlorinated ring in the PCB congener of interest. This means, for example, that dichlorobenzene would be a suitable incineration surrogate for 2,2',3,3',4-pentachlorobiphenyl, monochlorobenzene would be a suitable incineration surrogate for 3,3',4,5-tetrachlorobiphenyl and pentachlorobenzene would be a surrogate for decachlorobiphenyl. As suitable experimental data is generated, thermal stability data on PCBs will be furnished in the updated ranking.

Although not currently listed specifically on the Appendix VIII list, the incinerability of chlorinated dibenzo-p-dioxin and dibenzofuran isomers are of intense interest. As further testing proceeds, we plan to furnish stability data on these important compounds.

D.4 References

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Table D-1. Principal Hazardous Organic Constituent Thermal Stability Index

Principal Hazardous Organic Constituent	Rank
CLASS 1	
CYANOGEN {ETHANEDINITRILE}	1
HYDROGEN CYANIDE {HYDROCYANIC ACID} [2]	2
BENZENE [2]	3
SULFUR HEXAFLUORIDE [3]	4
NAPHTHALENE [2]	5
FLUORANTHENE {BENZO[j,k]FLUORENE}	6
BENZO[j]FLUORANTHENE {7,8-BENZOFLUORANTHENE}	7
BENZO[b]FLUORANTHENE {2,3-BENZOFLUORANTHENE}	8
BENZANTHRACENE (1,2-) {BENZ[a]ANTHRACENE}	9
CHRYSENE {1,2-BENZPHENANTHRENE}	10
BENZO[a]PYRENE {1,2-BENZOPYRENE}	11
DIBENZ[a,h]ANTHRACENE {1,2,5,6-DIBENZANTHRACENE}	12
INDENO(1,2,3-cd)PYRENE {1,10-(1,2-PHENYLENE)PYRENE}	13
DIBENZO[a,h]PYRENE {1,2,5,6-DIBENZOPYRENE}	14
DIBENZO[a,i]PYRENE {1,2,7,8-DIBENZOPYRENE}	15
DIBENZO[a,e]PYRENE {1,2,4,5-DIBENZOPYRENE}	16
CYANOGEN CHLORIDE {CHLORINE CYANIDE}	17-18
ACETONITRILE {ETHANENITRILE} [2]	17-18
CHLOROBENZENE [2]	19
ACRYLONITRILE {2-PROPENENITRILE} [2]	20
DICHLOROBENZENE {1,4-DICHLOROBENZENE}	21-22
CHLORONAPHTHALENE (1-) [2]	21-22
CYANOGEN BROMIDE {BROMINE CYANIDE}	23-24
DICHLOROBENZENE {1,2-DICHLOROBENZENE} [2]	23-24
DICHLOROBENZENE {1,3-DICHLOROBENZENE} [2]	25
TRICHLOROBENZENE (1,3,5-TRICHLOROBENZENE) [2] [4]	26-27
TRICHLOROBENZENE (1,2,4-TRICHLOROBENZENE) [2]	26-27
TETRACHLOROBENZENE (1,2,3,5-TETRACHLOROBENZENE) [2] [4]	20
CHLOROMETHANE {METHYL CHLORIDE} [2]	29-30
TETRACHLOROBENZENE (1,2,4,5-TETRACHLOROBENZENE)	29-30
PENTACHLOROBENZENE [2]	31-33
HEXACHLOROBENZENE [2]	31-33
BROMOMETHANE {METHYL BROMIDE} [2]	31-33
TETRACHLORODIBENZO-p-DIOXIN (2,3,7,8-) {TCDD}	34
CLASS 2	
TOLUENE {METHYLBENZENE} [2]	35
TETRACHLOROETHENE [2]	36
CHLOROANILINE {CHLOROBENZENAMINE}	37
DDE{1,1-DICHLORO-2,2-BIS(4-CHLOROPHENYLETHYLENE}	38
FORMIC ACID {METHANOIC ACID}	39-40
PHOSGENE {CARBONYL CHLORIDE}	39-40
TRICHLOROETHENE [2]	41
DIPHENYLAMINE {N-PHENYLBENZENAMINE}	42-44
DICHLOROETHENE (1,1-) [2]	42-44
FLUOROACETIC ACID	42-44
DIMETHYLBENZ[a]ANTHRACENE (7,12-)	45
ANILINE {BENZENAMINE}	46-50
FORMALDEHYDE {METHYLENE OXIDE}	46-50
MALONONITRILE {PROPANEDINITRILE}	46-50
METHYL CHLOROCARBONATE {CARBONOCHLORIDIC ACID, METHYL ESTER}	46-50

Table D-1. Principal Hazardous Organic Constituent Thermal Stability Index (continued)

Principal Hazardous Organic Constituent	Rank
METHYL ISOCYANATE {METHYLCARBYLAMINE}	46-50
AMINOBIPHENYL (4-) {[1,1'-BIPHENYL]-4-AMINE}	51
NAPHTHYLAMINE (1-)	52-53
NAPHTHYLAMINE (2-)	52-53
DICHLOROETHENE (trans-1,2-) [2]	54
FLUOROACETAMIDE (2-)	55-56
PROPYN-1-OL (2-) {PROPARGYL ALCOHOL}	55-56
PHENYLENEDIAMINE (1,4) {BENZENEDIAMINE}	57-59
PHENYLENEDIAMINE (1,2-) {BENZENEDIAMINE}	57-59
PHENYLENEDIAMINE (1,3-) {BENZENEDIAMINE}	57-59
BENZIDINE {[1,1'-BIPHENYL]-4,4'DIAMINE}	60-64
ACRYLAMIDE {2-PROPENAMIDE}	60-64
DIMETHYLPHENETHYLAMINE (alpha, alpha-)	60-64
METHYL METHACRYLATE {2-PROPENOIC ACID, 2-METHYL-, METHYL ESTER}	60-64
VINYL CHLORIDE (CHLOROETHENE)	60-64
DICHLOROMETHANE {METHYLENE CHLORIDE} [2]	65-66
METHACRYLONITRILE {2-METHYL-2-PROPENENITRILE} [2]	65-66
DICHLOROBENZIDINE (3,3'-)	67
METHYLCHOLANTHRENE (3-)	68
TOLUENEDIAMINE (2,6-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (1,4-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (2,4-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (1,3-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (3,5-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (3,4-) {DIAMINOTOLUENE}	69-77
CHLORO-1,3-BUTADIENE (2-) {CHLOROPRENE}	69-77
PRONAMIDE {3,5-DICHLORO-N-[1,1-DIMETHYL-2-PROPYNYL] BENZAMIDE}	69-77
ACETYLAMINOFLUORENE (2-) {ACETAMIDE,N-[9H-FLUOREN-2-YL]-}	69-77
CLASS 3	
DIMETHYLBENZIDINE (3,3'-)	78
n-PROPYLAMINE {1-PROPANAMINE}	79
PYRIDINE [2]	80
PICOLINE (2-) {PYRIDINE, 2-METHYL-}	81-84
DICHLOROPROPENE (1,1-) [2]	81-84
THIOACETAMIDE {ETHANETHIOAMIDE}	81-84
1,2,2-TRICHLORO-1,1,2-TRIFLUOROETHANE [2] [3]	81-84
BENZ[c]ACRIDINE {3,4-BENZACRIDINE}	85-88
DICHLORODIFLUOROMETHANE [2]	85-88
ACETOPHENONE {ETHANONE, 1-PHENYL-} [2]	85-88
TRICHLOROFLUOROMETHANE [2]	85-88
DICHLOROPROPENE (trans-1,2-)	89-91
ETHYL CYANIDE {PROPIONITRILE} [2]	89-91
BENZOQUINONE {1,4-CYCLOHEXADIENEDIONE}	89-91
DIBENZ[a,h]ACRIDINE {1,2,5,6-DIBENZACRIDINE}	92-97
DIBENZ[a,j]ACRIDINE {1,2,7,8-DIBENZACRIDINE}	92-97
HEXACHLOROBUTADIENE (trans-1,3) [2]	92-97
NAPHTHOQUINONE (1,4-) {1,4-NAPHTHALENEDIONE}	92-97
DIMETHYL PHTHALATE [2]	92-97
ACETYL CHLORIDE {ETHANOYL CHLORIDE} [2]	92-97
ACETONYLBENZYL-4-HYDROXYCOUMARIN (3-alpha-) {WARFARIN}	98-99
MALEIC ANHYDRIDE {2,5-FURANDIONE}	98-99

Table D-1. Principal Hazardous Organic Constituent Thermal Stability Index (continued)

Principal Hazardous Organic Constituent	Rank
PHENOL {HYDROXYBENZENE}	100-101
DIBENZO[c,g]CARBAZOLE (7H-) {3,4,5,6-DIBENZCARBAZOLE}	100-101
CHLOROPHENOL (2-)	102
CRESOL (1,3-) {METHYLPHENOL}	103
CRESOL (1,4-) {METHYLPHENOL} [2]	104-105
CRESOL (1,2-) {METHYLPHENOL}	104-105
ACROLEIN {2-PROPENAL}	106-107
DIHYDROXY-ALPHA-[METHYLAMINO]METHYL BENZYL ALCOHOL (3,4-)	106-107
METHYL ETHYL KETONE {2-BUTANONE} [2]	108-109
DIETHYLSTILBESTEROL	108-109
BENZENETHIOL {THIOPHENOL} [2]	110
RESORCINOL {1,3-BENZENEDIOL}	111
ISOBUTYL ALCOHOL {2-METHYL-1-PROPANOL} [2]	112
CROTONALDEHYDE {2-BUTENAL} [2]	113-115
DICHLOROPHENOL (2,4-)	113-115
DICHLOROPHENOL (2,6-)	113-115
METHYLACTONITRILE (2-) {PROPANENITRILE,2-HYDROXY-2-METHYL}	116-118
ALLYL ALCOHOL {2-PROPEN-1-OL}	116-118
CHLOROCRESOL {4-CHLORO-3-METHYLPHENOL}	116-118
DIMETHYLPHENOL (2,4-)	119
CLASS 4	
CHLOROPROPENE 3-{ALLYL CHLORIDE} [2]	120
DICHLOROPROPENE (cis-1,3-)	121-125
DICHLOROPROPENE (trans-1,3-)	121-125
TETRACHLOROETHANE (1,1,2,2-) [2]	121-125
TRICHLOROPHENOL (2,4,5-)	121-125
TRICHLOROPHENOL (2,4,6-)	121-125
CHLOROETHANE (ETHYL CHLORIDE) [4] [5]	126
DICHLOROPROPENE (2,3-)	127-130
HYDRAZINE (DIAMINE) [5]	127-130
BENZYL CHLORIDE {CHLOROMETHYLBENZENE} [2]	127-130
DIBROMOMETHANE {METHYLENE BROMIDE} [2]	127-130
DICHLOROETHANE (1,2-) [2]	131
MUSTARD GAS {bis[2-CHLOROETHYL]-SULFIDE}	132-134
NITROGEN MUSTARD	132-134
N,N-BIS(2-CHLOROETHYL)2-NAPHTHYLAMINE {CHLORNAPHAZINE}	132-134
DICHLOROPROPENE (3,3-)	135
DICHLORO-2-BUTENE (1,4-)	136-140
TETRACHLOROPHENOL (2,3,4,6-)	136-140
TETRACHLOROMETHANE {CARBONTETRACHLORIDE} [2]	136-140
BROMOACETONE {1-BROMO-2-PROPANONE}	136-140
HEXACHLOROPHENE {2,2'-METHYLENEbis[3,4,6-TRICHLOROPHENOL]}	136-140
DIOXANE (1,4-) {1,4-DIETHYLENE OXIDE} [2]	141
CHLORAMBUCIL	142
NITROBENZENE [2]	143
CHLOROPROPIONITRILE (3-) {3-CHLOROPROPANENITRILE} [2]	143-144
DICHLORO-2-PROPANOL (1,1-)	145-146
DDD {DICHLORODIPHENYLDICHLOROETHANE}	145-146
DICHLORO-2-PROPANOL (1,3-)	147
PHTHALIC ANHYDRIDE {1,2-BENZENEDICARBOXYLIC ACID ANHYDRIDE}	148-150
METHYL PARATHION	148-150

Table D-1. Principal Hazardous Organic Constituent Thermal Stability Index (continued)

Principal Hazardous Organic Constituent	Rank
NITROPHENOL (4-)	148-150
CHLORODIFLUOROMETHANE [2] [4]	151-153
PENTACHLOROPHENOL	151-153
HEXACHLOROCYCLOHEXANE {LINDANE} [2]	151-153
DICHLOROFLUOROMETHANE [2] [4]	154-157
DINITROBENZENE (1,3-)	154-157
NITROANILINE {4-NITROBENZENAMINE}	154-157
PENTACHLOROETHANE [2]	154-157
DINITROBENZENE (1,4-)	158-161
DINITROBENZENE (1,2-)	158-161
TRICHLOROETHANE (1,1,2-) [2]	158-161
TRICHLOROMETHANE {CHLOROFORM} [2]	158-161
DIELDRIN	162-164
ISODRIN	162-164
ALDRIN	162-164
DICHLOROPROPANE (1,3-) [5]	165
NITROTOLUIDINE (5-) {BENZENAMINE,2-METHYL-5-NITRO-}	166-167
CHLOROACETALDEHYDE	166-167
TRICHLOROPROPANE (1,2,3-) [2]	168-173
DINITROTOLUENE (2,4-)	168-173
DINITROTOLUENE (2,6-)	168-173
HEXACHLOROCYCLOPENTADIENE	168-173
BENZAL CHLORIDE {ALPHA, ALPHA-DICHLOROTOLUENE} [2]	168-173
DICHLORO-1-PROPANOL (2,3-)	168-173
ETHYLENE OXIDE {OXIRANE} [5]	174
DICHLOROETHANE (1,1-) {ETHYLIDENE DICHLORIDE} [5]	175-178
DIMETHYLCARBAMOYLCHLORIDE	175-178
GLYCIDYALDEHYDE {1-PROPANOL-2,3-EPOXY}	175-178
DDT {DICHLORODIPHENYLTRICHLOROETHANE}	175-178
DICHLOROPROPANE (1,2-) {PROPYLENE DICHLORIDE} [5]	179
AURAMINE	180-181
HEPTACHLOR	180-181
DICHLOROPROPANE (1,1-) [5]	182
CHLORO-2,3-EPOXYPROPANE (1-) {OXIRANE,2-CHLOROMETHYL-}	183-186
DINITROPHENOL (2,4-)	183-186
bis(2-CHLOROETHYL)ETHER [2]	183-186
TRINITROBENZENE {1,3,5-TRINITROBENZENE}	183-186
BUTYL-4,6-DINITROPHENOL (2-sec-) {DNBP}	187-188
CYCLOHEXYL-4,6-DINITROPHENOL (2-)	187-188
bis(2-CHLOROETHOXY)METHANE	189-192
CHLORAL {TRICHLOROACETALDEHYDE}	189-192
TRICHLOROMETHANETHIOL	189-192
DINITROCRESOL (4,6-) {PHENOL,2,4-DINITRO-6-METHYL-}	189-192
HEPTACHLOR EPOXIDE	193
DIEPOXYBUTANE (1,2,3,4-) {2,2'-BIOXIRANE}	194
CLASS 5	
BENZOTRICHLORIDE {TRICHLOROMETHYLBENZENE}	195-196
METHAPYRILENE	195-196
PHENACETIN {N-[4-ETHOXYPHENYL]ACETAMIDE}	197-198
METHYL HYDRAZINE [5]	197-198
DIBROMOETHANE (1,2-) {ETHYLENE DIBROMIDE}	199

Table D-1. Principal Hazardous Organic Constituent Thermal Stability Index (continued)

Principal Hazardous Organic Constituent	Rank
AFLATOXINS	200
TRICHLOROETHANE (1,1,1-) {METHYL CHLOROFORM} [2]	201
HEXACHLOROETHANE [2]	202-203
BROMOFORM {TRIBROMOMETHANE} [2]	202-203
CHLOROBENZILATE	204-207
ETHYL CARBAMATE {URETHAN} {CARBAMIC ACID, ETHYL ESTER}	204-207
ETHYL METHACRYLATE {2-PROPENOIC ACID, 2-METHYL-,ETHYL ESTER}	204-207
LASIOCARPINE	204-207
AMITROLE {1H-1,2,4-TRIAZOL-3-AMINE}	208-209
MUSCIMOL {5-AMINOMETHYL-3-ISOAZOTOL}	208-209
IODOMETHANE {METHYL IODIDE}	210
DICHLOROPHENOXYACETIC ACID (2,4-) {2,4-D}	211-213
CHLOROETHYLVINYLETHER (2-) {ETHENE,[2-CHLOROETHOXY]-} [2]	211-213
METHYLENE BIS(2-CHLOROANILINE) (4,4-)	211-213
DIBROMO-3-CHLOROPROPANE (1,2-)	214
TETRACHLOROETHANE (1,1,1,2-) [2]	215
DIMETHYLHYDRAZINE (1,1-) [5]	216-217
N,N-DIETHYLHYDRAZINE {1,2-DIETHYLHYDRAZINE}	216-217
CHLOROMETHYLMETHYL ETHER {CHLOROMETHOXYMETHANE}	218-220
DIMETHYL-1-METHYLTHIO-2-BUTANONE,O-[(METHYLAMINO)-CARBONYL] OXIME (3,3-) {THIOFANOX}	218-220
DIMETHYLHYDRAZINE (1,2-)	218-220
CHLORDANE (ALPHA AND GAMMA ISOMERS)	221
bis(CHLOROMETHYL)ETHER {METHANE-OXYbis[2-CHLORO-]}	222-223
PARATHION [5]	222-223
DICHLOROPROPANE (2,2-) [5]	224
MALEIC HYDRAZIDE {1,2-DIHYDRO-3,6-PYRIDAZINEDIONE}	225
BROMOPHENYL PHENYL ETHER (4-) {BENZENE,1-BROMO-4-PHENOXY-}	226
bis(2-CHLOROISOPROPYL)ETHER	227-228
DIHYDROSAFROLE {1,2-METHYLENEDIOXY-4-PROPYLBENZENE}	227-228
METHYL METHANESULFONATE {METHANESUFONIC ACID, METHYL ESTER}	229
PROPANE SULFONE (1,3-) {1,2-OXATHIOLANE,2,2-DIOXIDE}	230
SACCHARIN {1,2-BENZOISOTHIAZOLIN-3-ONE,1,1-DIOXIDE}	231
METHYL-2-METHYLTHIO-PROPIONALDEHYDE-O-(METHYLCARBONYL)OXIME(2-)	232-233
METHYOMYL	232-233
HEXACHLOROPROPENE [2]	234
PENTACHLORONITROBENZENE {PCNB}	235-239
DIALLATE {S-(2,3-DICHLOROALLYL)DIISOPROPYL THIOCARBAMATE)	235-239
ETHYLENEIMINE {AZIRIDINE}	235-239
ARAMITE	235-239
DIMETHOATE	235-239
TRICHLOROPHENOXYACETIC ACID (2,4,5-) {2,4,5-T}	240-241
TRICHLOROPHENOXYPROPIONIC ACID (2,4,5-) {2,4,5-TP} {SILVEX}	240-241
tris(2,3-DIBROMOPROPYL)PHOSPHATE	242
METHYLAZIRIDINE (2-) {1,2-PROPYLENIMINE}	243-244
METHOXYCHLOR	243-244
BRUCINE {STRYCHNIDIN-10-ONE,2,3-DIMETHOXY-}	245-246
KEPONE	245-246
ISOSAFROLE {1,2-METHYLENEDIOXY-4-ALLYLBENZENE}	247-249
SAFROLE {1,2-METHYLENE-4-ALLYLBENZENE}	247-249
tris(1-AZRIDINYL) PHOSPHINE SULFIDE	247-249
DIMETHOXYBENZIDINE (3,3'-)	250
DIPHENYLHYDRAZINE (1,2-)	251
O,O-DIETHYLPHOSPHORIC ACID,O-p-NITROPHENYL ESTER	252

Table D-1. Principal Hazardous Organic Constituent Thermal Stability Index (continued)

Principal Hazardous Organic Constituent	Rank
CLASS 6	
n-BUTYLBENZYL PHTHALATE [2]	253
O,O-DIETHYL-O-2-PYRAZINYL PHOSPHOROTHIOATE	254
DIMETHYLAMINOAZOBENZENE	255
DIETHYL PHTHALATE	256-257
O,O-DIETHYL-S-METHYL ESTER OF PHOSPHORIC ACID	256-257
O,O-DIETHYL S-[(ETHYLTHIO)METHYL]ESTER OF PHOSPHORODITHIOIC ACID	258-259
CITRUS RED No. 2 {2-NAPHTHOL,1-[(2,5-DIMETHOXYPHENYL)AZO]}	258-259
TRYPAN BLUE	260
ETHYL METHANESULFONATE {METHANESULFONIC ACID, ETHYL ESTER}	261-265
DISULFOTON	261-265
DIISOPROPYLFLUOROPHOSPHATE {DFP}	261-265
O,O,O-TRIETHYL PHOSPHOROTHIOATE	261-265
Di-n-BUTYL PHTHALATE	261-265
PARALDEHYDE {2,4,6-TRIMETHYL-1,3,5-TRIOXANE} [5]	266
Di-n-OCTYL PHTHALATE [2]	267
OCTAMETHYLPYROPHOSPHORAMIDE {OCTAMETHYLDIPHOSPHORAMIDE}	268
bis(2-ETHYLHEXYL)PHTHALATE	269-270
METHYLTHIOURACIL	269-270
PROPYLTHIOURACIL	271
CLASS 7	
STRYCHNINE {STRYCHNIDIN-10-ONE}	272
CYCLOPHOSPHAMIDE	273-276
NICOTINE {(S)-3-[1-METHYL-2-PYRROLIDINYL]PYRIDINE}	273-276
RESERPINE	273-276
TOLUIDINE HYDROCHLORIDE {2-METHYL-BENZENAMINE HYDROCHLORIDE}	273-276
TOLYLENE DIISOCYANATE {1,3-DIISOCYANATOMETHYLBENZENE}	277
ENDRIN	278
BUTANONE PEROXIDE (2-) {METHYL ETHYL KETONE, PEROXIDE}	279
TETRAETHYLPYROPHOSPHATE	280
NITROGLYCERINE {TRINITRATE-1,2,3-PROPANETRIOL} [5]	281
TETRAETHYLDITHIOPYROPHOSPHATE	282
ETHYLENEbisDITHIOCARBAMIC ACID	283
TETRANITROMETHANE [5]	284
URACIL MUSTARD {5-[bis(2-CHLOROETHYL)AMINO]URACIL}	285
ACETYL-2-THIOUREA (1-) {ACETAMIDE,N-[AMINOTHIOXOMETHYL]-}	286-290
CHLOROPHENYL THIOUREA (1-) {THIOUREA,[2-CHLOROPHENYL]-}	286-290
N-PHENYLTHIOUREA	286-290
NAPHTHYL-2-THIOUREA (1-) {THIOUREA,1-NAPHTHALENYL-}	286-290
THIOUREA {THIOCARBAMIDE}	286-290
DAUNOMYCIN	291-292
ETHYLENE THIOUREA {2-IMIDAZOLIDINETHIONE}	291-292
THIOSEMICARBAZIDE {HYDRAZINECARBOTHIOAMIDE}	293-294
MELPHALAN {ALANINE,3-[p-bis(2-CHLOROETHYL)AMINO]PHENYL-,L-}	293-294
DITHIOBIURET (2,4-) {THIOIMIDODICARBONIC DIAMIDE}	295-296
THIURAM {bis[DIMETHYLTHIOCARBAMOYL]DISULFIDE}	295-296
AZASERINE {L-SERINE,DIAZOACETATE[ESTER]}	297
HEXAETHYL TETRAPHOSPHATE	298
NITROGEN MUSTARD N-OXIDE	299-300
NITROQUINOLINE-1-OXIDE (4-)	299-300
CYCASIN {beta-D-GLUCOPYRANOSIDE,[METHYL-ONN-AZOXY]METHYL-}	301

Table D-1. Principal Hazardous Organic Constituent Thermal Stability Index (continued)

Principal Hazardous Organic Constituent	Rank
STREPTOZOTOCIN	302
N-METHYL-N'-NITRO-N-NITROSOGUANIDINE	303-318
N-NITROSO-DI-ETHANOLAMINE {[2,2'-NITROSOIMINO]bisETHANOL}	303-318
N-NITROSO-DI-N-BUTYLAMINE {N-BUTYL-N-NITROSO-1-BUTANAMINE}	303-318
N-NITROSO-N-ETHYLUREA {N-ETHYL-N-NITROSOCARBAMIDE}	303-318
N-NITROSO-N-METHYLUREA {N-METHYL-N-NITROSOCARBAMIDE}	303-318
N-NITROSO-N-METHYLURETHANE	303-318
N-NITROSODIETHYLAMINE {N-ETHYL-N-NITROSOETHANAMINE}	303-318
N-NITROSODIMETHYLAMINE {DIMETHYLNITROSAMINE}	303-318
N-NITROSOMETHYLETHYLAMINE {N-METHYL-N-NITROSOETHANAMINE}	303-318
N-NITROSOMETHYLVINYLAMINE {N-METHYL-N-NITROSOETHENAMINE}	303-318
N-NITROSOMORPHOLINE	303-318
N-NITROSONORNICOTINE	303-318
N-NITROSOPIPERIDINE {HEXAHYDRO-N-NITROSOPYRIDINE}	303-318
N-NITROSOSARCOSINE	303-318
NITROSOPYRROLIDINE {N-NITROSOTETRAHYDROPYRROLE}	303-318
DI-n-PROPYLNITROSAMINE {N-NITROSO-DI-n-PROPYLAMINE}	303-318
OXABICYCLO[2.2.1]HEPTANE-2,3-DICARBOXYLIC ACID (7-) {ENDOTHAL}	319
ENDOSULFAN	320

FOOTNOTES:

1. UNITS OF TEMPERATURE ARE DEGREES CELSIUS.

2. **BOLDFACE** INDICATES COMPOUND THERMAL STABILITY IS "EXPERIMENTALLY EVALUATED" (RANKING BASED ON UDRI EXPERIMENTAL DATA COUPLED WITH REACTION KINETIC THEORY).

3. NON-APPENDIX VIII COMPOUND.

4. N.O.S. LISTING; RANKING IS PRESENTED BASED ON EITHER UDRI OR LITERATURE EXPERIMENTAL DATA COUPLED WITH REACTION KINETIC THEORY.

5. *ITALICS* INDICATE COMPOUND THERMAL STABILITY IS RANKED BASED ON LITERATURE EXPERIMENTAL DATA COUPLED WITH REACTION KINETIC THEORY.

Table D-2. Principal Hazardous Organic Constituent Thermal Stability Index - Alphabetized

Principal Hazardous Organic Constituent	Rank
ACETONITRILE {ETHANENITRILE} [2]	17-18
ACETONYLBENZYL-4-HYDROXYCOUMARIN (3-alpha-) {WARFARIN}	98-99
ACETOPHENONE {ETHANONE, 1-PHENYL-} [2]	85-88
ACETYL CHLORIDE {ETHANOYL CHLORIDE} [2]	92-97
ACETYL-2-THIOUREA (1-) {ACETAMIDE,N-[AMINOTHIOXOMETHYL]-}	286-290
ACETYLAMINOFLUORENE (2-) {ACETAMIDE,N-[9H-FLUOREN-2-YL]-}	69-77
ACROLEIN {2-PROPENAL}	106-107
ACRYLAMIDE {2-PROPENAMIDE}	60-64
ACRYLONITRILE {2-PROPENENITRILE} [2]	20
AFLATOXINS	200
ALDRIN	162-164
ALLYL ALCOHOL {2-PROPEN-1-OL}	116-118
AMINOBIPHENYL (4-) {[1,1' BIPHENYL]-4-AMINE}	51
AMITROLE {1H-1,2,4-TRIAZOL-3-AMINE}	208-209
ANILINE {BENZENAMINE}	46-50
ARAMITE	235-239
AURAMINE	180-181
AZASERINE {L-SERINE,DIAZOACETATE[ESTER]}	297
BENZAL CHLORIDE {ALPHA, ALPHA-DICHLOROTOLUENE} [2]	168-173
BENZANTHRACENE (1,2-) {BENZ[a]ANTHRACENE}	9
BENZENE [2]	3
BENZENETHIOL {THIOPHENOL} [2]	110
BENZIDINE {[1,1'-BIPHENYL]-4,4' DIAMINE}	60-64
BENZOQUINONE {1,4-CYCLOHEXADIENEDIONE}	89-91
BENZOTRICHLORIDE {TRICHLOROMETHYLBENZENE}	195-196
BENZO[a]PYRENE {1,2-BENZOPYRENE}	11
BENZO[b]FLUORANTHENE {2,3-BENZOFLUORANTHENE}	8
BENZO[j]FLUORANTHENE {7,8-BENZOFLUORANTHENE}	7
BENZYL CHLORIDE {CHLOROMETHYLBENZENE} [2]	127-130
BENZ[c]ACRIDINE {3,4-BENZACRIDINE}	85-88
bis(2-CHLOROETHOXY)METHANE	189-192
bis(2-CHLOROETHYL)ETHER [2]	183-186
bis(2-CHLOROISOPROPYL)ETHER	227-228
bis(2-ETHYLHEXYL)PHTHALATE	269-270
bis(CHLOROMETHYL)ETHER {METHANE-OXYbis[2-CHLORO-]}	222-223
BROMOACETONE {1-BROMO-2-PROPANONE}	136-140
BROMOFORM {TRIBROMOMETHANE} [2]	202-203
BROMOMETHANE {METHYL BROMIDE} [2]	31-33
BROMOPHENYL PHENYL ETHER (4-) {BENZENE,1-BROMO-4-PHENOXY-}	226
BRUCINE {STRYCHNIDIN-10-ONE,2,3-DIMETHOXY-}	245-246
BUTANONE PEROXIDE (2-) {METHYL ETHYL KETONE, PEROXIDE}	279
BUTYL-4,6-DINITROPHENOL (2-sec-) {DNBP}	187-188
CHLORAL {TRICHLOROACETALDEHYDE}	189-192
CHLORAMBUCIL	142
CHLORDANE (ALPHA AND GAMMA ISOMERS)	221
CHLORO-1,3-BUTADIENE (2-) {CHLOROPRENE}	69-77
CHLORO-2,3-EPOXYPROPANE (1-) {OXIRANE,2-CHLOROMETHYL-}	183-186
CHLOROACETALDEHYDE	166-167
CHLOROANILINE {CHLOROBENZENAMINE}	37
CHLOROBENZENE [2]	19
CHLOROBENZILATE	204-207
CHLOROCRESOL {4-CHLORO-3-METHYLPHENOL}	116-118

Table D-2. Principal Hazardous Organic Constituent Thermal Stability Index - Alphabetized (continued)

Principal Hazardous Organic Constituent	Rank
CHLORODIFLUOROMETHANE [2] [4]	151-153
CHLOROETHANE (ETHYL CHLORIDE) [4] [5]	126
CHLOROETHYLVINYLETHER (2-) {ETHENE,[2-CHLOROETHOXY]-} [2]	211-213
CHLOROMETHANE {METHYL CHLORIDE} [2]	29-30
CHLOROMETHYLMETHYL ETHER {CHLOROMETHOXYMETHANE}	218-220
CHLORONAPHTHALENE (1-) [2]	21-22
CHLOROPHENOL (2-)	102
CHLOROPHENYL THIOUREA (1-) {THIOUREA,[2-CHLOROPHENYL]-}	286-290
CHLOROPROPENE (3-) {ALLYL CHLORIDE} [2]	120
CHLOROPROPIONITRILE (3-) {3-CHLOROPROPANENITRILE} [2]	143-144
CHRYSENE {1,2-BENZPHENANTHRENE}	10
CITRUS RED No. 2 {2-NAPHTHOL,1-[(2,5-DIMETHOXYPHENYL)AZO]}	258-259
CRESOL (1,2-) {METHYLPHENOL}	104-105
CRESOL (1,3-) {METHYLPHENOL}	103
CRESOL (1,4-) {METHYLPHENOL} [2]	104-105
CROTONALDEHYDE {2-BUTENAL} [2]	113-115
CYANOGEN BROMIDE {BROMINE CYANIDE}	23-24
CYANOGEN CHLORIDE {CHLORINE CYANIDE}	17-18
CYANOGEN {ETHANEDINITRILE}	1
CYCASIN {beta-D-GLUCOPYRANOSIDE,[METHYL-ONN-AZOXY]METHYL-}	301
CYCLOHEXYL-4,6-DINITROPHENOL (2-)	187-188
CYCLOPHOSPHAMIDE	273-276
DAUNOMYCIN	291-292
DDD {DICHLORODIPHENYLDICHLOROETHANE}	145-146
DDE{1,1-DICHLORO-2,2-BIS(4-CHLOROPHENYLETHYLENE}	38
DDT {DICHLORODIPHENYLTRICHLOROETHANE}	175-178
Di-n-BUTYL PHTHALATE	261-265
Di-n-OCTYL PHTHALATE [2]	267
DI-n-PROPYLNITROSAMINE {N-NITROSO-DI-n-PROPYLAMINE}	303-318
DIALLATE {S-(2,3-DICHLOROALLYL)DIISOPROPYL THIOCARBAMATE)	235-239
DIBENZO[a,e]PYRENE {1,2,4,5-DIBENZOPYRENE}	16
DIBENZO[a,h]PYRENE {1,2,5,6-DIBENZOPYRENE}	14
DIBENZO[a,i]PYRENE {1,2,7,8-DIBENZOPYRENE}	15
DIBENZO[c,g]CARBAZOLE (7H-) {3,4,5,6-DIBENZCARBAZOLE}	100-101
DIBENZ[a,h]ACRIDINE {1,2,5,6-DIBENZACRIDINE}	92-97
DIBENZ[a,h]ANTHRACENE {1,2,5,6-DIBENZANTHRACENE}	12
DIBENZ[a,j]ACRIDINE {1,2,7,8-DIBENZACRIDINE}	92-97
DIBROMO-3-CHLOROPROPANE (1,2-)	214
DIBROMOETHANE (1,2-) {ETHYLENE DIBROMIDE}	199
DIBROMOMETHANE {METHYLENE BROMIDE} [2]	127-130
DICHLORO-1-PROPANOL (2,3-)	168-173
DICHLORO-2-BUTENE (1,4-)	136-140
DICHLORO-2-PROPANOL (1,1-)	145-146
DICHLORO-2-PROPANOL (1,3-)	147
DICHLOROBENZENE {1,2-DICHLOROBENZENE} [2]	23-24
DICHLOROBENZENE {1,3-DICHLOROBENZENE} [2]	25
DICHLOROBENZENE {1,4-DICHLOROBENZENE}	21-22
DICHLOROBENZIDINE (3,3'-)	67
DICHLORODIFLUOROMETHANE [2]	85-88
DICHLOROETHANE (1,1-) {ETHYLIDENE DICHLORIDE} [5]	175-178
DICHLOROETHANE (1,2-) [2]	131
DICHLOROETHENE (1,1-) [2]	42-44

Table D-2. Principal Hazardous Organic Constituent Thermal Stability Index - Alphabetized (continued)

Principal Hazardous Organic Constituent	Rank
DICHLOROETHENE (trans-1,2-) [2]	54
DICHLOROFLUOROMETHANE [2] [4]	154-157
DICHLOROMETHANE {METHYLENE CHLORIDE} [2]	65-66
DICHLOROPHENOL (2,4-)	113-115
DICHLOROPHENOL (2,6-)	113-115
DICHLOROPHENOXYACETIC ACID (2,4-) {2,4-D}	211-213
DICHLOROPROPANE (1,1-) [5]	182
DICHLOROPROPANE (1,2-) {PROPYLENE DICHLORIDE} [5]	179
DICHLOROPROPANE (1,3-) [5]	165
DICHLOROPROPANE (2,2-) [5]	224
DICHLOROPROPENE (1,1-) [2]	81-84
DICHLOROPROPENE (2,3-)	127-130
DICHLOROPROPENE (3,3-)	135
DICHLOROPROPENE (cis-1,3-)	121-125
DICHLOROPROPENE (trans-1,2-)	89-91
DICHLOROPROPENE (trans-1,3-)	121-125
DIELDRIN	161-163
DIEPOXYBUTANE (1,2,3,4-) {2,2'-BIOXIRANE}	194
DIETHYL PHTHALATE	256-257
DIETHYLSTILBESTEROL	108-109
DIHYDROSAFROLE {1,2-METHYLENEDIOXY-4-PROPYLBENZENE}	227-228
DIHYDROXY-ALPHA-[METHYLAMINO]METHYL BENZYL ALCOHOL (3,4-)	106-107
DIISOPROPYLFLUOROPHOSPHATE {DFP}	261-265
DIMETHOATE	235-239
DIMETHOXYBENZIDINE (3,3'-)	250
DIMETHYL PHTHALATE [2]	92-97
DIMETHYL-1-METHYLTHIO-2-BUTANONE,O-[(METHYLAMINO)-CARBONYL] OXIME (3,3-) {THIOFANOX}	218-220
DIMETHYLAMINOAZOBENZENE	255
DIMETHYLBENZIDINE (3,3'-)	78
DIMETHYLBENZ[a]ANTHRACENE (7,12-)	45
DIMETHYLCARBAMOYLCHLORIDE	175-178
DIMETHYLHYDRAZINE (1,1-) [5]	216-217
DIMETHYLHYDRAZINE (1,2-)	218-220
DIMETHYLPHENETHYLAMINE (alpha, alpha-)	60-64
DIMETHYLPHENOL (2,4-)	119
DINITROBENZENE (1,2-)	158-161
DINITROBENZENE (1,3-)	154-157
DINITROBENZENE (1,4-)	158-161
DINITROCRESOL (4,6-) {PHENOL,2,4-DINITRO-6-METHYL-}	189-192
DINITROPHENOL (2,4-)	183-186
DINITROTOLUENE (2,4-)	168-173
DINITROTOLUENE (2,6-)	168-173
DIOXANE (1,4-) {1,4-DIETHYLENE OXIDE} [2]	141
DIPHENYLAMINE {N-PHENYLBENZENAMINE}	42-44
DIPHENYLHYDRAZINE (1,2-)	251
DISULFOTON	261-265
DITHIOBIURET (2,4-) {THIOIMIDODICARBONIC DIAMIDE}	295-296
ENDOSULFAN	320
ENDRIN	278
ETHYL CARBAMATE {URETHAN} {CARBAMIC ACID, ETHYL ESTER}	204-207
ETHYL CYANIDE {PROPIONITRILE} [2]	89-91
ETHYL METHACRYLATE {2-PROPENOIC ACID, 2-METHYL-,ETHYL ESTER}	204-207

Table D-2. Principal Hazardous Organic Constituent Thermal Stability Index - Alphabetized (continued)

Principal Hazardous Organic Constituent	Rank
ETHYL METHANESULFONATE {METHANESULFONIC ACID, ETHYL ESTER}	261-265
ETHYLENE OXIDE {OXIRANE} [5]	174
ETHYLENE THIOUREA {2-IMIDAZOLIDINETHIONE}	291-292
ETHYLENEbisDITHIOCARBAMIC ACID	283
ETHYLENEIMINE {AZIRIDINE}	235-239
FLUORANTHENE {BENZO[j,k]FLUORENE}	6
FLUOROACETAMIDE (2-)	55-56
FLUOROACETIC ACID	42-44
FORMALDEHYDE {METHYLENE OXIDE}	46-50
FORMIC ACID {METHANOIC ACID}	39-40
GLYCIDYALDEHYDE {1-PROPANOL-2,3-EPOXY}	175-178
HEPTACHLOR	180-181
HEPTACHLOR EPOXIDE	193
HEXACHLOROBENZENE [2]	31-33
HEXACHLOROBUTADIENE (trans-1,3) [2]	92-97
HEXACHLOROCYCLOHEXANE {LINDANE} [2]	151-153
HEXACHLOROCYCLOPENTADIENE	168-173
HEXACHLOROETHANE [2]	202-203
HEXACHLOROPHENE {2,2'-METHYLENEbis[3,4,6-TRICHLOROPHENOL]}	136-140
HEXACHLOROPROPENE [2]	234
HEXAETHYL TETRAPHOSPHATE	298
HYDRAZINE (DIAMINE)	127-130
HYDROGEN CYANIDE {HYDROCYANIC ACID} [2]	2
INDENO(1,2,3-cd)PYRENE {1,10-(1,2-PHENYLENE)PYRENE}	13
IODOMETHANE {METHYL IODIDE}	210
ISOBUTYL ALCOHOL {2-METHYL-1-PROPANOL} [2]	112
ISODRIN	162-164
ISOSAFROLE {1,2-METHYLENEDIOXY-4-ALLYLBENZENE}	247-249
KEPONE	245-246
LASIOCARPINE	204-207
MALEIC ANHYDRIDE {2,5-FURANDIONE}	98-99
MALEIC HYDRAZIDE {1,2-DIHYDRO-3,6-PYRIDAZINEDIONE}	225
MALONONITRILE {PROPANEDINITRILE}	46-50
MELPHALAN {ALANINE,3-[p-bis(2-CHLOROETHYL)AMINO]PHENYL-,L-}	293-294
METHACRYLONITRILE {2-METHYL-2-PROPENENITRILE} [2]	65-66
METHAPYRILENE	195-196
METHOXYCHLOR	243-244
METHYL CHLOROCARBONATE {CARBONOCHLORIDIC ACID, METHYL ESTER}	46-50
METHYL ETHYL KETONE {2-BUTANONE} [2]	108-109
METHYL HYDRAZINE [5]	197-198
METHYL ISOCYANATE {METHYLCARBYLAMINE}	46-50
METHYL METHACRYLATE {2-PROPENOIC ACID, 2-METHYL-, METHYL ESTER}	60-64
METHYL METHANESULFONATE {METHANESULFONIC ACID, METHYL ESTER}	229
METHYL PARATHION	148-150
METHYL-2-METHYLTHIO-PROPIONALDEHYDE-O-(METHYLCARBONYL)OXIME(2-)	232-233
METHYLACTONITRILE (2-) {PROPANENITRILE,2-HYDROXY-2-METHYL}	116-118
METHYLAZIRIDINE (2-) {1,2-PROPYLENIMINE}	243-244
METHYLCHOLANTHRENE (3-)	68
METHYLENE BIS(2-CHLOROANILINE) (4,4-)	211-213
METHYLTHIOURACIL	269-270
METHYOMYL	232-233
MUSCIMOL {5-AMINOMETHYL-3-ISOAZOTOL}	208-209

Table D-2. Principal Hazardous Organic Constituent Thermal Stability Index - Alphabetized (continued)

Principal Hazardous Organic Constituent	Rank
MUSTARD GAS {bis[2-CHLOROETHYL]-SULFIDE}	132-134
N,N-BIS(2-CHLOROETHYL)2-NAPHTHYLAMINE {CHLORNAPHAZINE}	132-134
N,N-DIETHYLHYDRAZINE {1,2-DIETHYLHYDRAZINE}	216-217
n-BUTYLBENZYL PHTHALATE [2]	253
N-METHYL-N'-NITRO-N-NITROSOGUANIDINE	303-318
N-NITROSO-DI-ETHANOLAMINE {[2,2'-NITROSOIMINO]bisETHANOL}	303-318
N-NITROSO-DI-N-BUTYLAMINE {N-BUTYL-N-NITROSO-1-BUTANAMINE}	303-318
N-NITROSO-N-ETHYLUREA {N-ETHYL-N-NITROSOCARBAMIDE}	303-318
N-NITROSO-N-METHYLUREA {N-METHYL-N-NITROSOCARBAMIDE}	303-318
N-NITROSO-N-METHYLURETHANE	303-318
N-NITROSODIETHYLAMINE {N-ETHYL-N-NITROSOETHANAMINE}	303-318
N-NITROSODIMETHYLAMINE {DIMETHYLNITROSAMINE}	303-318
N-NITROSOMETHYLETHYLAMINE {N-METHYL-N-NITROSOETHANAMINE}	303-318
N-NITROSOMETHYLVINYLAMINE {N-METHYL-N-NITROSOETHENAMINE}	303-318
N-NITROSOMORPHOLINE	303-318
N-NITROSONORNICOTINE	303-318
N-NITROSOPIPERIDINE {HEXAHYDRO-N-NITROSOPYRIDINE}	303-318
N-NITROSOSARCOSINE	303-318
N-PHENYLTHIOUREA	286-290
n-PROPYLAMINE {1-PROPANAMINE}	79
NAPHTHALENE [2]	5
NAPHTHOQUINONE (1,4-) {1,4-NAPHTHALENEDIONE}	92-97
NAPHTHYL-2-THIOUREA (1-) {THIOUREA,1-NAPHTHALENYL-}	286-290
NAPHTHYLAMINE (1-)	52-53
NAPHTHYLAMINE (2-)	52-53
NICOTINE {(S)-3-[1-METHYL-2-PYRROLIDINYL]PYRIDINE}	273-276
NITROANILINE {4-NITROBENZENAMINE}	154-157
NITROBENZENE [2]	143
NITROGEN MUSTARD	132-134
NITROGEN MUSTARD N-OXIDE	299-300
NITROGLYCERINE {TRINITRATE-1,2,3-PROPANETRIOL} [5]	281
NITROPHENOL (4-)	148-150
NITROQUINOLINE-1-OXIDE (4-)	299-300
NITROSOPYRROLIDINE {N-NITROSOTETRAHYDROPYRROLE}	303-318
NITROTOLUIDINE (5-) {BENZENAMINE,2-METHYL-5-NITRO-}	166-167
O,O,O-TRIETHYL PHOSPHOROTHIOATE	261-265
O,O-DIETHYL S-[(ETHYLTHIO)METHYL]ESTER OF PHOSPHORODITHIOIC ACID	258-259
O,O-DIETHYL-O-2-PYRAZINYL PHOSPHOROTHIOATE	254
O,O-DIETHYL-S-METHYL ESTER OF PHOSPHORIC ACID	256-257
O,O-DIETHYLPHOSPHORIC ACID,O-p-NITROPHENYL ESTER	252
OCTAMETHYLPYROPHOSPHORAMIDE {OCTAMETHYLDIPHOSPHORAMIDE}	268
OXABICYCLO[2.2.1]HEPTANE-2,3-DICARBOXYLIC ACID (7-) {ENDOTHAL}	319
PARALDEHYDE {2,4,6-TRIMETHYL-1,3,5-TRIOXANE} [5]	266
PARATHION [5]	222-223
PENTACHLOROBENZENE [2]	31-33
PENTACHLOROETHANE [2]	154-157
PENTACHLORONITROBENZENE {PCNB}	235-239
PENTACHLOROPHENOL	151-153
PHENACETIN {N-[4-ETHOXYPHENYL]ACETAMIDE}	197-198
PHENOL {HYDROXYBENZENE}	100-101
PHENYLENEDIAMINE (1,2-) {BENZENEDIAMINE}	57-59
PHENYLENEDIAMINE (1,3-) {BENZENEDIAMINE}	57-59

Table D-2. Principal Hazardous Organic Constituent Thermal Stability Index - Alphabetized (continued)

Principal Hazardous Organic Constituent	Rank
PHENYLENEDIAMINE (1,4) {BENZENEDIAMINE}	57-59
PHOSGENE {CARBONYL CHLORIDE}	39-40
PHTHALIC ANHYDRIDE {1,2-BENZENEDICARBOXYLIC ACID ANHYDRIDE}	148-150
PICOLINE (2-) {PYRIDINE, 2-METHYL-}	81-84
PRONAMIDE {3,5-DICHLORO-N-[1,1-DIMETHYL-2-PROPYNYL] BENZAMIDE}	69-77
PROPANE SULFONE (1,3-) {1,2-OXATHIOLANE,2,2-DIOXIDE}	230
PROPYLTHIOURACIL	271
PROPYN-1-OL (2-) {PROPARGYL ALCOHOL}	55-56
PYRIDINE [2]	80
RESERPINE	273-276
RESORCINOL {1,3-BENZENEDIOL}	111
SACCHARIN {1,2-BENZOISOTHIAZOLIN-3-ONE,1,1-DIOXIDE}	231
SAFROLE {1,2-METHYLENE-4-ALLYLBENZENE}	247-249
STREPTOZOTOCIN	302
STRYCHNINE {STRYCHNIDIN-10-ONE}	272
SULFUR HEXAFLUORIDE [3]	4
TETRACHLOROBENZENE (1,2,3,5-TETRACHLOROBENZENE) [2] [4]	20
TETRACHLOROBENZENE (1,2,4,5-TETRACHLOROBENZENE)	29-30
TETRACHLORODIBENZO-p-DIOXIN (2,3,7,8-) {TCDD}	34
TETRACHLOROETHANE (1,1,1,2-) [2]	215
TETRACHLOROETHANE (1,1,2,2-) [2]	121-125
TETRACHLOROETHENE [2]	36
TETRACHLOROMETHANE {CARBONTETRACHLORIDE} [2]	136-140
TETRACHLOROPHENOL (2,3,4,6-)	136-140
TETRAETHYLDITHIOPYROPHOSPHATE	282
TETRAETHYLPYROPHOSPHATE	280
TETRANITROMETHANE [5]	284
THIOACETAMIDE {ETHANETHIOAMIDE}	81-84
THIOSEMICARBAZIDE {HYDRAZINECARBOTHIOAMIDE}	293-294
THIOUREA {THIOCARBAMIDE}	286-290
THIURAM {bis[DIMETHYLTHIOCARBAMOYL]DISULFIDE}	295-296
TOLUENE {METHYLBENZENE} [2]	35
TOLUENEDIAMINE (1,3-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (1,4-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (2,4-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (2,6-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (3,4-) {DIAMINOTOLUENE}	69-77
TOLUENEDIAMINE (3,5-) {DIAMINOTOLUENE}	69-77
TOLUIDINE HYDROCHLORIDE {2-METHYL-BENZENAMINE HYDROCHLORIDE}	273-276
TOLYLENE DIISOCYANATE {1,3-DIISOCYANATOMETHYLBENZENE}	277
TRICHLOROBENZENE (1,2,4-TRICHLOROBENZENE) [2]	26-27
TRICHLOROBENZENE (1,3,5-TRICHLOROBENZENE) [2] [4]	26-27
TRICHLOROETHANE (1,1,1-) {METHYL CHLOROFORM} [2]	201
TRICHLOROETHANE (1,1,2-) [2]	158-161
TRICHLOROETHENE [2]	41
TRICHLOROFLUOROMETHANE [2]	85-88
TRICHLOROMETHANE {CHLOROFORM} [2]	195-196
TRICHLOROMETHANETHIOL	189-192
TRICHLOROPHENOL (2,4,5-)	121-125
TRICHLOROPHENOL (2,4,6-)	121-125
TRICHLOROPHENOXYACETIC ACID (2,4,5-) {2,4,5-T}	240-241
TRICHLOROPHENOXYPROPIONIC ACID (2,4,5-) {2,4,5-TP} {SILVEX}	240-241

Table D-2. Principal Hazardous Organic Constituent Thermal Stability Index - Alphabetized (continued)

Principal Hazardous Organic Constituent	Rank
TRICHLOROPROPANE (1,2,3-) [2]	168-173
TRICHLORO-(1,2,2)-TRIFLUOROETHANE (1,1,2) [2] [3]	81-84
TRINITROBENZENE {1,3,5-TRINITROBENZENE}	183-186
tris(1-AZRIDINYL) PHOSPHINE SULFIDE	247-249
tris(2,3-DIBROMOPROPYL)PHOSPHATE	242
TRYPAN BLUE	260
URACIL MUSTARD {5-[bis(2-CHLOROETHYL)AMINO]URACIL}	285
VINYL CHLORIDE (CHLOROETHENE)	60-64

FOOTNOTES:

1. UNITS OF TEMPERATURE ARE DEGREES CELSIUS.

2. **BOLDFACE** INDICATES COMPOUND THERMAL STABILITY IS "EXPERIMENTALLY EVALUATED" (RANKING BASED ON UDRI EXPERIMENTAL DATA COUPLED WITH REACTION KINETIC THEORY).

3. NON-APPENDIX VIII COMPOUND.

4. N.O.S. LISTING; RANKING IS PRESENTED BASED ON EITHER UDRI OR LITERATURE EXPERIMENTAL DATA COUPLED WITH REACTION KINETIC THEORY.

5. *ITALICS* INDICATE COMPOUND THERMAL STABILITY IS RANKED BASED ON LITERATURE EXPERIMENTAL DATA COUPLED WITH REACTION KINETIC THEORY.

Table D-3. Appendix VIII Thermal Stability Classes

Class	Compound Ranking	$T_{99}(2)$ Range
1	1-34	1,590-900
2	35-77	895-800
3	78-119	790-705
4	120-193	695-604
5	194-252	600-425
6	253-271	415-360
7	272-320	320-100

APPENDIX E

Energy and Mass Balance Computer Program

E.1 Energy and Mass Balance

A computer program has been developed by Energy and Environmental Research Corporation (EER) under contract to the EPA to perform energy and mass balance calculations on hazardous waste incinerators.

The calculations are performed for a single zone incinerator or for an incinerator system composed of single zones in series. The composition of gases and solids in a zone is assumed to be the same as the exit composition--that of complete reaction; the temperature in a zone is assumed to be the same as the exit temperature; and the residence time within a zone is assumed to be the mean residence time. Products of one zone enter the next zone at the exit temperature of the first zone. In cases where there is a significant heat loss between the incinerator units, a transition zone is included between the units to allow the products to enter the second unit at a lower temperature than they exit the first.

This section discusses the components of the June 1987 version of the EER program and the principles, assumptions, and limitations involved. Because the inputs and outputs of the model are in English units, this section is written in English units.

E.1.1 Input

Inputs to the energy and mass balance include feed rate, temperature, heating value, heat capacity, heat of vaporization, and composition of all input streams to each unit including wastes, fuels, water, air, and oxygen; incinerator design specifications including the thickness and conductivity of the refractory, the volume of the unit, the area of the refractory and any cooled surfaces, and the outer shell temperature; and the air pollution control equipment (APCE) design specifications including gas volumetric capacity, acid capacity, quench water capacity and temperature, and the temperature to which the gas must be quenched. Table E-1 shows a typical blank input form.

Feed rates are in the form of mass flows. Preheat denotes the temperature at which a stream enters the incinerator. Proximate analysis is a standard analytical procedure used to characterize fuels consisting of mass percentages of fixed carbon, volatiles, ash, and moisture. Elemental analysis consists of the dry mass percentages of carbon, hydrogen, nitrogen, sulfur, ash, oxygen and chlorine. Halogens other than chlorine are treated as chlorine by multiplying their mass percentage by the ratio of atomic weight of chlorine to the atomic weight of the halogen and renormalizing so that the total mass percentage is 100.

Heating value is input as the higher or gross heating value, the way it is typically measured and reported. The higher heating value (HHV) is defined as the heat of complete combustion of the fuel/waste at 77°F (298°K) with all product water in liquid form and all product chlorine in the form of HCl. If the heating value is unknown, it can be estimated from the fuel/waste composition by equation 1:

$$\begin{aligned} HHV = {} & 1.8\,[(100 - ASH - MOISTURE)/100] \\ & \times \{83.2C + 275.15H + 25.0S \\ & + 15.0N - 25.8(O) \\ & - 568.4\,[1 - \exp(-0.582\,Cl/C)]\}\ Btu/lb \end{aligned} \qquad (1)$$

where ASH and MOISTURE are mass percentages on a wet as-fired basis and C, H, S, N, Cl, and O are mass percentages on a dry ash-free basis. To convert from a dry basis to a dry ash-free basis, divide each mass fraction by [100 - ASH_{wet}/(100 - MOISTURE)]. Note that equation 1 includes the heat of solution of HCl in the value for the high heating value; this is not a common usage. Normal nomenclature defines high heating value as the sum of the waste's (or fuel's) lower heating value (LHV) and the latent heat of vaporization of the water formed in the combustion process. For highly chlorinated material, however, the heat of solution of the HCl also becomes significant and is, therefore, included here.

Heat capacity is only important if the preheat temperature is significantly different from the reference temperature of 77°F (298°K). The heat capacity depends on the composition: aqueous wastes generally have a heat capacity around 1.0,

Table E-1. Energy and Mass Balance Input Data.

	FEED RATE (LB/H)	PREHEAT (^{O}F)	PROXIMATE ANALYSIS (PERCENT) (AS RECEIVED)				HEATING VALUE (HIGHER AS RECVD) (BTU/LB)	HEAT CAPACITY (AS RECEIVED) (BTU/LB)	HEAT OF VAPORI-ZATION (DRY) (BTU/LB)	ELEMENTAL ANALYSIS (DRY PERCENT)						
			FIXED CARBON	VOLATILES	ASH	MOISTURE				C	H	N	S	ASH	O	Cl
LIQUID WASTE																
SOLID WASTE																
PRIMARY FUEL																
SECONDARY FUEL																
PRIMARY AIR																
SECONDARY AIR																
WATER																
OXYGEN																
ASH DROPOUT																
HAZARDOUS COMPOUNDS																

DESIGN SPECIFICATIONS	PCC	SCC
REFRACTORY THICKNESS (IN)		
REFRACTORY CONDUCTIVITY (BTU IN/H FT^{2} ^{O}F)		
UNIT VOLUME (FT^{3})		
REFRACTORY SURFACE AREA (FT^{2})		
COOLED SURFACE AREA (FT^{2})		
OUTER SHELL TEMPERATURE (^{O}F)		

APCD

GAS CAPACITY (SCFM)	
STACK GAS TEMPERATURE (^{O}F)	
HCl CAPACITY (LB/H)	
QUENCH WATER CAPACITY (GPM)	
QUENCH WATER TEMPERATURE (^{O}F)	

organic wastes around 0.4, and inert solids around 0.2 Btu/lb-°F.

Heat of vaporization is generally incorporated into the heating value. If the heating value is given for the fuel/waste in liquid form, the heat of vaporization should be entered as zero. Heat of vaporization is only for the dry fuel/waste. Moisture vaporization is automatically taken into account in the program.

The refractory thickness is the distance between the inside and the outside wall of the refractory. The refractory conductivity is the effective conductivity of the refractory as if it were a flat slab of uniform composition. For a cylindrical incinerator, the effective thermal conductivity can be calculated from equation 2:

$$K_{eff} = \frac{K \times t_o}{r_i \ln\left(\frac{r_o}{r_i}\right)} \qquad (2)$$

where K_{eff} and K are the effective and actual thermal conductivities, t_o is the overall thickness, and r_o and r_i are the outer and inner refractory radii. For a cylindrical incinerator with layers of refractory, the composite thermal conductivity can be calculated from equation 3:

$$K_{eff} = \frac{t_o}{r_i\left[\frac{\ln\left(\frac{r_1}{r_i}\right)}{K_1} + \frac{\ln\left(\frac{r_2}{r_i}\right)}{K_2} + \ldots \frac{\ln\left(\frac{r_n}{r_i}\right)}{K_n}\right]} \qquad (3)$$

For a flat wall with layers of refractory, the composite thermal conductivity can be calculated from equation 4:

$$K_{eff} = \frac{t_o}{\frac{t_1}{K_1} + \frac{t_2}{K_2} + \ldots \frac{t_n}{K_n}} \qquad (4)$$

For an incinerator with sections or walls with different refractories such as an incinerator with different insulation on its end walls, the effective thermal conductivity is the area-weighted average of the individual conductivities as calculated in equation 5:

$$K_{eff} = \frac{K_1A_1 + K_2A_2 + \ldots K_nA_n}{A_T} \qquad (5)$$

where A_i is the area of each section and A_T is the total refractory area.

The volume of the unit is the inside volume, and the refractory surface area is the inside refractory surface area. In cases where two units connect with an open surface in between rather than a wall, the area of the interface is added to the refractory surface area. The cooled surface area is the optical area of any cooled surfaces; thus, for a cooled plate, it is the area of one side of the plate; for a cooled tube against the wall, it is the length of the tube times the diameter; and for a cooled tube within the flow, it is the length of the tube times twice its diameter. The outer shell temperature is only important if the heat balance on the outer shell has been disabled. Otherwise, the program calculates outer shell temperature.

The APCD gas capacity is the specified maximum capacity of the APCD, which is usually dictated by the capacity of the ID fan. The HCl capacity is the capacity of the system to remove HCl. The available quench water is usually dictated by pump size. The quench water temperature serves as a limit temperature below which the gas cannot be quenched. The stack gas temperature is the temperature of effluent in the stack.

E.1.2 Mass Balance

The mass balance calculates the products of complete combustion of the mixture of all the inputs to each unit of the incinerator. Species considered include C, H, N, O, S, Cl, Ash, H_2O, O_2, CO_2, N_2, SO_2, and HCl.

Each input stream is broken down into the mass flows of its individual components by equation 6:

$$m_i = m_{stream} \times \text{mass fraction}_i \qquad (6)$$

where m is mass flow. Air is considered to be 23.31 percent O_2 and 76.69 percent N_2 by mass. All the mass flows of each species input into the unit are summed and divided by the molecule weight (MW) of that species to calculate molar flows (M) by equation 7:

$$\text{Molar Flow}_i = \frac{m_i}{MW_i} \qquad (7)$$

Table E-2 lists the molecular weights of each species.

Complete combustion is calculated according to the molar equations listed in Table E-3. A warning is issued if insufficient oxygen is present for complete combustion or if insufficient hydrogen is present for complete conversion of Cl to HCl.

The volumetric flow is calculated from the total flow by the ideal gas law in the form of equation 8:

Volumetric Flow (@ 70°F)

$$= \sum \text{Molar Flow}_i \times 386.7 \frac{\text{sft}^3}{\text{lb mole}} \quad (8)$$

Dry oxygen volume percentage is calculated from the molar flows by equation 9:

Dry O_2 Volume Percentage

$$= \frac{M_{O_2}}{M_{CO_2} + M_{N_2} + M_{O_2} + M_{SO_2}} \times 100\% \quad (9)$$

Finally, molar flows are converted back into mass flows by equation 10:

$$m_i = M_i \times MW_i \quad (10)$$

E.1.3 Energy Balance

The energy balance solves three equations:

Heat of Combustion + Sensible Heat
- Heat of Vaporization - Total Radiation
- Total Convection = 0 (11)

Radiation to Refractory
+ Convection to Refractory
- Conduction Through Refractory = 0 (12)

Conduction Through Refractory
- Radiation from Outer Shell
- Convection from Outer Shell = 0 (13)

for gas temperature, wall temperature, and outer shell temperature.

The heat of combustion is the heat released in the reaction of reactants to products at the reference state of 77°F with H_2O in liquid form. The heat of combustion is calculated by equation 14:

$$\text{Heat of Combustion} = \Sigma\,[(HHV_i \times m_i) - (\text{Heat of Solution}_i \times Cl_i \times m_i)] \quad (14)$$

where HHV is higher heating value and Heat of Solution is the energy released when gaseous HCl dissolves in water. The heat of solution of HCl is subtracted out because HHV is typically measured with HCl in aqueous form, but the reference state of HCl used in the program is gaseous. The heat of solution of HCl is based on a curve fit to data presented in Daniels and Alberty (1967) (1):

$$\text{Heat of Solution}_i = m_i \times Cl_i\,(1 - \text{Moisture}_i)\,887.36 \quad (15)$$

$$\left\{1 - \exp\left[\frac{-\left(\frac{H_2O}{HCl}\right)^{0.77}}{1.92}\right]\right\}$$

Table E-2. Molecular Weights of Species Considered in Energy and Mass Balance

Species	Molecular Weight
C	12
H	1
N	14
O	16
S	32
Cl	35.5
Ash	-
H_2O	18
O_2	32
N_2	28
CO_2	44
HCl	36.5
SO_2	64

Table E-3. Molar Equations for Complete Combustion

C + O_2	=	CO_2
H + $\frac{1}{4}O_2$	=	$\frac{1}{2}H_2O$
N	=	$\frac{1}{2}N_2$
O	=	$\frac{1}{2}O_2$
S + O_2	=	SO_2
Cl + H	=	HCl
H_2O	=	H_2O
Excess O_2	=	O_2
N_2	=	N_2
CO_2	=	CO_2
HCl	=	HCl

where (H_2O/HCl) is the molar ratio of H_2O to HCl produced in the oxidation of the fuel/waste as calculated by:

$$\left(\frac{H_2O}{HCl}\right) = \frac{\left(\frac{H}{1}\right) - \left(\frac{Cl}{35.5}\right)}{2 \times \left(\frac{Cl}{35.5}\right)} \quad (16)$$

Higher heating value is used because of the choice of liquid water as the reference state. The heat of vaporization is the energy required to convert reactant and product water to liquid H_2O at the reference temperature of 77°F according to equation 17:

$$H_{vap} = \left(m_{\text{reactant steam}} - m_{\text{product steam}}\right) \times 1{,}050.54 \frac{\text{Btu}}{\text{lb}} \quad (17)$$

where all product water is assumed to be in the form of steam. The change in sensible heat is the sensible heat of the products minus the sensible heat of the inputs. Sensible heats are calculated according to equation 18:

$$\text{Sensible Heat}_i = m_i C_{pi} (T - 77°F) \quad (18)$$

For input streams, T is the preheat temperature and C_p is the heat capacity which is given for fuel/waste streams and is assumed to be 1.00, 0.44, 0.24, and 0.22 Btu/lb°F for liquid water, steam, air, and oxygen, respectively. For products, T is the gas temperature, and Cp is the mean heat capacity of each species between the reference temperature and the gas temperature. For gas species, Cp is calculated according to equation 19:

$$C_{pi} = \left[a_i(T - T_{ref}) + \frac{b_i\left(T^2 - T_{ref}^2\right)}{2} + \frac{c_i\left(T^3 - T_{ref}^3\right)}{3} + \frac{d_i\left(T^4 - T_{ref}^4\right)}{4}\right] \div \left(T - T_{ref}\right) \quad (19)$$

with constants a, b, c, and d for species CO_2, H_2O, N_2, SO_2, HCl, and O_2 taken from Hougen, Watson and Ragatz (1967) (2). For ash, heat capacity is calculated from an integration of a formula from Perry and Chilton (1973) according to equation 20(3):

$$C_{p\,ash} = \frac{0.18\left(T - T_{ref}\right) + 0.00003\left(T^2 - T_{ref}^2\right)}{\left(T - T_{ref}\right)} \quad (20)$$

Heat loss through the wall is calculated from the area (A), the conductivity and thickness of the refractory, and from the difference between the inside refractory wall temperature and the outer shell temperature as shown in equation 21:

$$\text{Heat Loss Through Wall} = A\left(T_{wall} - T_{shell}\right)\frac{K}{t} \quad (21)$$

Heat loss through cooled surfaces is the sum of the convective and radiative heat transfer to those surfaces. Convective heat transfer is calculated according to equation 22:

$$\text{Convection} = h A \left(T_{gas} - T_{wall}\right) \quad (22)$$

where h is the convective heat transfer coefficient and T_{cool} can be substituted for T_{wall} for heat transfer to cooled surfaces. The heat transfer coefficient is defined by equation 23:

$$h = Nu \frac{K_{gas}}{D} \quad (23)$$

where K_{gas} is the thermal conductivity of the gas, Nu is the Nusselt number, and D is the effective diameter of the incinerator. For noncylindrical incinerators, the effective diameter and length (L) are calculated from the area and volume (V) by the simultaneous solution of equations 24 and 25:

$$A = \frac{2D^2\pi}{4} + D\pi L \quad (24)$$

$$V = \frac{L D^2 \pi}{4} \quad (25)$$

Gas thermal conductivity is approximated by a method taken from Perry and Chilton (1973) and tailored to combustion gases according to equation 26 (3):

$$K_{gas} = \frac{0.3703\mu\left(C_p + 0.0855\right)}{C_{p\,ref} + 0.0855} \quad (26)$$

where $C_{p\ ref}$ is the heat capacity of the gas at a reference temperature of 1,500°F and μ is the viscosity of the gas which is approximated by a method taken from Perry and Chilton (1973) and tailored to combustion gases according to equation 27 (3):

$$\mu = 3 \times 10^{-5}\left(\frac{T}{1{,}960°R}\right)^{1.5}\left[\frac{2{,}180.5°R}{(T + 220.5°R)}\right] \quad (27)$$

The Nusselt number is estimated from Kroll's correlation for tubular combustors as referenced by Field, et al (1967) according to equation 28 (4):

$$Nu = 0.023\,Re^{0.8}\,Pr^{0.4}\left[1 + \left(\frac{L}{D}\right)^{0.7}\right] \quad (28)$$

where Re is the Reynolds number and Pr is the Prandtl number. The Prandtl number is defined by equation 29:

$$Pr = \frac{C_p \mu}{K_{gas}} \quad (29)$$

and the Reynolds number is defined by equation 30:

$$Re = \frac{\rho U D}{\mu} \quad (30)$$

where ρ is the gas density which is calculated by equation 31:

$$\rho = MW_{mean} \times \frac{mole}{386.7\ sft^3} \times \frac{530°R}{T} \times \frac{sft^3}{ft^3} \quad (31)$$

MW_{mean} is the mean molecular weight of the gas as calculated in equation 32:

$$MW_{mean} = \frac{\sum m_i - m_{ash}}{\sum M_i} \quad (32)$$

and U is the gas velocity calculated from equation 33:

$$U = 4 \frac{\left(\sum m_i - m_{ash}\right)}{\rho D^2 \pi} \quad (33)$$

Radiation is the dominant mode of heat transfer at typical incineration temperatures. The general equation for emitted radiation is:

$$Radiation = \varepsilon A \sigma T^4 \quad (34)$$

where σ is the Stefan-Boltzmann constant. Emitted radiation can come from the gas, in which case ε is the emissivity of the gas, A is the total area of the incinerator unit, and T is the gas temperature; or it can come from the refractory wall (cooled surfaces are assumed to be too cold to radiate significantly), in which case ε is the emissivity of the refractory, A is the refractory area, and T is the refractory wall temperature.

Wall emissivity is assumed to be 0.8, typical of many dirty refractories. Gas emissivity is calculated by Johnson's (1973) (5) gray gas approach as described by Richter (1981) (6) where the emissivity of the absorbing gases is characterized as the sum of the emissivities of three weighted gray components:

$$\varepsilon_{ag} = \sum a_i \left[1 - \exp\left(-K_i BL\right)\right] \quad (35)$$

where BL is the mean beam length of the incinerator and the weighting factor a_i is a function of temperature:

$$a_i = b_i + \frac{c_i}{T} \quad (36)$$

The absorption coefficient K_i is a function of the partial pressures of the absorbing gases H_2O and CO_2:

$$K_i = d_i \left(P_{H_2O} + P_{CO_2}\right) \quad (37)$$

where:

$$P_{H_2O} = \frac{M_{H_2O}}{\sum M_i} \quad (38)$$

and

$$P_{CO_2} = \frac{M_{CO_2}}{\sum M_i} \quad (39)$$

Values of b, c, and d are tabulated in Table E-4. The emissivity due to soot is calculated as described by Sarofim (1978) (7):

$$\varepsilon_s = 1 - \left[1 + \frac{59.27}{°R\,ft} FV \times T \times BL\right]^4 \quad (40)$$

where FV is the volume of soot per volume of gas and is calculated from:

$$FV = \frac{m_{soot} \rho}{\rho_{soot}\left(\sum m_i - m_{ash}\right)} \quad (41)$$

where ρ_{soot} is assumed to be 2 g/cm3 and m_{soot} is assumed to be 2 percent of the volatile carbon.

$$m_{soot} = 0.02 \sum \left(m_i C \times Vol\right) \quad (42)$$

The emissivity of the composite gas is:

$$\varepsilon_g = 1 - \left(1 - \varepsilon_{ag}\right)\left(1 - \varepsilon_s\right) \quad (43)$$

BL is the mean beam length of the incinerator. The mean beam length is approximated by a curve fit to beam lengths of a gas radiating to cylinders of different dimensions:

$$BL = 0.3D + 0.65\left[1 - \exp\left(\frac{-0.6L}{D}\right)\right] \quad (44)$$

The radiative heat transfer calculation begins with emissions from the gas. The emitted radiation strikes the walls. The proportion which strikes the refractory wall is determined by the ratio of the refractory area to the total area with the remainder striking cooled surfaces. The proportion of the radiation which is absorbed by the wall is the same as the wall emissivity, assumed to be 0.8 for both refractory and cooled surfaces, the remainder being reflected. The reflected radiation, along with radiation emitted from the walls, passes through the gas. The proportion of the radiation which is absorbed by the gas is the same as the gas emissivity with the remainder passing through to strike the far wall. Radiation is followed in this manner, reflecting and being absorbed by refractory walls and cooled surfaces and being transmitted through and being absorbed by the gas until a negligible proportion remains. Radiative heat transfer from each element (gas, wall, and cooled surface) is determined by:

$$\text{Radiative Heat Transfer} = \text{Emission} - \sum \text{Absorption} \quad (45)$$

Table E-4. Weighted Gray Gas Constants

i	b	c, °R^{-1}	d, (ft-atm)$^{-1}$
1	0.13	0.000147	0
2	0.595	-0.0000833	0.258
3	0.275	-0.0000639	8.107

Heat transfer from the outer shell to the ambient surroundings is the sum of the heat transfer due to free convection and radiation. Free convection is calculated from a correlation for free convection from a horizontal cylinder taken from McAdams (1953) (8):

$$\text{Free Convection} = 0.18 \frac{\text{Btu/hr}}{°R} \left(T_{shell} - T_{ambient}\right)^{4/3} \times A_{shell} \quad (46)$$

and radiation is calculated from equation 34 using 0.7 as the outer shell emissivity.

A Newton Raphson iterative technique is used to solve equations 11 and 12 for an initial outer shell temperature guess. Initial gas and wall temperatures are estimated, and the left-hand sides of the equations and their derivatives are solved. Revised gas and wall temperatures are estimated from equations 47 and 48:

$$T_{gas\ new} = T_{gas\ old} - \frac{(12) \times \frac{\delta(11)}{\delta T_{wall}} - (11) \times \frac{\delta(12)}{\delta T_{wall}}}{\frac{\delta(12)}{\delta T_{gas}} \times \frac{\delta(11)}{\delta T_{wall}} - \frac{\delta(11)}{\delta T_{gas}} \times \frac{\delta(12)}{\delta T_{wall}}} \quad (47)$$

$$T_{wall\ new} = T_{wall\ old} - \frac{(11) \times \frac{\delta(12)}{\delta T_{gas}} - (12) \times \frac{\delta(11)}{\delta T_{gas}}}{\frac{\delta(12)}{\delta T_{gas}} \times \frac{\delta(11)}{\delta T_{wall}} - \frac{\delta(11)}{\delta T_{gas}} \times \frac{\delta(12)}{\delta T_{wall}}} \quad (48)$$

The iterative process is continued until T_{gas} and T_{wall} yield solutions to the left hand sides of equations 11 and 12 with absolute values less than 1/10,000 of the sensible heat in the unit. If the outer shell temperature is not given, the outer shell temperature estimate is revised, and the process is repeated until the absolute value of the left-hand side of equation 13 is also less than 1/10,000 of the sensible heat in the unit. At this point, the energy balance is complete.

For fluidized beds, heat transfer between the gas and walls is assumed to be fast; thus, gas temperature and wall temperature are assumed to be the same. Equations 11 and 12 are combined so that only two equations must be solved for T_{gas} and T_{shell}.

E.1.4 Residence Time

Mean residence time in a unit is calculated from the temperature, volume, and volumetric flow of the unit:

$$\text{Volumetric Flow}\ (@\ T_{gas}) = \text{Volumetric Flow}\ (@\ 70°F) \times \frac{T_{gas} + 460°R}{70°F + 460°R} \quad (49)$$

$$\tau = \frac{\text{Volume}}{\text{Volumetric Flow}\ (@\ T_{gas})} \quad (50)$$

E.1.5 Units In Series

For units in series, the products of complete combustion along with the sensible heat they carry are passed from one unit to the next and are added to all the new inputs to the next unit. If ash drops out of the first unit, its mass flow and sensible heat are subtracted out and not passed to the second unit.

E.1.6 APCE

The APCE calculations in the current version of the energy and mass balance simply determine the flow, acid loading, and quench water requirement of the effluent passing to the APCE. Developments are currently underway to allow more detailed evaluations of specific equipment performance such as ESPs, venturi scrubbers, packed tower, cyclones, and FFs. These will be incorporated into the software in future updates.

Flow is calculated in terms of dry volumetric flow from the last unit at standard conditions:

$$\text{Dry Volumetric Flow (@ 70°F)} = \left(\sum \text{Molar Flow}_i - M_{H_2O} \times 386.7 \frac{\text{sft}^3}{\text{lb mole}} \right) \quad (51)$$

Acid loading is simply the mass flow of HCl from the last unit:

$$\text{Acid Loading} = m_{HCl} \quad (52)$$

Quench water requirement is the amount of water necessary to quench the effluent from the exit temperature of the last unit to the temperature at which the gas is saturated with water. All cooling is assumed to occur by evaporation and changes in sensible heat.

First, the saturation temperature is estimated. The energy required to cool the gas to the saturation temperature is calculated:

$$\text{Sensible Heat} = m_{exhaust} C_{p\,mean} \left(T_{exhaust} - T_{saturated} \right) \quad (53)$$

where the mean heat capacity is calculated from equations 19 and 20. Then the amount of water necessary to cool the exhaust gas is calculated:

$$m_{H_2O} = \frac{\text{Sensible Heat}}{C_{p\,water} \left(T_{saturated} - T_{water} \right) \Delta H_{vap\,water}} \quad (54)$$

The water content of the effluent is compared with the vapor pressure curve of water to determine how close the effluent is to saturation. The saturation temperature estimate is adjusted and equations 53 and 54 are recalculated. This iterative process continues until the effluent is within 0.5°F of saturation.

As the effluent cools from the quenched temperature to the stack temperature, the vapor pressure of water decreases and the excess water is assumed to drop out so that the effluent remains saturated. Thus, the total flow at the stack is calculated by equation 55:

$$\text{Stack Volumetric Flow (@70°F)} = \frac{\text{Dry Volumetric Flow (@ 70°F)}}{1\,\text{atm} - \text{Vapor Pressure of Water (@ stack temperature)}} \quad (55)$$

E.1.7 Limitations of the Current Procedure

The June 1987 version of the energy and mass balance procedure is subject to the following limitations:

1. It is only applicable to fuel-lean incinerators. The complete combustion assumption is no longer valid under fuel-rich situations.
2. It tends to overpredict temperatures in high-temperature, nearly stoichiometric conditions where significant equilibrium concentrations of CO and OH exist.
3. It is not applicable to cold-wall, flame-dominated incinerators where waste destruction may be controlled by mixing and by flame temperature which is very different from exit temperature.
4. It is of limited value for incinerators which cannot be characterized by a single mean temperature, such as a long incinerator with a significant temperature profile.
5. It does not account for unquantified heat losses which are not evident in the input data. Heat losses from often overlooked sources such as water-cooled burners and probes, view ports, gaps in the refractory, etc., may account for most of the heat loss in some incinerators. Thus, the program tends to overpredict temperatures in incinerators with significant, unquantified heat losses.

E.2 References

1. Daniels, F. and R.A. Alberty. *Physical Chemistry.* New York: John Wiley and Sons. 1967, p. 53.
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Energy Balances. New York: John Wiley and Sons. 1967.

3. Perry, R.H. and C.H. Chilton. *Chemical Engineers' Handbook - Fifth Edition*. New York: McGraw-Hill. 1973.

4. Field, M.A., D.W. Gill, B.B. Morgan, and P.G.W. Hawksley. *Combustion of Pulverised Coal*. Leatherhead: The British Coal Utilisation Research Association. 1967, p. 119.

5. Johnson, T.R. and J.M. Beer. *The Zone Method Analysis of Radiant Heat Transfer: A Model for Luminous Radiation*. J. Inst. Fuel. 46:388. 1973.

6. Richter, W. *Assessment of Pulverized Coal Fired Combustor Performance--Models for Coal Combustor Performance, Analytical Tool Verification*. Topical Report. DOE Contract No. DE-AC-80PC30297. 1981.

7. Sarofim, A.F. and H.C. Hottel. *Radiative Transfer in Combustion Chambers: Influence of Alternative Fuels*. Washington: Hemisphere Publishers. 1978 pp. 199-217.

8. McAdams, W.H. *Heat Transmission*. New York: McGraw-Hill. 1953, p. 177.

APPENDIX F
Example Reporting Forms

This appendix contains copies of blank forms that may be used as a format guide to summarize the results of the trial burn. These forms are only intended to summarize certain, fundamental, information in a format which will facilitate review of the report. They do not call for all of the information which is needed in a full trial burn report. Because every incinerator system is somewhat different, in many cases additional information will be necessary. Conversely, some of the information listed on the forms may not be needed for the evaluation. The applicant should, however, be aware that using as consistent as possible a format, for summarizing the trial burn results will make it easier for the reviewer to evaluate the report and, hence, expedite the permitting procedure.

Table F-1 lists the forms and how they are to be used. The forms are grouped into the following categories:

1. Facility and design information, Forms 1 and 2--This information should be included in the trial burn plan as well as in the report.
2. Listing of the target settings for the trial burn, Forms 3, 4, 5, and 6--This information can be included in the trial burn plan as well as in the report.
3. Summary of the system's operating conditions and performance during the trial burn, Forms 3, 4, 5, 6, 7, 8, 9, 10 and 11--These forms can be used to summarize the data for each run, they can also be used to present a summary of the information for each test of the trial burn. In this way, the reviewer can evaluate the summary of the results of the trial burn and if additional information on the runs for that test is desired, it is it can be found on the same form summarizing the results of each run.
4. Recordkeeping, Forms 10 and 12--These forms can be used to keep the log of the monitoring parameters required by the permit during operation and during the trial burn, if needed.

These forms should be presented in the report on only one side of the paper--no two-sided copies. This allows the permit reviewer to spread them out and compare the entries.

Table F-1. Recommended Usage of Sample Forms in Trial Burn Report

Form no.	Title	Number of copies/Purpose
1	Summary of Facility Information	1/a
2	Summary of Design Information	1/a
3	Description of Waste Streams	1/a
4	Summary of Test Conditions (Waste Feed)	1 per test/b*
5	Summary of Operating Parameter Values	1 per test/b 1 per run/c
6	Summary of System Performance	1 per test/b 1 per run/c
7	Method 5 and Particulate Results	1 per run/c
8a	Input Rates	1 per run/c
8b	Chloride Emissions	1 per run/c
9a	POHC Emissions (May be used for volatiles and semivolatiles or use Form 9c for semivolatiles separately.)	1 per run/c
9b	POHC Input Rates	1 per run/c
9c	Semivolatile POHC Emissions (May be used in lieu of Form 9a for semivolatile emission results.)	1 per run/c
10	Monitoring Data for Halides and Inorganic Ash and Operations	1 per run/c
11	List of Samples	1 per test/d
12	Emergency Shutdown and Permit Compliance Record	1/Operation only

Note: Submit pages that have been copied on one side only to facilitate evaluation and review.

a To indicate the range of values that would be encountered during operation or to describe the facility.
b To summarize the results of each test, i.e., average of the runs for that test condition.
c To summarize the results of each run. (The average of these data for each test constitute to input to "b," above.)
d As a QA/QC check on the samples taken during the test.

*If waste composition changes for each run then Form 3 should be included to identify the actual composition of the wastes burned during each run.

Form 1. Summary of Facility Information

EPA facility ID No. _____

Facility name _____

Contact Person _____

Telephone No. _____

Facility Address _____

_____

_____

EPA Region _____

Person responsible for trial burn report _____

Telephone No. _____

Company name _____

Address _____

_____

_____

Date _____

Have proper QA/QC procedures been followed? Yes _____ No _____

Person responsible for QA/QC _____

Title _____

Address _____

_____

_____

Telephone No. _____

Form 2. Summary of Design Information

Parameter	Units			
Incinerator ID				
Installation date (year)				
Type of incinerator				
		PCC	SCC	System
Inside dimensions (dia. x length or height x width x length)				
Cross sectional area				
Combustion chamber volume				
Design heat release rate				
Refractory thickness[a]				
Refractory conductivity[a]				
Refractory surface area[a]				
Cooled surface area[a]				
Design pressure				
ID fan capacity				
Stack diameter				
Stack height				
APCE design information (as applicable)				
Type(s) (quench, Venturi, ESP, etc.)				
Maximum inlet temperature				
Minimum inlet temperature				
Maximum inlet pressure				
Minimum inlet pressure				
Design pressure drop (range)				
Design liquid flow (range)				
Design gas flow (range)				
Surface area (bags, plates)				
Voltage (specify AC/DC)				
Current				
HCl removal capacity				

Burner identification[b]	Type	Waste stream(s)	Atomizing fluid pressure[c]	Type atomizing fluid

[a]Required for mass and energy balance.
[b]Only need to identify burners used for waste.
[c]If different from design specifications, explain.

Form 3. Description of Waste Streams

Complete one of the following three columns:
Expected operating conditions _____ (check)

Run results
_____ Run number
_____ Date

Test results, Test # _____
Average of runs
Nos. ____ ____ ____ ____ ____ ____ ____

Parameter	Units	Waste stream identifiers						
		_____	_____	_____	_____	_____	_____	_____
Type[a]		_____	_____	_____	_____	_____	_____	_____
Type of feed[b]		_____	_____	_____	_____	_____	_____	_____
Location of feed		_____	_____	_____	_____	_____	_____	_____
Nominal feed rate[c]	_____	_____	_____	_____	_____	_____	_____	_____
Container size	_____	_____	_____	_____	_____	_____	_____	_____
Container type[d]	_____	_____	_____	_____	_____	_____	_____	_____
Container Frequency[e]	_____	_____	_____	_____	_____	_____	_____	_____
Physical state	_____	_____	_____	_____	_____	_____	_____	_____
HHV	_____	_____	_____	_____	_____	_____	_____	_____
Density	_____	_____	_____	_____	_____	_____	_____	_____
Viscosity	_____	_____	_____	_____	_____	_____	_____	_____
Ultimate Analysis								
Water	_____	_____	_____	_____	_____	_____	_____	_____
Ash	_____	_____	_____	_____	_____	_____	_____	_____
Carbon‡	_____	_____	_____	_____	_____	_____	_____	_____
Hydrogen‡	_____	_____	_____	_____	_____	_____	_____	_____
Oxygen‡	_____	_____	_____	_____	_____	_____	_____	_____
Chlorine‡	_____	_____	_____	_____	_____	_____	_____	_____
Sulfur‡	_____	_____	_____	_____	_____	_____	_____	_____
Nitrogen‡	_____	_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____	_____	_____

(continued)

Form 3. Description of Waste Streams (concluded)

Parameter	Units	Waste stream identifiers						
Organic Constituents (list)[f]								
Metals and salts (list)								

‡Only organic and acid or acid-forming compounds of these fed to incinerator.
[a]High BTU liquid, aqueous waste, sludge, containerized solids, etc.
[b]Steam atomizing nozzle, ram feed, etc.
[c]Lb/h, kg/h, etc.
[d]Fiber drum, steel drum, etc.
[e]One container every 5 min.
[f]Identify POHC's with an asterisk (*).

Form 4. Summary of Test Conditions (Waste Feeds)

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test)			
		_____	_____	_____	_____
Test Dates		_____	_____	_____	_____
Elapsed time average	_____	_____	_____	_____	_____
Feed rate of each waste burned					
1._____					
Size of containers	_____	_____	_____	_____	_____
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
2._____					
Size of containers	_____	_____	_____	_____	_____
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
3._____					
Size of containers	_____	_____	_____	_____	_____
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
4._____					
Size of containers	_____	_____	_____	_____	_____
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
5._____					
Size of containers	_____	_____	_____	_____	_____
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Total (mean) feed rate of all wastes to PCC	_____	_____	_____	_____	_____
Total (mean) feed rate of all wastes to SCC	_____	_____	_____	_____	_____
Auxilliary fuel used (total)					
Fuel _____	_____	_____	_____	_____	_____
Fuel _____	_____	_____	_____	_____	_____
Fuel _____	_____	_____	_____	_____	_____

(continued)

Form 4. Summary of Test Conditions (Waste Feeds) (concluded)

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) _____	_____	_____	_____
Metals and salts					
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
Organic Chloride	_____	_____	_____	_____	_____
Other materials of concern					
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____

Form 5. Summary of Operating Parameter Values

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) _____	_____	_____	_____
PCC temperature					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
SCC temperature					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Combustion gas flowrate (identify on P&I or schematic where measured)					
Actual T = _____, P = _____					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
@STP T = _____, P = _____					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Waste feed pressure	_____	_____	_____	_____	_____
Atomizing fluid pressure	_____	_____	_____	_____	_____
Combustion air blower power	_____	_____	_____	_____	_____
ID fan power	_____	_____	_____	_____	_____
PCC pressure					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
SCC pressure					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
APCE operating conditions					
Quench					
Inlet temperature mean	_____	_____	_____	_____	_____
Outlet temperature mean	_____	_____	_____	_____	_____
Water feed rate					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____

(continued)

Form 5. Summary of Operating Parameter Values (concluded)

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test)			
		_____	_____	_____	_____
APCE (as applicable)					
Water/liquor flowrate					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Inlet temperature mean	_____	_____	_____	_____	_____
Exit temperature mean	_____	_____	_____	_____	_____
Pressure drop					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
L/G ratio					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Influent pH					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Effluent pH					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Scrubbant blowdown rate	_____	_____	_____	_____	_____
Nozzle pressure					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Plate voltage					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Current					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Sparking rate mean	_____	_____	_____	_____	_____

Form 6. Summary of System Performance

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test)			
		_____	_____	_____	_____
Performance					
Flue gas					
Flowrate (actual), mean	_____	_____	_____	_____	_____
Flowrate (STP), mean	_____	_____	_____	_____	_____
Velocity (actual), mean	_____	_____	_____	_____	_____
Velocity (STP) mean	_____	_____	_____	_____	_____
Flue gas composition (by volume)					
H_2O	_____	_____	_____	_____	_____
O_2 (by volume, dry)	_____	_____	_____	_____	_____
N_2 (by volume, dry)	_____	_____	_____	_____	_____
CO_2 (by volume, dry)	_____	_____	_____	_____	_____
CO (by volume, dry)	_____	_____	_____	_____	_____
Total unburned hydrocarbons	_____	_____	_____	_____	_____
SO_x	_____	_____	_____	_____	_____
NO_x	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
CO (corrected to 7% O_2)					
Maximum	_____	_____	_____	_____	_____
Minimum	_____	_____	_____	_____	_____
Mean	_____	_____	_____	_____	_____
Particulate emissions					
Actual emission rate	_____	_____	_____	_____	_____
Actual concentration	_____	_____	_____	_____	_____
% Isokinetic	_____	_____	_____	_____	_____
Concentration corrected to 7% O_2	_____	_____	_____	_____	_____
Metal _____	_____	_____	_____	_____	_____
Metal _____	_____	_____	_____	_____	_____
Metal _____	_____	_____	_____	_____	_____
Metal _____	_____	_____	_____	_____	_____
Emission rate	_____	_____	_____	_____	_____
Into APCE	_____	_____	_____	_____	_____
Out from APCE	_____	_____	_____	_____	_____
% removal	_____	_____	_____	_____	_____

(continued)

Form 6. Summary of System Performance (concluded)

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test)			
		_____	_____	_____	_____
HCL					
Emission rate	_____	_____	_____	_____	_____
Into APCE	_____	_____	_____	_____	_____
Out from APCE	_____	_____	_____	_____	_____
% removal	_____	_____	_____	_____	_____
POHC input					
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
POHC emissions					
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____
DRE for POHC					
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____
_____	%	_____	_____	_____	_____

Form 7. Method 5 and Particulate Results[a]

Parameter	Units[a]	Test or Run No.		
		_____	_____	_____
Sample time	_____	_____	_____	_____
Sample volume[b]	_____	_____	_____	_____
Stack gas volumetric flowrate	_____	_____	_____	_____
Stack gas volumetric flowrate[b]	_____	_____	_____	_____
Stack gas temperature	_____	_____	_____	_____
Stack gas moisture	% vol.	_____	_____	_____
Oxygen concentration[c]	%	_____	_____	_____
Carbon dioxide concentration[c]	%	_____	_____	_____
Percent isokinetic	%	_____	_____	_____
Particulate collected	_____	_____	_____	_____
Particulate concentration	_____	_____	_____	_____
Particulate concentration corrected to 7% oxygen	_____	_____	_____	_____

[a] Either metric or English units are acceptable as long as consistency is maintained throughout the report.
[b] Dry standard basis.
[c] From Orsat analysis.

Form 8a. Chlorine Input Rates

	Test or run no. ________			Test or run no. ________			Test or run no. ________		
Waste/fuel stream	Feedrate (kg/min)	Chlorine concentration (%)	Chlorine input rate (g/min)	Feedrate (kg/min)	Chlorine Concentration (%)	Chlorine input rate (g/min)	Feedrate (kg/min)	Chlorine concentration (%)	Chlorine input rate (g/min)
Total									

Form 8b. HCl Emissions[a,b] and Removal Efficiency

Run No.	Sample period	Sample volume[c]	HCl collected[d]		HCl concentration[e]	Stack gas flow rate[f]	Cl^- emission rate	HCl emission rate[g]	HCl removal effciency (%)
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
Blank value									

a Either metric or English units are acceptable as long as consistency is maintained throughout the report.
b This table is formatted to use chloride results from a single MM5 train (only one chloride emission sample is required per run). If two MM5 trains are run, both sets of HCl data should be reported.
c Sample volume is dry standard liters of stack gas.
d Show value corrected for blank in parentheses.
e Blank corrected as applicable.
f Stack gas flow rate is dry normal (standard) m^3/min.
g Chloride emissions (lb/h) x 1.03.

Form 9a. POHC Emissions

Run No.	Trap pair (for VOST)	Sample period (_____)[b]	Sample volume (_____)[b]	Mass of each POHC collected (_____)[a]	(_____)[a]	(_____)[a]	(_____)[a]	(_____)[a]	(_____)[a]
_____	1	_____	_____	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
				_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
_____	2	_____	_____	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
				_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
_____	3	_____	_____	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
				_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
	Total/average[d]	_____	_____	_____	_____	_____	_____	_____	_____
POHC concentration (_____)[b]				_____	_____	_____	_____	_____	_____
Stack gas flow rate (_____)[b]				_____					
Emission rate (_____)[b]				_____	_____	_____	_____	_____	_____
_____	1	_____	_____	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
				_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
_____	2	_____	_____	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
				_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
_____	3	_____	_____	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
				_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]	_____ (_____)[c]
	Total/average[d]	_____	_____	_____	_____	_____	_____	_____	_____
POHC concentration (_____)[b]				_____	_____	_____	_____	_____	_____
Stack gas flow rate (_____)[b]				_____					
Emission rate (_____)[b]					_____	_____	_____	_____	_____
Average blank value[d] (_____)[b]				_____	_____	_____	_____	_____	_____
Standard deviation[d] (_____)[b]				_____	_____	_____	_____	_____	_____
Range of blank values[d] (_____)[b]				_____	_____	_____	_____	_____	_____

Note: This format is structured for VOST results. It may be used for MM5, a similar format would be used for integrated bag sampling for volatiles. Guidance for blank correction is provided in the "Practical Guide—Trial Burns for Hazardous Waste Incinerators," Final Report, EPA-600/2-86-050, 1986.

Note: Use parentheses to present results if two collectors are used in series (i.e., dual adsoprtion tubes on VOST).

[a] Either metric or English units are acceptable as long as consistency is maintained throughout the report.

[b] Sample volume is dry standard liters of stack gas.

[c] Stack gas flowrate is dry normal (standard) m^3/min.

[d] totals for sample period, volume, and amount collected; averages for concentration, flowrate, and emissions rate.

[e] Indicate whether all (both field blanks and trip blanks) are used or whether only field blanks are used.

Form 9b. POHC Input Rate, [Test Run] No.___

Waste/Fuel stream	Waste feedrate[b] (kg/min)[a]		POHC concentration[c] (%)[a]/feedrate (g/min)[a]					DRE
			______	______	______	______	______	______
______	______	d	______	______	______	______	______	______
	______	e	______	______	______	______	______	______
______	______	d	______	______	______	______	______	______
	______	e	______	______	______	______	______	______
______	______	d	______	______	______	______	______	______
	______	e	______	______	______	______	______	______
______	______	d	______	______	______	______	______	______
	______	e	______	______	______	______	______	______
______	______	d	______	______	______	______	______	______
	______	e	______	______	______	______	______	______
______	______	d	______	______	______	______	______	______
	______	e	______	______	______	______	______	______
______	______	d	______	______	______	______	______	______
	______	e	______	______	______	______	______	______
Total POHC feedrate			______	______	______	______	______	______

a Give units.
b Give feedrate measured during this run/test.
c Give concentration measured from sample taken during this test/run.
d Give concentration at POHC in each waste.
e Give feedrate of each POHC.

Form 9c. Semivolatile POHC Emissions[a]

Run No.	Sample period	Sample volume[b]	POHC collected		POHC concentration		Stack gas flowrate[c]	Emission rate	
			SV POHC No. 1	SV POHC No. 2	SV POHC No. 1	SV POHC No. 2		SV POHC No. 1	SV POHC No. 2
_____	_____	_____	_____ (_____)	_____ (_____)	_____	_____	_____	_____	_____
_____	_____	_____	_____ (_____)	_____ (_____)	_____	_____	_____	_____	_____
_____	_____	_____	_____ (_____)	_____ (_____)	_____	_____	_____	_____	_____
Average blank value			_____	_____					
Standard deviation			_____	_____					
Range of blank values			_____	_____					

[a] Either metric or English units are acceptable as long as consistency is maintained throughout the report

[b] Sample volume is dry at standard conditions (specify).

[c] Stack gas flowrate is dry at standard conditions (specify).

NOTE: This form may be used in lieu of Form 9b for summarizing emission results for semivolatile compounds.

Form 10. Monitoring Data for Halides and Inorganic Ash Input[a]

Run/Test No._____ Maximum halides input rate = _____

Maximum inorganic ash input rate = _____

Part A. Waste analysis data[b]

Waste name	Sample ID no(s).[c]	Total halides (%) (F, Cl, Br, I)	Inorganic ash (%)	Specific gravity
Pumpable wastes				
P1.				
P2.				
P3.				
Containerized wastes				
C1.				
C2.				
C3.				

(continued)

Form 10. Monitoring Data for Halides and Inorganic Ash Input[a]

Part B. Calculation of input rates

	Pumpable wastes					Containerized wastes							
Time period	Waste No.	Avg. flowrate for period	Mass feed rate	Halide input rate	Ash input rate	Waste No.	No. containers charged	Total mass charged	Mass feed rate	Halide input rate	Ash input rate	Total Halide input rate	Total Ash input rate
0000 - 0400	P1					C1						–	–
	P2					C2						–	–
	P3					C3						–	–
	Total for pumpable wastes					Total for containerized wastes							
0400 -0800	P1					C1						–	–
	P2					C2						–	–
	P3					C3						–	–
	Total for pumpable wastes					Total for containerized wastes							
0800 - 1200	P1					C1						–	–
	P2					C2						–	–
	P3					C3						–	–
	Total for pumpable wastes					Total for containerized wastes							
1200 - 1600	P1					C1						–	–
	P2					C2						–	–
	P3					C3						–	–
	Total for pumpable wastes					Total for containerized wastes							
1600 - 2000	P1					C1						–	–
	P2					C2						–	–
	P3					C3						–	–
	Total for pumpable wastes					Total for containerized wastes							
2000 - 2400	P1					C1						–	–
	P2					C2						–	–
	P3					C3						–	–
	Total for pumpable wastes					Total for containerized wastes							

(continued)

Form 10. Monitoring Data for Halides and Inorganic Ash Input[a] (concluded)

Equations:[d]

$$\text{Pumpable waste average flowrate (L/min)} = \text{Time-weighted average from continuously monitoring data logger}$$

or

$$= \frac{\text{Volume at end of period (L)} - \text{volume at beginning of period (L)}}{240 \text{ min}}$$

$$\text{Pumpable waste mass feed rate} = \text{average flowrate (L/min)} \times \text{specific gravity (kg/L)} \times 60 \text{ min/h}$$

$$\text{Containerized waste total mass charged (KG)} = \sum_{i=1}^{n} \text{Gross weight (kg)} - \text{container tare weight (kg)}$$

where n = number of containers charged during 4-h period

$$\text{Containerized mass feed rate} = \frac{\text{Total mass charged (kg)}}{4 \text{ h}}$$

$$\text{Halide/ash input rate} = \frac{\text{\% Halide/ash}}{100} \times \text{Mass feed rate}$$

[a] Either metric or English units are acceptable as long as consistency is maintained throughout the report.
[b] Begin new form for each new set of analysis results.
[c] If more than one sample is involved, list sample numbers and provide average results.
[d] For clarity metric units are shown; English units can be used if desired as long as consistency is maintained throughout the report.

Form 11. List of Samples

Test No.	Run No.	Type sample	ID no.	Date taken	Date analyzed	Notes[a]

[a]Note any problems, i.e., broken sample (by whom or where), damaged samples, questionable data, problems with analytical equipment, etc.

Form 12. Emergency Shutdown and Permit Compliance Record

Facility ID No._____

Month_____ Year_____

Permit exceedence No.	Date	Time	Description of problem	Minimum/maximum value recorded (worst case)	Automatic shutdown—check (√) as appropriate: PCC waste automatic shutdown	SCC waste automatic shutdown	Thermal relief vent opened[a]	Time (min) waste shut-off	Check (√) if no shutdown[b]	Description of corrective action	Regulatory authorities notified (yes/no)
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											

[a] This example form describes the information generally needed for an emergency shutdown and permit compliance record. However, more space should be provided in actual forms if needed for adequate descriptions of problems and corrective actions.

[b] Exceedance based upon facility operational records (no automatic waste shutdown triggered); corrective actions to address any malfunction of automatic waste feed shutoff system should also be described)

APPENDIX G

Example Reporting Forms Filled Out for Data from Example Problem

General Facility Information

Form 1. Summary of Facility Information

EPA facility ID No.	123456789
Facility name	XYZ Chemical Company
Contact Person	John F. Smith
Telephone No.	(111) 555-5555
Facility Address	13 Pumpkin Lane Smith City, ST 12345
EPA Region	XI
Person responsible for trial burn report	John F. Smith
Telephone No.	see above
Company name	see above
Address	
Date	June 13, 1988
Have proper QA/QC procedures been followed?	Yes XX No
Person responsible for QA/QC	Mary Jane Doe
Title	Quality Assurance Manager
Address	Chemical Laboratory Consultants 1313 Gourd Street Juice City, ST 54321
Telephone No.	(111) 555-6666

Form 2. Summary of Design Information

Parameter	Units			
Incinerator ID		Rotary Kiln or RKI		
Installation date (year)		1981		
Type of incinerator		Rotary Kiln with SCC		
Inside dimensions (dia. x length or height x width x length)	m x m	PCC 3.4 x 6.7	SCC 3.6 x 7.5	System -----
Cross sectional area	m^2	8.8	10.3	-----
Combustion chamber volume	m^3	59	78	-----
Design heat release rate	10^6 kJ/h	72	36	108
Refractory thickness[a]	cm	15	15	-----
Refractory conductivity[a]	kJ/s-m-°C	0.00144	0.00144	-----
Refractory surface area[a]	m^2	88	106	-----
Cooled surface area[a]		0	0	-----
Design pressure		slightly neg.	slightly neg.	-----
ID fan capacity	nm^3/min	-----	-----	570
Stack diameter/area	m/m^2	-----	-----	0.61/1.17
Stack height	m			18.3

APCE design information (as applicable)		
Type(s) (quench, Venturi, ESP, etc.)		3-stage wet ionizing scrubber
Maximum inlet temperature	°C	96-gas 38-water
Minimum inlet temperature	°C	N/A-gas 4-water
Maximum inlet pressure		N/A
Minimum inlet pressure		N/A
Design pressure drop (range)		N/A
Design liquid flow (range)	L/min	400-800
Design gas flow (range)	m^3/min	400-800
Surface area (bags, plates)		
Voltage (specify AC/DC)	kV	30
Current		variable, dependent on loading
HCl removal capacity		unknown--to be determined by test

Burner identification[b]	Type	Waste stream(s)	Atomizing fluid pressure[c]	Type atomizing fluid
SL	Lance	SL	N/A	N/A
B-1	Air atomiz.	L1-L5 in PCC	20-50 psi	Air
B-2 a,b,c	Air atomiz.	L2-L5 in SCC	20-50 psi	Air

[a]Required for mass and energy balance.

[b]Only need to identify burners used for waste.

[c]If different from design specifications, explain.

Form 3. Description of Waste Streams

Complete one of the following three columns:
Expected operating conditions XX (check)

Run results
_____ Run number
_____ Date

Test results, Test # _____
Average of runs
Nos. ___ ___ ___ ___ ___ ___ ___

Parameter	Units	Waste stream identifiers S1	S2	L1	L2	L3	L4	L5
Type[a]		solids	solids	Lo Btu liq	Hi Btu liq	Hi Btu liq	Hi Btu Liq	Hi Btu Liq
Type of feed[b]		drum	bulk	nozzle	nozzle	nozzle	nozzle	nozzle
Location of feed		PCC	PCC	PCC/SCC	PCC/SCC	PCC/SCC	PCC/SCC	PCC/SCC
Nominal feed rate[c]	kg/min	18.6	8.4	31	2	0.4	6	0.4
Container size	gal	SS	-----	-----	-----	-----	-----	-----
Container type[d]	-----	steel drum	-----	-----	-----	-----	-----	-----
Container Frequency[e]	min	1/6 min	-----	-----	-----	-----	-----	-----
Physical state		solid	solid	liquid	liquid	liquid	liquid	liquid
HHV	kJ/kg	20,900	20,600	nil	32,700	35,460	31,500	34,600
Density								
Viscosity								
Ultimate Analysis								
Water	% wt	4	20	98.67	15	2	2	10
Ash (wet basis)	% wt	45	39	0.07	1	2	0.8	3
Carbon‡ (wet basis)	% wt	36	28	0.05	50	78	52.2	48
Hydrogen‡ (wet basis)	% wt	9	11	0.01	16	10	15	20
Oxygen‡ (wet basis)	% wt	3.8	2	1	3	8	4	14
Chlorine‡ (wet basis)	% wt	2.2	-----	0.2	15	-----	26	5
Sulfur‡ (wet basis)	% wt	-----	-----	-----	-----	-----	-----	-----
Nitrogen‡ (wet basis)	% wt	-----	-----	-----	-----	-----	-----	-----
_____	_____							
_____	_____							
_____	_____							

(continued)

Form 3. Description of Waste Streams (concluded)

Parameter	Units	Waste stream identifiers S1	S2	L1	L2	L3	L4	L5
Organic Constituents (list)[f]								
Carbon tetrachloride	% wt (wet)	1.1	-----	-----	6.8	-----	18	
Trichloro-ethylene*	% wt (wet)	1.6	-----	-----	-----	-----	6	
Toluene	% wt (wet)	-----	0.1	0.02	-----	16	-----	
Chloroform	% wt (wet)	-----	-----	0.14	-----	-----	-----	
Perchloro-ethylene*	% wt (wet)	-----	-----	-----	10	-----	-----	
Bis(2-chloro)-ethylether	% wt (wet)	-----	-----	-----	-----	-----	1	
Trichloro-benzene*	% wt (wet)	-----	-----	-----	-----	-----	5	
Phenol	% wt (wet)	-----	-----	-----	-----	26	-----	
Metals and salts (list)								

‡Only organic and acid or acid-forming compounds of these fed to incinerator.
[a]High BTU liquid, aqueous waste, sludge, containerized solids, etc.
[b]Steam atomizing nozzle, ram feed, etc.
[c]Lb/h, kg/h, etc.
[d]Fiber drum, steel drum, etc.
[e]One container every 5 min.
[f]Identify POHC's with an asterisk (*).

Form 3. Description of Waste Streams

Complete one of the following three columns:
Expected operating conditions XX (check)

Run results
_____ Run number
_____ Date

Test results, Test # _____
Average of runs
Nos. ____ ____ ____ ____ ____ ____ ____

Parameter	Units	Waste stream identifiers: SL						
Type[a]		sludge						
Type of feed[b]		Lance						
Location of feed								
Nominal feed rate[c]	kg/min	y						
Container size	gal	-----						
Container type[d]		-----						
Container Frequency[e]		-----						
Physical state		sludge						
HHV	kJ/kg	6,200						
Density		-----						
Viscosity		-----						
Ultimate Analysis								
Water	% wt	70						
Ash	% wt	14						
Carbon‡	% wt	10						
Hydrogen‡	% wt	3						
Oxygen‡	% wt	2.99						
Chlorine‡	% wt	0.01						
Sulfur‡								
Nitrogen‡								

(continued)

Form 3. Description of Waste Streams (concluded)

Parameter	Units	Waste stream identifiers: SI						
Organic Constituents (list)[f]								
Chlorobenzene	% wt (wet)	0.03						
Metals and salts (list)								

‡Only organic and acid or acid-forming compounds of these fed to incinerator.
[a]High BTU liquid, aqueous waste, sludge, containerized solids, etc.
[b]Steam atomizing nozzle, ram feed, etc.
[c]Lb/h, kg/h, etc.
[d]Fiber drum, steel drum, etc.
[e]One container every 5 min.
[f]Identify POHC's with an asterisk (*).

Form 4. Summary of Test Conditions (Waste Feeds)

Test No. target (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Tests 1,2,3			
Test Dates		N/A			
Elapsed time average					
Feed rate of each waste burned					
1. S1 (drummed waste)					
Size of containers	55 gal drum				
Maximum					
Minimum					
Mean	kg/min	27			
2. S1 (sludge)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	9			
3. L1 (aqueous)					
Size of containers					
Maximum					
Minimum					
Mean (PCC)	kg/min	31			
4. L2 (Hi Btu)					
Size of containers					
Maximum					
Minimum					
Mean (SCC)	kg/min	2.3			
5. L$ (Hi Btu)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	6			
Total (mean) feed rate of all wastes to PCC	kg/min	75			
Total (mean) feed rate of all wastes to SCC	kg/min	6			
Auxilliary fuel used (total)					
Fuel	as needed to maintain temperatures				
Fuel					
Fuel					

(continued)

Form 4. Summary of Test Conditions (Waste Feeds) (concluded)

Test No. target (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Tests 1,2,3			
Metals and salts					
Organic Chloride	g/min	2,650			
Other materials of concern					
None					

Form 5. Summary of Operating Parameter Values

Test No. target (if data for a run)

Data from each run or average for each test (min. 3 runs = 1 test)

Parameter	Units	Tests 1,2,3			
PCC temperature					
Maximum					
Minimum					
Mean	°C	900			
SCC temperature					
Maximum					
Minimum					
Mean	°C	1,000			
Combustion gas flowrate (identify on P&I or schematic where measured)					
Actual T = 80°C, P = 1 atm					
Maximum					
Minimum					
Mean	m^3/min	600			
@STP T = 20°C, P = 1 atm					
Maximum					
Minimum					
Mean	m^3/min	500			
Waste feed pressure					
Atomizing fluid pressure		N/A			
Combustion air blower power		N/A			
ID fan power		N/A			
PCC pressure					
Maximum					
Minimum					
Mean					
SCC pressure					
Maximum					
Minimum					
Mean					
APCE operating conditions					
Quench					
Inlet temperature mean	°C	1,000			
Outlet temperature mean	°C	80			
Water feed rate					
Maximum					
Minimum					
Mean	L/min	900			

(continued)

Form 5. Summary of Operating Parameter Values (concluded)

Test No. target (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Tests 1,2,3			
APCE (as applicable)		Stage 1	Stage 2	Stage 3	Total APCE
Water/liquor flowrate					
Maximum					
Minimum					
Mean	L/min	320	140	140	161
Inlet temperature mean	°C				80
Exit temperature mean	°C				80
Pressure drop					
Maximum					
Minimum					
Mean					N/A
L/G ratio					
Maximum					
Minimum					
Mean	L/m^3	.5	.2	.2	1
Influent pH					
Maximum					
Minimum					
Mean					7.0
Effluent pH					
Maximum					
Minimum					
Mean					N/A
Scrubbant blowdown rate	L/min				15
Nozzle pressure					
Maximum					
Minimum					
Mean					N/A
Plate voltage					
Maximum					
Minimum					
Mean	kV				30
Current					
Maximum		N/A			
Minimum					
Mean					
Sparking rate mean					

Form 6. Summary of System Performance

Test No. target (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Test 1	Test 2	Test 3	
Performance					
Flue gas					
Flowrate (actual), mean	m^3/min	614	614	589	
Flowrate (STP), mean	m^3/min	510	510	490	
Velocity (actual), mean					
Velocity (STP) mean					
Flue gas composition (by volume)					
H_2O	As established by tests at specified conditions.				
O_2 (by volume, dry)					
N_2 (by volume, dry)					
CO_2 (by volume, dry)					
CO (by volume, dry)					
Total unburned hydrocarbons					
SO_x					
NO_x					
CO (corrected to 7% O_2)					
Maximum	ppm	<100	<100	<100	
Minimum					
Mean					
Particulate emissions					
Actual emission rate	To be measured.				
Actual concentration					
% Isokinetic					
Concentration corrected to 7% O_2					
Metal					
Metal					
Metal					
Metal					
Emission rate					
Into APCE					
Out from APCE					
% removal					

(continued)

Form 6. Summary of System Performance (concluded)

Test No. target (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Tests 1,2,3			
HCL					
Emission rate	To be measured.				
Into APCE					
Out from APCE					
% removal					
POHC input					
trichloroethylene	g/min	353			
perchloroethylene	g/min	220			
trichlorobenzene	g/min	835			
POHC emissions					
	To be measured.				
DRE for POHC					
	%	To be measured.			

Summary of Results of Tests 1, 2, and 3

(Results of each test are means of the results of the three runs for that test.)

Form 3. Description of Waste Streams

Complete one of the following three columns:
Expected operating conditions _____ (check)

Run results
_____ Run number
_____ Date

Test results, Test # 1, 2, 3
Average of runs
Nos. 1 2 3 ___ ___ ___ ___

Parameter	Units	Waste stream identifiers: S1	SL	L1	L2	L4		
Type[a]		solids	sludge	water	Hi Btu liq	Hi Btu liq		
Type of feed[b]		drum	lance	nozzle	nozzle	nozzle		
Location of feed		PCC	PCC	PCC	PCC	SCC		
Nominal feed rate[c]	kg/min	27	9	30	2.3	6		
Container size		55 gal	N/A	N/A	N/A	N/A		
Container type[d]		steel drum						
Container Frequency[e]		1/minutes						
Physical state								
HHV								
Density								
Viscosity								
Ultimate Analysis								
Water	% wt	4	70	98.67	15	2		
Ash	% wt	45	14	0.07	1	0.8		
Carbon‡	% wt	36	10	0.05	50	52.2		
Hydrogen‡	% wt	9	3	0.01	16	15		
Oxygen‡	% wt	3.8	2.99	1	3	4		
Chlorine‡	% wt	2.2	0.01	0.2	15	26		
Sulfur‡	% wt	-----	-----	-----	-----	-----		
Nitrogen‡	% wt	-----	-----	-----	-----	-----		
_____	_____							
_____	_____							
_____	_____							

(continued)

Form 3. Description of Waste Streams (concluded)

Parameter	Units	Waste stream identifiers						
		S1	SL	L1	L2	L4		
Organic Constituents (list)[f]								
Carbon-tetrachloride	% wt (wet)	1.1	-----	-----	6.8	18		
Trichloro-ethylene*	% wt (wet)	1.6	-----	-----	-----	6		
Toluene	% wt (wet)	-----	-----	0.02	-----	-----		
Chloroform	% wt (wet)	-----	-----	0.14	-----	-----		
Perchloro-ethylene*	% wt (wet)	-----	-----	-----	10	-----		
Bis(2-chloro)-ethylether	% wt (wet)	-----	-----	-----	-----	1		
Trichloro-benzene*	% wt (wet)	-----	-----	-----	-----	5		
Phenol	% wt (wet)	-----	-----	-----	-----	-----		
Chlorobenzene	% wt (wet)	-----	0.03	-----	-----	-----		
Metals and salts (list)								

‡Only organic and acid or acid-forming compounds of these fed to incinerator.
[a]High BTU liquid, aqueous waste, sludge, containerized solids, etc.
[b]Steam atomizing nozzle, ram feed, etc.
[c]Lb/h, kg/h, etc.
[d]Fiber drum, steel drum, etc.
[e]One container every 5 min.
[f]Identify POHC's with an asterisk (*).

Form 4. Summary of Test Conditions (Waste Feeds)

Test No. summary of test results (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Test 1	Test 2	Test 3	
Test Dates		5/12-13/87	5/13-14/87	5/15-16/87	
Elapsed time average	min	120	120	120	
Feed rate of each waste burned					
1. S1 drummed					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	27.0	28.8	27.0	
2. SL sludge					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	8.4	7.8	7.8	
3. L1 aqueous					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	30.0	30.6	28.8	
4. L2 Hi Btu liq (PCC)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	2.2	2.3	2.3	
5. L4 Hi Btu liq (SCC)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	5.9	6.0	6.0	
Total (mean) feed rate of all wastes to PCC	kg/min	72.6	73.2	69.0	
Total (mean) feed rate of all wastes to SCC	kg/min	5.9	6.0	6.0	
Auxilliary fuel used (total) (mean per run for each test)					
Fuel natural gas	kg/min	5.71	5.65	5.60	
Fuel					
Fuel					

(continued)

Form 4. Summary of Test Conditions (Waste Feeds) (concluded)

Test No. summary of test results (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Test 1	Test 2	Test 3	
Metals and salts					
Organic Chloride	g/min	2.52	2.64	2.52	
Other materials of concern					

Form 5. Summary of Operating Parameter Values

Test No. summary of test results (if data for a run)

Data from each run or average for each test (min. 3 runs = 1 test)

Parameter	Units	Test 1	Test 2	Test 3	
PCC temperature					
Maximum	°C	916	821	804	
Minimum	°C	910	804	793	
Mean	°C	914	814	800	
SCC temperature					
Maximum	°C	1,049	1,010	971	
Minimum	°C	1,032	954	954	
Mean	°C	1,040	982	958	
Combustion gas flowrate (identify on P&I or schematic where measured)					
Actual T = 71, P = 1 atm					
Maximum	m^3/min	892	892	838	
Minimum	m^3/min	830	830	813	
Mean	m^3/min	866	866	827	
@STP T = 20°C, P = 1 atm					
Maximum	m^3/min	515	518	498	
Minimum	m^3/min	481	496	484	
Mean	m^3/min	501	508	492	
Waste feed pressure		Cannot be measured.			
Atomizing fluid pressure	psi	30	30	30	
Combustion air blower power		N/A	N/A	N/A	
ID fan power					
PCC pressure					
Maximum	mm H_2O	-1.6	-2.0	-2.6	
Minimum	mm H_2O	-2.6	-2.0	-2.0	
Mean	mm H_2O	-2.2	-2.0	-2.4	
SCC pressure					
Maximum	mm H_2O	-7.6	-8.9	-8.1	
Minimum	mm H_2O	-8.6	-8.9	-8.6	
Mean	mm H_2O	-8.2	-8.9	-8.4	
APCE operating conditions					
Quench					
Inlet temperature mean	°C	1,040	982	958	
Outlet temperature mean	°C	78	80	79	
Water feed rate					
Maximum		965	927	958	
Minimum		852	840	871	
Mean	L/min	910	886	915	

(continued)

Form 5. Summary of Operating Parameter Values (concluded)

Test No. summary of test results (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Test 1	Test 2	Test 3	
APCE (as applicable)					
Water/liquor flowrate					
Maximum					
Minimum					
Mean	L/min	606	606	606	
Inlet temperature mean	°C	78	80	79	
Exit temperature mean		72	72	71	
Pressure drop					
Maximum					
Minimum					
Mean		N/A	N/A	N/A	
L/G ratio					
Maximum					
Minimum					
Mean		0.70	0.70	0.70	
Influent pH (into IWS)					
Maximum	pH	6.8	7.5	7.3	
Minimum	pH	6.3	6.7	6.9	
Mean	pH	6.6	7.1	7.1	
Effluent pH (out of IWS)					
Maximum	pH	4.7	3.1	4.1	
Minimum	pH	2.9	2.9	3.3	
Mean	pH	3.8	3.0	3.7	
Scrubbant blowdown rate					
Nozzle pressure					
Maximum					
Minimum					
Mean		N/A	N/A	N/A	
Plate voltage					
Maximum					
Minimum					
Mean					
Current					
Maximum					
Minimum					
Mean					
Sparking rate mean		N/A			

Table G-1. Response to APCE Parameters, Form 6 "Summary of Test Results"

Parameter	Units	Test No. 1	Test No. 2	Test No. 3
IWS water flowrates				
1st stage IWS water flowrate	L/min	322	322	321
2nd stage IWS water flowrate	L/min	142	142	142
3rd stage IWS water flowrate	L/min	142	142	142
Total	L/min	606	606	606
IWS current and voltage				
IWS Unit 1A-DC Current	mA	23.3	23.2	23.5
IWS Unit 1A-DC Voltage	kV	30.5	30.0	29.1
IWS Unit 1B-DC Current	mA	16.1	14.9	15.6
IWS Unit 1B-DC Voltage	kV	31.2	30.8	29.4
IWS Unit 2A-DC Current	mA	104.9	94.5	109.8
IWS Unit 2A-DC Voltage	kV	27.9	29.0	26.2
IWS Unit 2B-DC Current	mA	101.1	94.2	94.2
IWS Unit 2B-DC Voltage	kV	28.8	29.0	25.9

Form 6. Summary of System Performance

Test No. summary of test results (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Test 1	Test 2	Test 3	
Performance					
Flue gas					
Flowrate (actual), mean					
Flowrate (STP), mean (wet)	m^3/s	501	508	492	
Velocity (actual), mean (wet)	m/s	12.3	12.3	11.8	
Velocity (STP) mean (wet)	m/s	10.5	10.5	10.1	
Flue gas composition (by volume)					
H_2O	%	32.4	32.4	32.4	
O_2 (by volume, dry)	%	10.7	10.9	11.1	
N_2 (by volume, dry)	%	81.6	81.4	81.2	
CO_2 (by volume, dry)	%	7.7	7.7	7.7	
CO (by volume, dry)	ppm	31.2	45.5	50.5	
Total unburned hydrocarbons					
SO_x					
NO_x					
CO (corrected to 7% O_2)					
Maximum					
Minimum					
Mean		48	71	80	
Particulate emissions					
Actual emission rate	mg/min	12.9	22.1	15.8	
Actual concentration	mg/Nm^3	38.2	64.4	47.5	
% Isokinetic	mg/Nm^3	59.5	100.4	75.4	
Concentration corrected to 7% O_2					
Metal					
Metal					
Metal					
Metal					
Emission rate					
Into APCE					
Out from APCE					
% removal					

(continued)

Form 6. Summary of System Performance (concluded)

Test No. summary of test results (if data for a run)

Data from each run or average for each test (min. 3 runs = 1 test)

Parameter	Units	Test 1	Test 2	Test 3	
HCL					
Emission rate	kg/h	1.06	0.64	1.29	
Into APCE	kg/h	200	156	153	
Out from APCE					
% removal	%	99.47	99.59	99.16	
POHC input					
trichloroethylene	g/min	353			
tetrachloroethylene	g/min	222			
trichlorobenzene	g/min	828			
POHC emissions					
trichloroethylene	g/min	0.0082			
tetrachloroethylene	g/min	0.0036			
trichlorobenzene	g/min	0.0166			
DRE for POHC					
trichloroethylene	%	99.998	99.998	99.997	
tetrachloroethylene	%	99.998	99.997	99.998	
trichlorobenzene	%	99.998	99.996	99.996	

Summary of Results

Runs 1-1, 1-2, and 1-3

Form 4. Summary of Test Conditions (Waste Feeds)

Test No. 1 (if data for a run)

Data from each run or average for each test (min. 3 runs = 1 test)

Parameter each	Units	1-1	1-2	1-3	
Test Dates		5/12/88	5/12/88	5/13/88	
Elapsed time average	min	120	120	120	
Feed rate of each waste burned					
1. S1 drummed (PCC)					
Size of containers		55 gal	55 gal	55 gal	
Maximum					
Minimum					
Mean	kg/min	27.2	26.5	25.7	
2. SL sludge (PCC)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	8.32	8.32	9.08	
3. L1 aquoeous (PCC)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	30.3	30.3	28.8	
4. L2 Hi Btu (PCC)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	2.19	2.23	2.27	
5. L4 Hi Btu (SCC)					
Size of containers					
Maximum					
Minimum					
Mean	kg/min	5.90	5.75	5.98	
Total (mean) feed rate of all wastes to PCC		68.0	67.4	65.9	
Total (mean) feed rate of all wastes to SCC		5.90	5.75	5.98	
Auxilliary fuel used (total)					
Fuel natural gas	kg/min	5.71	5.70	5.71	
Fuel					
Fuel					

(continued)

Form 4. Summary of Test Conditions (Waste Feeds) (concluded)

Test No. 1 (if data for a run) Parameter each	Units	Data from each run or average for each test (min. 3 runs = 1 test) 1-1	1-2	1-3	
Metals and salts					
none					
Organic Chloride					
Other materials of concern					
none					

Form 5. Summary of Operating Parameter Values

Test No. 1 (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Run 1-1	Run 1-2	Run 1-3	
PCC temperature					
Maximum	°C	962	968	969	
Minimum	°C	850	916	916	
Mean	°C	910	916	916	
SCC temperature					
Maximum	°C	1,118	1,115	1,113	
Minimum	°C	1,022	1,020	1,019	
Mean	°C	1,049	1,038	1,032	
Combustion gas flowrate (identify on P&I or schematic where measured)					
Actual T = _____, P = 1 atm					
Maximum @ quench outlet					
Minimum					
Mean	m^3/min	931	956	845	
@STP T = 20°C, P = 1 atm					
Maximum					
Minimum					
Mean	m^3/min	867	891	787	
Waste feed pressure		Not measured.			
Atomizing fluid pressure	psi	30	30	30	
Combustion air blower power		N/A	N/A	N/A	
ID fan power		Not measured.			
PCC pressure					
Maximum					
Minimum					
Mean	mm H_2O	-1.6	-2.6	-2.5	
SCC pressure					
Maximum					
Minimum					
Mean	mm H_2O	-8.0	-8.4	-7.6	
APCE operating conditions					
Quench					
Inlet temperature mean		Same as SCC temperature.			
Outlet temperature mean	°C	79	79	77	
Water feed rate					
Maximum					
Minimum					
Mean	L/min	852	912	965	

(continued)

Form 5. Summary of Operating Parameter Values (concluded)

Test No. 1 (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) Run 1-1	Run 1-2	Run 1-3	
APCE (as applicable)					
Water/liquor flowrate		See next page.			
Maximum					
Minimum					
Mean	L/min	603	603	603	
Inlet temperature mean					
Exit temperature mean	°C	71	72	71	
Pressure drop					
Maximum					
Minimum					
Mean					
L/G ratio					
Maximum					
Minimum					
Mean	L/m^3	0.65	0.63	0.71	
Influent pH					
Maximum	pH	6.3	6.9	6.6	
Minimum	pH	6.3	6.6	6.1	
Mean	pH	6.3	6.7	6.5	
Effluent pH					
Maximum	pH	4.1	4.3	4.2	
Minimum	pH	2.9	3.5	3.5	
Mean	pH	3.6	4.0	3.8	
Scrubbant blowdown rate					
Nozzle pressure					
Maximum		N/A			
Minimum					
Mean					
Plate voltage					
Maximum		See next page.			
Minimum					
Mean					
Current					
Maximum		See next page.			
Minimum					
Mean					
Sparking rate mean		N/A			

Table G-2. Response to APCE Parameters, Addendum to Form 5

Parameter	Units	Run No. 1-1	1-2	1-3
IWS water flowrate				
1st stage IWS water flowrate	L/min	321	322	322
2nd stage IWS water flowrate	L/min	142	142	142
3rd stage IWS water flowrate	L/min	142	142	142
Total	L/min	605	606	606
IWS current and voltage				
IWS Unit 1A-DC Current	mA	33.8	21.8	14.2
IWS Unit 1A-DC Voltage	kV	30.0	30.5	31.0
IWS Unit 1B-DC Current	mA	21.1	16.5	10.7
IWS Unit 1B-DC Voltage	kV	31.1	30.6	31.8
IWS Unit 2A-DC Current	mA	94.2	126.1	94.4
IWS Unit 2A-DC Voltage	kV	28.2	27.8	27.7
IWS Unit 2B-DC Current	mA	105.4	116.2	81.7
IWS Unit 2B-DC Voltage	kV	28.8	29.0	28.5

Form 6. Summary of System Performance

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) 1-1	1-2	1-3	
Performance					
Flue gas					
Flowrate (actual), mean	m^3/min	866	866	827	
Flowrate (STP), mean	m^3/min	501	508	492	
Velocity (actual), mean	m/s	12.3	12.3	11.8	
Velocity (STP) mean	m/s	7.1	7.2	7.0	
Flue gas composition (by volume)					
H_2O	%	32.0	33.0	32.2	
O_2 (by volume, dry)	%	10.55	10.60	10.81	
N_2 (by volume, dry)	%	82.3	81.3	81.3	
CO_2 (by volume, dry)	%	7.2	8.1	7.9	
CO (by volume, dry)	ppm	46.2	20.3	34.9	
Total unburned hydrocarbons					
SO_x					
NO_x					
CO (corrected to 7% O_2)					
Maximum					
Minimum					
Mean	ppm	62.0	29.9	52.2	
Particulate emissions					
Actual emission rate					
Actual concentration					
% Isokinetic	%	98.7	97.1	98.8	
Concentration corrected to 7% O_2	mg/Nm^3	80.2	65.5	32.8	
Metal _____					
Metal _____					
Metal _____					
Metal _____					
Emission rate					
Into APCE					
Out from APCE					
% removal					

(continued)

Form 6. Summary of System Performance (concluded)

Test No. _____ (if data for a run) Parameter	Units	Data from each run or average for each test (min. 3 runs = 1 test) 1-1	1-2	1-3	
HCL					
Emission rate					
Into APCE	g/min	2,590	2,520	2,550	
Out from APCE	g/min	9.34	13.8	17.6	
% removal	%	99.64	99.43	99.31	
POHC input					
trichloroethylene	g/min	353	345	360	
perchloroethylene	g/min	220	220	225	
trichlorobenzene	g/min	835	856	794	
POHC emissions					
trichloroethylene	g/min	0.014	0.0069	0.0036	
perchloroethylene	g/min	0.0022	0.0066	0.0020	
trichlorobezene	g/min	0.0418	0.0017	0.0064	
DRE for POHC					
trichloroethylene	%	99.9960	99.9980	99.9990	
perchloroethylene	%	99.9990	99.9970	99.9991	
trichlorobenzene	%	99.9950	99.9998	99.9992	

Form 7. Method 5 and Particulate Results[a]

Parameter	Units[a]	Test or Run No. 1-1	1-2	1-3
Sample time	min	120	120	120
Sample volume[b]	Nm^3	2.013	2.015	1.914
Stack gas volumetric flowrate	m^3/min	875	892	830
Stack gas volumetric flowrate[b]	Nm^3/min	507	515	481
Stack gas temperature	°C	71	72	71
Stack gas moisture	% vol.	32.0	33.0	32.2
Oxygen concentration[c]	%	10.8	10.6	10.7
Carbon dioxide concentration[c]	%	7.2	8.1	7.9
Percent isokinetic	%	98.7	97.1	98.8
Particulate collected	mg	117.0	98.2	46.3
Particulate concentration	mg/Nm^3	58.1	48.7	24.2
Particulate concentration corrected to 7% oxygen	mg/Nm^3	80.2	65.5	32.8

a Either metric or English units are acceptable as long as consistency is maintained throughout the report.
b Dry standard basis.
c From Orsat analysis.

Form 8a. Chlorine Input Rates

Waste/fuel stream	Test or run no. 1-1 Feedrate (kg/min)	Chlorine concentration (%)	Chlorine input rate (g/min)	Test or run no. 1-2 Feedrate (kg/min)	Chlorine Concentration (%)	Chlorine input rate (g/min)	Test or run no. 1-3 Feedrate (kg/min)	Chlorine concentration (%)	Chlorine input rate (g/min)
Drummed waste (S1)	27.2	2.29	624	26.5	2.21	585	25.7	2.22	570
Sludge (SL)	8.32	0.0098	0.9	8.32	0.0096	0.8	9.08	0.0094	0.8
Organic liquid-kiln (L2)	2.19	15.4	337	2.23	15.2	339	2.27	14.7	337
Organic liquid-scc (L4)	5.90	26.6	1,570	5.75	26.2	1,530	5.98	26.5	1,590
Wastewater-kiln (L1)	30.3	0.200	61	30.3	0.199	60	28.8	0.200	60
Natural gas	5.71	N/A	-----	5.70	N/A	-----	5.71	N/A	-----
Total	79.6		2,590	78.8		2,520	77.5		2,550

Form 8b. HCl Emissions[a,b] and Removal Efficiency

Run No.	Sample period	Sample volume[c]	HCl collected[d]		HCl concentration[e]	Stack gas flow rate[f]	Cl^- emission rate	HCl emission rate[g]	HCl removal effciency (%)
1-1	120	2.013	9.15	(18.4)	507	9.34	0.560	1.24	99.64
1-2	120	2.015	13.35	(26.9)	515	13.8	0.831	1.83	99.45
1-3	120	1.914	19.14	(36.6)	481	17.6	1.057	2.33	99.31
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
				( )					
Blank value			0.12						

a Either metric or English units are acceptable as long as consistency is maintained throughout the report.
b This table is formatted to use chloride results from a single MM5 train (only one chloride emission sample is required per run). If two MM5 trains are run, both sets of HCl data should be reported.
c Sample volume is dry standard liters of stack gas.
d Show value corrected for blank in parentheses.
e Blank corrected as applicable.
f Stack gas flow rate is dry normal (standard) m^3/min.
g Chloride emissions (lb/h) x 1.03.

Form 9b.POHC Input Rate, [Run] No. 1-1

Waste/Fuel stream	Waste feedrate[b] (kg/min)[a]		POHC concentration[c] (%)[a]/feedrate (g/min)[a] TCE	PCE	TCB			DRE
S1 drummed	27.2	d	<0.0002	<0.0002	1.97			
		e	-----	-----	536			
SL sludge	8.32	d	<0.0003	<0.0004	<0.0006			
		e	-----	-----	-----			
L1 aqueous	30.3	d	<0.0017	<0.0019	<0.0028			
		e	-----	-----	-----			
L2 Hi Btu liq (PCC)	2.19	d	<0.0016	10.0	<0.0024			
		e	-----	220	-----			
L4 Hi Btu liq (SCC)	5.90	d	5.98	<0.0018	5.06			
		e	353	-----	299			
Auxiliary fuel, natural gas	5.71	d	-----	-----	-----			
		e	-----	-----	-----			
		d						
		e						
Total POHC feedrate			353	220	835			

a Give units.
b Give feedrate measured during this run/test.
c Give concentration measured from sample taken during this test/run.
d Give concentration at POHC in each waste.
e Give feedrate of each POHC.

Form 9b.POHC Input Rate, [Run] No. 1-2

Waste/Fuel stream	Waste feedrate[b] (kg/min)[a]		POHC concentration[c] (%)[a]/feedrate (g/min)[a] TCE	PCE	TCB			DRE
S1 drummed	26.5	d	<0.0002	<0.0002	1.97			
		e	-----	-----	522			
SL sludge	8.32	d	<0.0003	<0.0004	<0.0006			
		e	-----	-----	-----			
L1 aqueous	30.3	d	<0.0017	<0.0019	<0.0028			
		e	-----	-----	-----			
L2 Hi Btu liq (PCC)	.23	d	<0.0016	10.0	<0.0024			
		e	-----	223	-----			
L4 Hi Btu liq (SCC)	5.75	d	5.98	<0.0018	5.06			
		e	343	-----	291			
Auxiliary fuel, natural gas	5.70	d	-----	-----	-----			
		e	-----	-----	-----			
		d						
		e						
Total POHC feedrate			343	223	813			

a Give units.
b Give feedrate measured during this run/test.
c Give concentration measured from sample taken during this test/run.
d Give concentration at POHC in each waste.
e Give feedrate of each POHC.

Form 9b.POHC Input Rate, [Run] No. 1-3

Waste/Fuel stream	Waste feedrate[b] (kg/min)[a]		POHC concentration[c] (%)[a]/feedrate (g/min)[a] TCE	PCE	TCB			DRE
S1 drummed	25.7	d	0.0002	0.0002	1.97			
		e	-----	-----	506			
SL sludge	9.08	d	0.0003	0.0004	0.0006			
		e	-----	-----	-----			
L1 aqueous	28.8	d	0,0017	0.0019	0.0028			
		e	-----	-----	-----			
L2 Hi Btu liq (PCC)	2.27	d	0.0016	10.0	0.0024			
		e	-----	227	-----			
L4 Hi Btu liq (SCC)	5.98	d	5.98	0.0018	5.06			
		e	347	-----	293			
Auxiliary fuel, natural gas	5.71	d	-----	-----	-----			
		e	-----	-----	-----			
		d						
		e						
Total POHC feedrate			347	227	799			

a Give units.
b Give feedrate measured during this run/test.
c Give concentration measured from sample taken during this test/run.
d Give concentration at POHC in each waste.
e Give feedrate of each POHC.

Figure G-1. Strip chart recording of combustion temperatures – run 1-1.

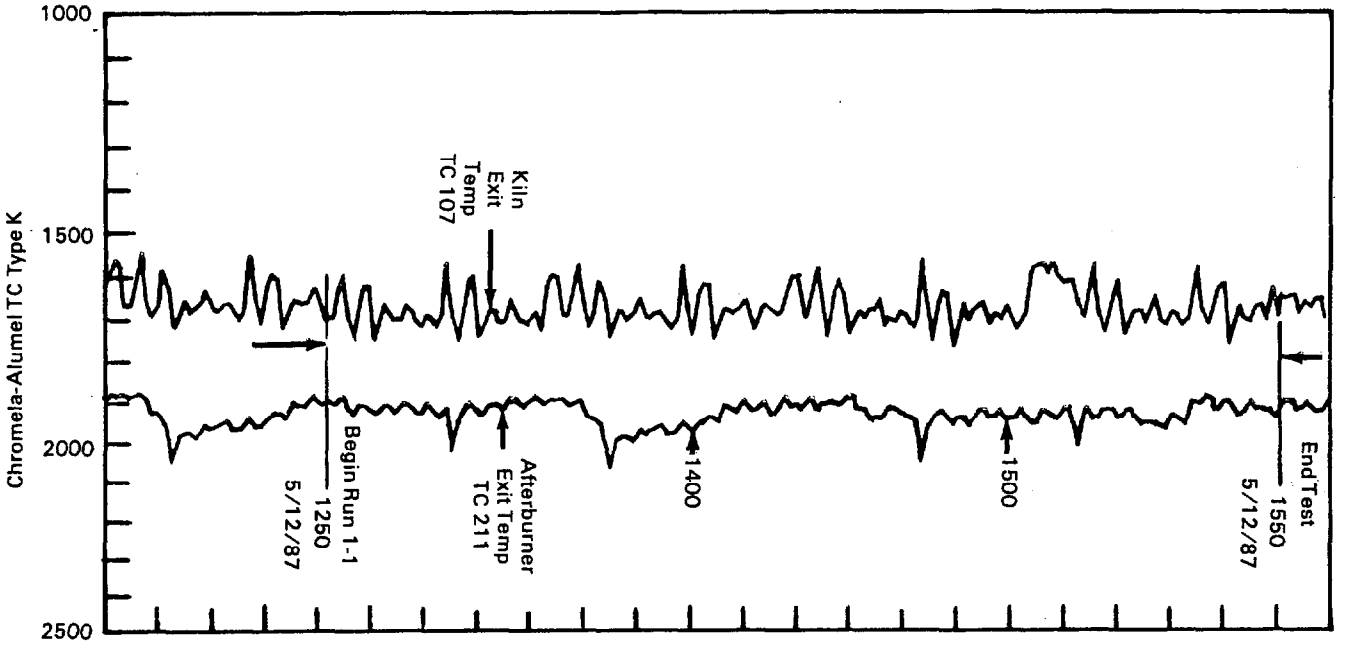
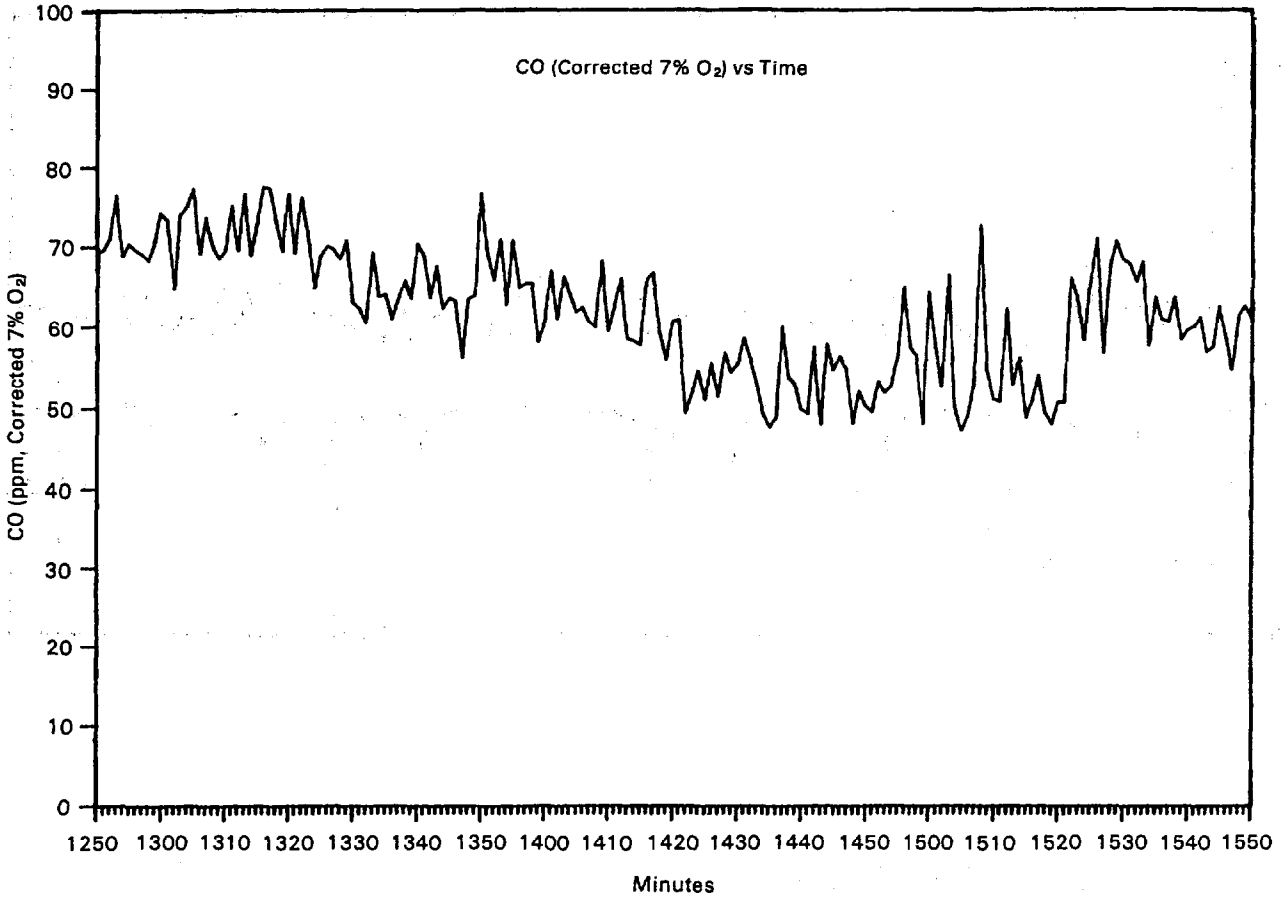


Figure G-2. Plot of corrected CO readings from data logger 1-min averages - run 1-1.



Form 9a. POHC Emissions

Run No.	Trap pair (for VOST)	Sample period (min)[b]	Sample volume (L)[b]	Mass of each POHC collected: TCE (µg)[a]	PCE (µg)[a]	( )[a]	( )[a]	( )[a]	( )[a]
1-1	1	40	20.3	435 ( )[c]	68 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	2	40	19.7	662 ( )[c]	103 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	3	40	19.7	567 ( )[c]	88 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	Total/average[d]	120	59.7	1,664	259				
POHC concentration (µg/L)[b]				28	4.3				
Stack gas flow rate (µm³/min)[b]			507						
Emission rate (µg/min)[b]				14,000	2,200				
1-2	1	40	19.7	244 ( )[c]	238 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	2	40	19.8	317 ( )[c]	304 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	3	40	19.7	226 ( )[c]	216 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	Total/average[d]	120	59.2	793	758				
POHC concentration (µg/L)[b]									
Stack gas flow rate (µm³/min)[b]				515					
Emission rate (µg/min)[b]					6,900	6,600			
Average blank value[d] ( )[b]				13	24				
Standard deviation[d] ( )[b]				7	22				
Range of blank values[d] ( )[b]				9-18	10-58				

Note: This format is structured for VOST results. It may be used for MM5, a similar format would be used for integrated bag sampling for volatiles. Guidance for blank correction is provided in the "Practical Guide—Trial Burns for Hazardous Waste Incinerators," Final Report, EPA-600/2-86-050, 1986.

Note: Use parentheses to present results if two collectors are used in series (i.e., dual adsoprtion tubes on VOST).

[a] Either metric or English units are acceptable as long as consistency is maintained throughout the report.

[b] Sample volume is dry standard liters of stack gas.

[c] Stack gas flowrate is dry normal (standard) m^3/min.

[d] totals for sample period, volume, and amount collected; averages for concentration, flowrate, and emissions rate.

[e] Indicate whether all (both field blanks and trip blanks) are used or whether only field blanks are used.

Form 9a. POHC Emissions

Run No.	Trap pair (for VOST)	Sample period (min)[b]	Sample volume (l)[b]	Mass of each POHC collected: TCE (µg)[a]	PCE (µg)[a]	( )[a]	( )[a]	( )[a]	( )[a]
1-3	1	40	19.8	135 ( )[c]	76 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	2	40	19.9	67 ( )[c]	38 ( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	3	40	20.0	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	Total/average[d]	120	59.7						
	POHC concentration (µg/l)[b]			4.2	7.5				
	Stack gas flow rate (µm³/min)[b]		481						
	Emission rate (µg/min)[b]			3,600	2,000				
	1			( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	2			( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	3			( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
				( )[c]	( )[c]	( )[c]	( )[c]	( )[c]	( )[c]
	Total/average[d]								
	POHC concentration ( )[b]								
	Stack gas flow rate ( )[b]								
	Emission rate ( )[b]								
	Average blank value[d] ( )[b]								
	Standard deviation[d] ( )[b]								
	Range of blank values[d] ( )[b]								

Note: This format is structured for VOST results. It may be used for MM5, a similar format would be used for integrated bag sampling for volatiles. Guidance for blank correction is provided in the "Practical Guide—Trial Burns for Hazardous Waste Incinerators," Final Report, EPA-600/2-86-050, 1986.

Note: Use parentheses to present results if two collectors are used in series (i.e., dual adsoprtion tubes on VOST).

[a] Either metric or English units are acceptable as long as consistency is maintained throughout the report.

[b] Sample volume is dry standard liters of stack gas.

[c] Stack gas flowrate is dry normal (standard) m^3/min.

[d] totals for sample period, volume, and amount collected; averages for concentration, flowrate, and emissions rate.

[e] Indicate whether all (both field blanks and trip blanks) are used or whether only field blanks are used.

Table G-3. Combustion Temperature Data Taken From Strip Chart – Run 1

Time (min)	SCC Temp (°F)	Kiln Temp (°C)	Time (min)	SCC Temp (°F)	Kiln Temp (°C)
1250	1889	1688	1336	1894	1686
1251	1894	1689	1337	1891	1633
1252	1893	1623	1338	1885	1563
1253	1872	1595	1339	1894	1670
1254	1913	1693	1340	1927	1710
1255	1925	1730	1341	1929	1679
1256	1898	1661	1342	1941	1602
1257	1901	1616	1343	1967	1646
1258	1906	1613	1344	2045	1736
1259	1917	1743	1345	1985	1705
1300	1918	1699	1346	1980	1666
1301	1892	1653	1347	1973	1694
1302	1904	1677	1348	1985	1688
1303	1919	1693	1349	1983	1674
1304	1899	1699	1350	1955	1650
1305	1889	1660	1351	1971	1689
1306	1898	1678	1352	1961	1694
1307	1919	1700	1353	1956	1682
1308	1923	1710	1354	1946	1680
1309	1889	1682	1355	1969	1695
1310	1906	1693	1356	1966	1714
1311	1927	1710	1357	1964	1694
1312	1932	1679	1358	1936	1569
1313	1903	1564	1359	1954	1675
1314	2004	1685	1400	1961	1727
1315	1936	1743	1401	1948	1649
1316	1920	1670	1402	1931	1612
1317	1893	1591	1403	1924	1620
1318	1904	1613	1404	1926	1738
1319	1921	1741	1405	1940	1705
1320	1922	1722	1406	1899	1671
1321	1899	1671	1407	1900	1680
1322	1899	1669	1408	1905	1680
1323	1896	1702	1409	1909	1667
1324	1911	1694	1410	1882	1644
1325	1878	1649	1411	1903	1678
1326	1880	1679	1412	1911	1722
1327	1901	1695	1413	1901	1680
1328	1901	1703	1414	1898	1663
1329	1885	1693	1415	1922	1674
1330	1880	1674	1416	1921	1687
1331	1887	1724	1417	1905	1683
1332	1900	1624	1418	1877	1635
1333	1886	1589	1419	1900	1599
1334	1890	1603	1420	1893	1602
1335	1885	1685	1421	1908	1674

(continued)

Table G-3. Combustion Temperature Data Taken From Strip Chart – Run 1 (concluded)

Time (min)	SCC Temp (°F)	Kiln Temp (°C)	Time (min)	SCC Temp (°F)	Kiln Temp (°C)
1422	1888	1692	1509	1926	1564
1423	1881	1624	1510	1936	1592
1424	1909	1577	1511	1910	1607
1425	1895	1656	1512	1901	1612
1426	1888	1746	1513	1925	1608
1427	1894	1646	1514	1984	1668
1428	1895	1601	1515	1921	1701
1429	1892	1639	1516	1915	1647
1430	1880	1736	1517	1930	1570
1431	1878	1705	1518	1934	1684
1432	1909	1675	1519	1909	1737
1433	1908	1694	1520	1912	1679
1434	1923	1673	1521	1908	1615
1435	1932	1674	1522	1935	1614
1436	1927	1647	1523	1921	1738
1437	1926	1712	1524	1910	1697
1438	1903	1696	1525	1931	1676
1439	1906	1706	1526	1945	1678
1440	1921	1681	1527	1939	1709
1441	1925	1685	1528	1942	1674
1442	1933	1716	1529	1940	1643
1443	1920	1703	1530	1956	1705
1444	2030	1562	1531	1954	1709
1445	1954	1661	1532	1917	1683
1446	1942	1748	1533	1936	1687
1447	1918	1670	1534	1945	1708
1448	1915	1628	1535	1950	1702
1449	1936	1645	1536	1886	1664
1450	1947	1763	1537	1898	1573
1451	1931	1726	1538	1892	1674
1452	1929	1659	1539	1876	1714
1453	1947	1702	1540	1904	1671
1454	1928	1679	1541	1918	1628
1455	1910	1673	1542	1891	1614
1456	1910	1663	1543	1893	1760
1457	1932	1711	1544	1911	1715
1458	1932	1687	1545	1929	1661
1459	1911	1699	1546	1920	1704
1500	1930	1675	1547	1893	1707
1501	1934	1677	1548	1908	1672
1502	1934	1722	1549	1905	1663
1503	1907	1692	1550	1914	1704
1504	1929	1682			
1505	1944	1584			
1506	1947	1572	AVG	1919.6	1670.2
1507	1909	1573	MIN	1872	1562
1508	1918	1590	MAX	2045	1763

Table G-4. CEM Data From Data Logger Files – Run 1

Time (min)	O_2 (%)	CO (ppm)	Corr CO (ppm)
1250	10.59	51.46	69.2
1251	10.49	52.03	69.7
1252	10.45	53.70	71.1
1253	10.35	57.74	76.4
1254	10.47	51.96	68.8
1255	10.30	53.85	70.4
1256	10.20	53.29	69.7
1257	10.31	52.87	69.1
1258	10.37	52.15	68.2
1259	10.27	54.04	70.7
1300	10.38	56.07	74.2
1301	10.63	54.78	73.4
1302	10.64	48.36	64.8
1303	10.61	55.18	73.9
1304	10.52	56.03	75.1
1305	10.50	57.69	77.3
1306	10.59	51.60	69.1
1307	10.51	54.98	73.7
1308	10.54	52.38	70.2
1309	10.55	51.18	68.6
1310	10.55	51.94	69.6
1311	10.47	56.09	75.2
1312	10.64	51.96	69.6
1313	10.46	57.20	76.6
1314	10.59	51.50	69.0
1315	10.63	54.47	73.0
1316	10.50	57.91	77.6
1317	10.49	57.77	77.4
1318	10.48	54.84	73.5
1319	10.50	51.92	69.6
1320	10.77	56.53	76.7
1321	10.60	51.07	69.3
1322	10.72	56.17	76.2
1323	10.51	53.73	72.0
1324	10.62	48.40	64.8
1325	10.56	51.48	69.0
1326	10.36	52.99	70.1
1327	10.33	52.73	69.8
1328	10.51	51.69	68.4
1329	10.32	53.52	70.8
1330	10.45	47.68	63.1
1331	10.34	47.09	62.3
1332	10.50	45.75	60.5
1333	10.36	52.35	69.3
1334	10.45	48.23	63.8
1335	10.37	48.42	64.1
1336	10.42	46.15	61.1

(continued)

Table G-4. CEM Data From Data Logger Files – Run 1 (continued)

Time (min)	O_2 (%)	CO (ppm)	Corr CO (ppm)
1337	10.51	47.93	63.4
1338	10.50	49.63	65.7
1339	10.64	47.48	63.6
1340	10.47	52.55	70.4
1341	10.50	51.55	69.1
1342	10.59	47.49	63.6
1343	10.44	50.99	67.5
1344	10.50	47.09	62.3
1345	10.35	48.07	63.6
1346	10.41	47.82	63.3
1347	10.34	42.47	56.2
1348	10.53	47.40	63.5
1349	10.62	47.14	63.9
1350	10.88	55.84	76.7
1351	10.85	49.51	68.9
1352	10.80	47.90	65.8
1353	10.75	51.62	70.9
1354	10.64	46.26	62.7
1355	10.63	52.20	70.8
1356	10.62	47.81	64.8
1357	10.64	48.16	65.3
1358	10.62	48.14	65.3
1359	10.58	42.87	58.1
1400	10.60	44.69	60.6
1401	10.64	49.88	66.8
1402	10.45	45.63	61.1
1403	10.64	49.40	66.2
1404	10.37	48.55	64.3
1405	10.48	46.77	61.9
1406	10.45	47.17	62.4
1407	10.37	45.82	60.6
1408	10.49	45.31	60.0
1409	10.67	50.20	68.1
1410	10.82	43.31	59.5
1411	10.71	46.15	62.6
1412	10.60	48.64	66.0
1413	10.66	43.15	58.5
1414	10.90	42.37	58.2
1415	10.81	42.05	57.8
1416	10.62	48.53	65.8
1417	10.51	49.76	66.7
1418	10.59	44.14	59.1
1419	10.52	41.78	56.0
1420	10.64	45.32	60.7
1421	10.54	45.50	61.0
1422	10.64	36.92	49.5
1423	10.63	38.69	51.8

(continued)

Table G-4. CEM Data From Data Logger Files – Run 1 (continued)

Time (min)	O_2 (%)	CO (ppm)	Corr CO (ppm)
1424	10.54	40.80	54.7
1425	10.60	38.17	51.1
1426	10.57	41.49	55.6
1427	10.61	38.45	51.5
1428	10.61	42.41	56.8
1429	10.61	40.68	54.5
1430	10.77	40.86	55.4
1431	10.61	43.21	58.6
1432	10.56	41.75	55.9
1433	10.62	39.76	53.3
1434	10.43	37.22	49.3
1435	10.51	36.14	47.8
1436	10.46	37.02	49.0
1437	10.51	45.39	60.1
1438	10.42	40.65	53.8
1439	10.49	39.62	53.1
1440	10.65	37.28	50.0
1441	10.47	36.91	49.5
1442	10.50	43.00	57.6
1443	10.57	35.95	48.2
1444	10.56	43.24	57.9
1445	10.62	40.83	54.7
1446	10.55	42.15	56.5
1447	10.61	41.04	55.0
1448	10.51	36.05	48.3
1449	10.54	38.97	52.2
1450	10.52	37.61	50.4
1451	10.63	37.12	49.7
1452	10.45	39.85	53.4
1453	10.58	38.83	52.0
1454	10.57	39.44	52.8
1455	10.46	42.01	56.3
1456	10.68	47.83	64.9
1457	10.60	42.34	57.4
1458	10.61	41.65	56.5
1459	10.59	35.56	48.2
1500	10.74	46.86	64.4
1501	10.75	41.75	57.3
1502	10.72	38.39	52.7
1503	10.62	48.95	66.4
1504	10.70	37.16	50.4
1505	10.58	35.39	47.4
1506	10.63	36.67	49.1
1507	10.47	39.52	52.9
1508	10.56	54.24	72.7
1509	10.48	40.96	54.9
1510	10.56	38.23	51.2

(continued)

Table G-4. CEM Data From Data Logger Files – Run 1 (concluded)

Time (min)	O_2 (%)	CO (ppm)	Corr CO (ppm)
1511	10.48	38.05	51.0
1512	10.49	46.51	62.3
1513	10.48	39.53	53.0
1514	10.47	41.92	56.2
1515	10.53	36.59	49.0
1516	10.63	38.05	51.0
1517	10.55	40.40	54.1
1518	10.21	38.37	49.6
1519	9.94	38.21	48.2
1520	10.09	39.88	50.9
1521	9.96	39.82	50.8
1522	10.12	51.09	66.0
1523	10.25	49.26	63.6
1524	10.33	44.63	58.4
1525	10.45	49.42	65.4
1526	10.73	52.33	71.0
1527	10.86	41.34	56.8
1528	10.84	48.58	67.6
1529	11.02	50.81	70.7
1530	10.86	49.02	68.2
1531	10.98	48.69	67.7
1532	10.75	47.68	65.5
1533	10.80	49.45	67.9
1534	10.77	42.01	57.7
1535	10.74	46.30	63.6
1536	10.71	44.89	60.9
1537	10.77	44.68	60.6
1538	10.74	46.89	63.6
1539	10.62	43.02	58.3
1540	10.74	43.36	59.6
1541	10.63	44.23	60.0
1542	10.64	45.70	61.2
1543	10.49	43.04	57.0
1544	10.41	43.45	57.5
1545	10.51	47.26	62.5
1546	10.47	44.25	58.6
1547	10.34	41.33	54.7
1548	10.35	46.39	61.4
1549	10.61	46.71	62.6
1550	10.56	45.59	61.1
MINIMUM	9.94	35.39	47.4
MAXIMUM	11.02	57.91	77.6
AVERAGE	10.55	46.23	62.0

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