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Assessment of Incineration As A Treatment Method for Liquid Organic Hazardous Wastes

Background Report I: Description of Incineration Technology

DESCRIPTION OF INCINERATION TECHNOLOGY

March 1985

A background report for the study by
EPA's Office of Policy, Planning and
Evaluation: "Assessment of Incineration
As A Treatment Method For Liquid Organic
Hazardous Waste."

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EXECUTIVE SUMMARY

This study provides a baseline description of both land-based and ocean incineration technologies, identifies key issues regarding performance capabilities and operational techniques, and highlights the differences between the technologies with respect to these issues. The study focuses on the most common types of incinerators currently in use. On land, these are liquid injection incinerators and rotary kilns with liquid capability. For ocean incineration, the designs reviewed are the Vulcanus I and II and the two vessels under construction by the Tacoma Boat Company. Another ocean design in the conceptual stage, proposed by SeaBurn Inc., is also treated very briefly.

The information contained in the study is presented in this summary as a series of tables. The first is a summary table of key technological features, the second recaps the findings of the study and the issues raised with regard to the technologies covered, and the third discusses key differences.

TABLE 1: Summary of Key Features

FEATURES	LAND-BASED: LIQUID INJECTION	LAND-BASED: ROTARY KILN	OCEAN: VULCANUS I	OCEAN: VULCANUS II	OCEAN: TACOMA BOAT	OCEAN: SEABURN
Burns Liquids	Yes	Yes	Yes	Yes	Yes	Yes
Burns Solids, Sludges	No	Yes	No	No	No	No
Combustion System Design	Liquid is atomized and incinerated in fine droplet form.	Solids fed at high end and rotated through: liquids fed through atomizing nozzles or lances.	Liquid is atomized and incinerated in fine droplet form.			
Combustion Chamber	Fixed cylindrical chamber mounted horizontally or vertically. Refractory-lined	Rotating cylindrical chamber mounted at a slight incline from the horizontal. Refractory-lined.	Fixed cylindrical chambers mounted vertically. Refractory-lined. 2 incinerators	3 incinerators	Fixed cylindrical chambers mounted vertically. Refractory-lined. 2 incinerators per ship.	Fixed cylindrical chambers mounted horizontally. Refractory lined. 4 incinerators
Afterburner	May have	Generally used to ensure complete combustion	No	No	No	No
Combustion Air	Forced draft provides oxygen for combustion and turbulence for mixing.	Rotation of chamber exposes solids to heat to vaporize. Combustion air may be forced draft or induced draft or both.	Air provided by one fixed speed fan per incinerator.		Information unknown.	
Supplementary Fuel Used	Can be fed in depending on nature of wastes being burned.					
Waste Feed Rate (Gallons/Hour)	Range:<50 to 1000 Median: 150	Range: <50 to 2000	1650 per incinerator 3300 Total	4950 Total	2750 per incinerator or 5500 per vessel	810 per incinerator or 3240 per vessel
Air Pollution Controls	Usually will have control devices for acid gases and particulates. Must meet performance standards.		None	None	None	Seawater scrubber to dilute plume
Treatment of Ash and Scrubber Water	Ash and sludge from scrubber water disposed of in hazardous waste landfill. Water reused or treated and released.		Ash residues reincinerated or returned to land.			

Cont'd (TABLE 1)

FEATURES	LAND-BASED: LIQUID INJECTION	LAND-BASED: ROTARY KILN	OCEAN: VULCANUS I	OCEAN: VULCANUS II	OCEAN: TACOMA BOAT	OCEAN: SEABURN
Combustion Zone Temperature °C	815-1240	815-1240	1166 - 1600		Not yet demonstrated	
Residence Time-(seconds)	0.3-2.0	>2.0	1.0		Not yet demonstrated	
Heat Recovery	About 25% of incinerators employ heat recovery	About 30%	None	None	None	None
WASTE HANDLING ASPECTS:						
° Waste Transfer Points	For larger offsite facilities, wastes are transferred from trucks or rail to temporary storage/blending tanks; and directly pumped to incinerator.		Wastes transferred first to temp storage/blending area; then transported to port transfer area.		Plans integrated port site with temp. storage/blending capacity.	Plans direct link from generators to vessel through sealed tank containers transported by truck or train.
° Blending of Wastes	Blending tank or wastes mixed during burning.		Wastes blended prior to loading on vessels.			Blending may occur prior to or during burning.
Demonstrated Performance Levels						
° DRE/DE on POHCs	>99.99% for various POHCs.	>99.99% for various POHCs.	>99.99% for various POHCs.		Not yet demonstrated.	
° DRE/DE on PCBs	99.9971 to >99.9999%	>99.9999%	>99.9999%	Not yet demonstrated.		
SAMPLING AND MONITORING:						
° Waste Feed Sampled Routinely	Yes. Permit specifies plan for periodic verification of waste feed. Sampling frequency varies for different facilities.		Yes. Permit requires sampling be done prior to transport of wastes to vessel.			
° Routine Monitoring Done for:	CO, Waste Feed Rate, Combustion Zone Temperature, Combustion Gas Flow Rate, and Air Flow into Incinerator.		CO, CO_2, O_2, Waste Flow Rates. Air Flow into Incinerator, Wall Temperature. Auxiliary Fuel Flow (if used).			
° Automatic Waste Feed Cutoff Features	Yes. Permit specifies levels for operating parameters at which cutoff devices will be activated.					
° Ambient Monitoring	Ambient monitoring is not required under RCRA or TSCA.		Some environmental monitoring was required in past burns. Scope of future environmental monitoring to be determined in regulations.			

TABLE 2. Issues and Findings Concerning Ocean and Land-Based Incineration

ISSUE AREA	OCEAN INCINERATION	LAND-BASED INCINERATION
1) Atomizing Burner	° Issue: Critics say that rotary cup burners on Vulcanus are inadequately designed to ensure that complete combustion occurs. ° EPA Response: Regulation of incinerators should be based on performance, not design. Relationship of performance to design is not adequately understood.	° Finding: A variety of atomizer designs, including rotary cup burners, have been successfully employed. Design features are typically not an issue for land incinerators because of reliance on performance standards in regulations and permits.
2) Combustion Chamber	° Issue: Critics say that ocean combustion chamber design on Vulcanus is inadequate to ensure complete combustion because it does not provide sufficient turbulence, mixing of waste with oxygen or allow for sufficient residence time. ° EPA Response: Regulation should be based on performance, not design. Relationship of performance to design is inadequately understood.	° Finding: Combustion chamber design varies for different land-based incinerators. Design features are not an issue because of reliance on performance standards in regulations and permits.
3) Pollution Control and Acid Gas Emissions	° Issue: Absence of air pollution controls on ocean design results in emissions which may endanger human health and the environment. ° EPA Response: Removal of HCl and trace metal particulates expected to have no impact in an oceanic setting. Under the proposed regulations, additional environmental monitoring will be conducted to study effects of emissions.	° Finding: Scrubbers remove acid gases and particulates but are not essential for removing POHCs from combusted gases. EPA requires no environmental monitoring.
4) Energy Recovery	° Issue: Ocean incineration results in a loss of potential energy because ocean design lacks heat recovery equipment. ° EPA Response: Loss of energy does not directly affect human health or the environment. Market will dictate to incinerator operators the viability of including heat recovery equipment.	° Finding: Currently, land-based operators are showing greater interest in heat recovery equipment. According to a 1982 EPA study, about 25 percent of land-based incinerators burning liquid hazardous wastes employed heat recovery.

Cont'd Table 2.

ISSUE AREA	OCEAN INCINERATION	LAND-BASED INCINERATION
5) Waste Handling	° Issue: The mixing of incompatible wastes leading to runaway chemical reactions or explosions poses problems if not detected by routine testing methods prior to incineration. ° EPA Response: Testing of wastes for incompatibility is done prior to loading aboard ships. Regulations will specify types of waste analyses to be performed.	° Issue: Land-based facilities can potentially receive incompatible wastes. ° EPA Response: Testing of wastes for incompatibility is done at receiving end on a permit-specified basis. If an incompatible mixture is present and does not show up during testing, it would most likely react during temporary storage.
6) Waste Transfer	° Issue: Waste handling procedures and improper locations of facilities that handle hazardous waste pose potential risks and are of concern to the public.	
7) Similarity of Incinerators	° Issue: There is insufficient evidence to establish that all five Vulcanus (M/T Vulcanus and Vulcanus II) incinerators are equal. ° EPA Response: The proposed regulations address this issue by indicating that for incinerators similar design, shape, and size, comparisons on performance can be made, if they are on the same vessel. However, for different vessels, incinerators must undergo separate testing.	° Finding: RCRA provides for waiver of Trial Burns if incinerator is similar to an already permitted incinerator (criteria are established in Guidance Manual for Hazardous Waste Incinerator Permits).
8) PCB Residence Time	° Issue: The proposed one second residence time for PCB wastes in Vulcanus incinerators does not meet TSCA requirements of two seconds and is inadequate to ensure acceptable levels of destruction. ° EPA Response: Capability of ocean incineration is best measured by destruction achieved. Past results show that one second is sufficient.	° Finding: EPA has allowed onsite land-based facilities burining relatively low concentrations of PCBs to waive the PCB residence time requirement based upon demonstration of acceptable destruction and removal efficiencies (DREs).

Cont'd Table 2.

ISSUE AREA	OCEAN INCINERATION	LAND-BASED INCINERATION
9) Stack Gas Sampling	° Issue: Traversing procedures on Vulcanus were inadequate because they have only been done on one diameter; probe hasn't sampled all points; some traverses not done in a horizontal plane resulting in ambient air diluting pollutant concentrations and wall area not sampled in sufficient proportion to offset lower CE in that region. ° EPA Response: Stack gas sampling more difficult at-sea because of hot gases and ocean conditions. Proposed regulations will require applicant to follow EPA Sampling Procedures 40 CFR Part 60-Appendix A, Method 1-5, or the applicant may suggest other sampling methods which they must demonstrate to be comparable.	° Finding: Stack gas sampling, whether for POHCs or particulates, is facilitated for land-based incinerators because gases are cooled and slowed down following the srcubbing process.
	° Issue: Unburned POHCs and PICs may be in stack emissions adsorbed to solid minute particulate matter or to droplets. Should perform isokinetic sampling to measure for particulate matter. ° EPA Response: EPA believes that pure isokinetic sampling cannot be done in ocean incinerators because of non-laminar flow. EPA also believes that at elevated temperatures, POHCs and PICs are not attached to particulates, but rather exist as free vapors. To confirm this, proposed regulations will require isokinetic sampling which will be appropriately modified for consideration of ocean incineration characteristics.	° Finding: Isokinetic sampling according to EPA Sampling Procedures 40 CFR Part 60 - Appendix A, were developed for incinerators with laminar flow and operating temperatures which are more characteristic of land-based incinerators than ocean incinerators.
10) Waste Feed Rate Measurement	° Issue: Waste feed rate cannot be measured effectively by soundings in the vessel's tanks because of the ship's motion, thus DE analysis is inaccurate. ° EPA Response: EPA believes that soundings provide at least as accurate a measure of waste feed rate as do flow meters for DE calculation purposes; however proposed regulations will require continuous waste feed monitoring using flow meters in subsequent burns.	° Finding: Flow meters are used to monitor waste feed rate in land-based incinerators.

Cont'd Table 2.

ISSUE AREA	OCEAN INCINERATION	LAND-BASED INCINERATION
11) Wall Temperature	° Issue: Thermocouples to measure temperature are improperly located on Vulcanus, have given erratic reading, have not shown that uniform heat distribution exists, and don't give adequate measure of combustion zone temperature. ° EPA Response: Proposed regulations will require minimum incinerator temperature for purposes of automatic waste feed shutoff, and accurate devices to measure and record. Permit writer will determine whether temperature and measurement devices are adequate.	° Finding: Although the location of the temperature sensor will vary in different incinerators, temperature should always be monitored at the same point in a specific incinerator during routine operation. Permit writer determines whether temperature and measurement devices are adequate.
12) Measuring for Products of Incomplete Combustion (PICs)	° Issue: More emphasis should be placed on identification of possible organic compounds produced and emitted during ocean and land incineration. ° EPA Response: PIC emissions are currently unregulated because not enough is known about PIC formation, effects, and control, and health risks from the most toxic PICs have been found to be very small. Ocean incineration regulations will address this issue by requiring that more research be done on identifying and analyzing PIC emissions.	
13) Ambient Monitoring	° Issue: Past environmental studies were inadequate. More study is needed to determine effects of emissions or ambient air, water and marine biota. ° EPA Response: Proposed regulations will require comprehensive environmental monitoring studies as these are required under MPRSA and LDC.	° Issue: Ambient monitoring is not required under RCRA or TSCA statutes. ° EPA Response: EPA believes that if stack emissions are within regulatory limits there will be no adverse environmental effects. Moreover, accurate and reliable testing for ambient air effects is not feasible because emissions from many other emission sources are present.
14) Principal Organic Hazardous Constituents (POHCs)	° Issue: The overall POHC ranking system, which uses surrogates to represent many compounds based upon the degree of difficulty with which they can be burned, does not provide on adequate basis for determining incinerability. ° EPA Response: EPA is continuing to assess the reliability of the system, however believes it to be the best system currently available.	

TABLE 3 - SIMILARITIES AND KEY DIFFERENCES

LAND-BASED	OCEAN
1) Incinerator efficiency is determined by ability to achieve acceptable performance levels. It is not based on incinerator design.	1) Same
2) Land-based incinerator design generally incorporates scrubbers to meet particulate and acid gas standards.	2) Ocean incinerator design doesn't incorporate scrubbers to remove particulates and acid gas. (One proposed design to ocean incineration does incorporate scrubbers, but only to dilute the plume.)
3) Acid gas and particulate emissions are reduced by scrubber.	3) Acid gases are released but buffered by the ocean. Particulate emissions are limited by limiting metal content in wastes.
4) Scrubber water must be managed as a hazardous waste.	4) No scrubber water to be managed.
5) Frequency of analysis of incoming wastes is specified in permit. May be done periodically but not necessarily prior to every burn.	5) Wastes must be analyzed prior to every burn. Analysis is done at storage/blending area before wastes are transported to vessel.
6) Sampling and monitoring of stack gases during trial burns is conducted to establish that Destruction Efficiency on Principal Organic Hazardous Constituents can be met.	6) Same
7) Stack gas sampling is facilitated because combusted gases are cooled by the scrubbing process and their velocity is reduced.	7) Stack gas sampling is more difficult because of fast moving gases and hot gas temperatures.
8) Land-based incinerator design generally has a lower waste feed capacity than ocean design.	8) Ocean incineration design generally has a higher waste feed capacity than land-based design.

1. INTRODUCTION

This report provides a brief description of the technical aspects of land-based and ocean incineration in order to identify key differences in the two technologies. The objective is to provide a concise introduction to the design and performance of the two technologies, and discuss issues raised regarding their capability and reliability.

For land-based incineration, the description will focus on liquid injection and rotary kiln incinerators. Liquid injection incinerators are by far the most common type of incinerator used for burning liquid hazardous waste on land, and are the type used in the ocean incineration ships. Rotary kilns with liquid capability are far less common, but the major commercial competitors of ocean incineration operate with large rotary kilns. Other, less common alternatives for incineration of hazardous wastes are assessed in the alternative technologies paper prepared for the OPPE incineration study.

The description of ocean incineration will include the two commissioned vessels, the Vulcanus I and II, as well as the two additional ships under construction by the Tacoma Boat Company for At-Sea Incineration. We will discuss briefly the Seaburn Inc. and Environmental Oceanic Services proposals for incineration at sea, since they are only at the conceptual stage.

The assessment of incineration technology entails a comparison of key design features (including control technologies), performance characteristics, operating conditions affecting performance, waste handling features, and sampling and monitoring technology. While this report identifies characteristic emissions and waste handling techniques, it will not attempt to assess the potential human health or environmental impacts of the technologies, as this is done in the risk comparison paper.

We have used a wide variety of sources in compiling this report. Much of the information on basic design features is widely available in basic texts as well as EPA guidance. For specific findings on performance characteristics, we have relied heavily on background reports prepared for the OSW incinerator regulatory impact analysis, published reports on the Vulcanus Test Burns, and research supporting the development of the PCB regulations. In order to identify issues, we reviewed the voluminous public comments on the proposed Vulcanus permits and past regulations, and interviewed EPA staff and incinerator operators.

2. INCINERATOR DESIGN FEATURES

2.1 What is Incineration?

For liquid hazardous wastes, incineration is an engineered process that uses high-temperature thermal oxidation to convert the wastes to less hazardous materials. Incineration of simple, nonhalogenated wastes involves the oxidation of the carbon and hydrogen molecules present in organic wastes into carbon dioxide and water. For example:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

If conditions for complete combustion are not present, carbon monoxide is also formed, but this product can be minimized by appropriate controls on temperature, turbulence and oxygen. As a result, the presence of excessive carbon monoxide in the flue gas is commonly used as a measure of process upset.

In general, however, the products of incineration vary with the wastes that are burned. Many industrial processes generate liquid hazardous wastes containing halogenated materials, with chlorinated compounds being the most common. When chlorinated organic compounds are combusted, the products will include hydrogen chloride and small amounts of chlorine, as well as carbon dioxide and water. Other liquid hazardous wastes may contain metals, sulfur, or organically bound nitrogen and produce, when incinerated, oxides of metals, sulfur, and nitrogen.

In addition, all combustion sources, including hazardous waste incineration, will form small amounts of substances other than water, HCl and the simple oxides that are the expected products of the combustion reaction. These substances, known collectively as products of incomplete combustion (PICs) may be similar to or very different in chemical structure from the original constituents of the compounds incinerated. Little is known about how these substances are formed, or which substances are formed from the burning of specific wastes. The PICs which have received the most attention are the dioxin and dibenzofuran compounds because of their high toxicity to human health and the environment.

An important consideration for hazardous waste incineration is the heating value of the wastes. To maintain stable combustion, the heat released by combustion must also heat incoming waste to its ignition temperature and provide the activation energy for oxidation reactions to occur. The heating value of a waste normally decreases as the percentage of water increases and as the percentage of chlorine by weight in organic compounds increases. Liquid wastes with low heating values may require auxiliary fuel or blending with wastes that have higher Btu/lb values. As a practical matter, commercial incinerator operators dealing with wastes from a variety of sources will blend wastes to produce optimum values for Btu, chlorine, water, and other contents.

2.2 Basic Incineration Design Features

All waste incinerators on land consist of a waste feed system, a combustion air or oxygen system, a combustion chamber, combustion monitoring systems, and, if required, an air pollution control system and an ash removal system. The simple flow schematic in Figure 2.1 illustrates the relationships of these basic elements of incinerator design. These elements are applied somewhat differently in liquid injection and rotary kiln systems.

2.2.1 Liquid Injection Systems on Land

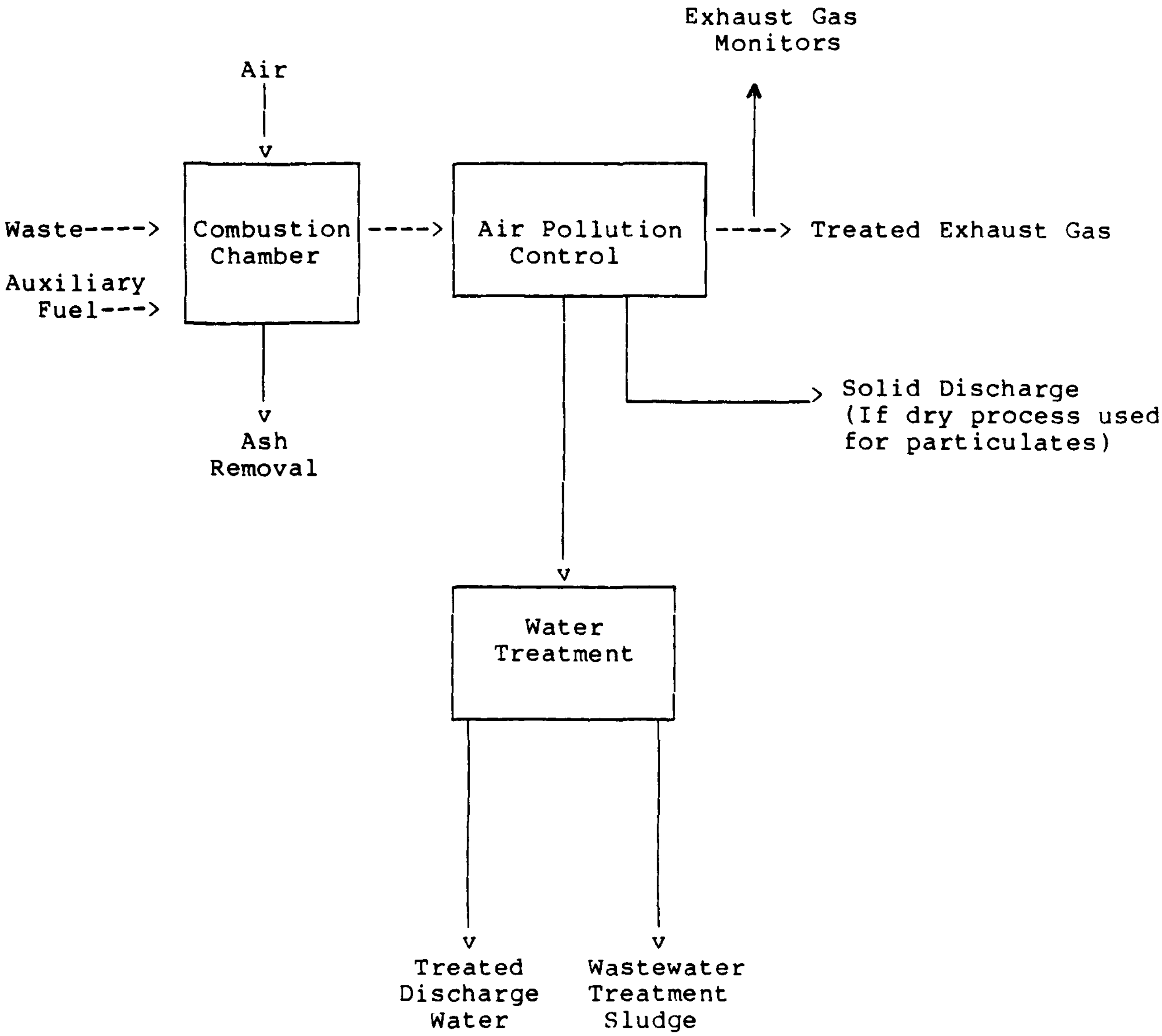
Capable of incinerating a wide range of liquids, gases and slurries, the liquid injection system is the most frequently used hazardous waste incineration system in the United States. The combustion system in a liquid injection incinerator has a very simple design with virtually no moving parts. A burner or nozzle atomizes the liquid waste and injects it into the combustion chamber where it volatilizes and is incinerated. A forced draft system supplies the combustion chamber with air to provide oxygen for combustion and turbulence for mixing. The combustion chamber is usually a cylinder lined with refractory brick, and may be fired horizontally (as illustrated in Figure 2.2), vertically upward, or vertically downward. The specific configurations are designed to satisfy the needs of the owner.

2.2.2 Rotary Kiln Systems on Land

Rotary kiln systems are capable of incinerating solid, sludge, liquid, and gaseous hazardous wastes either separately or simultaneously. Solid wastes are usually combusted with fuel or high-Btu liquid wastes in order to maintain high temperatures and aid in combustion of low heat content solids. Because of their versatility, rotary kilns have been used for large commercial facilities in the United States and regional hazardous waste management facilities in Europe.

A rotary kiln is a slowly rotating, refractory-lined cylinder that is mounted at a slight incline from the horizontal (Figure 2.3). Solid wastes enter at the high end of the kiln, and liquid or gaseous wastes enter through atomizing nozzles. Rotation of the kiln exposes the solids to the heat, vaporizes them, and allows them to combust by mixing with air. The rotation then causes the ash to move to the lower end of the kiln where it can be removed. Rotary kiln systems usually have a secondary combustion chamber or afterburner following the kiln to ensure more complete combustion of the wastes. The secondary chamber may also be fired with fuel or liquid wastes. Although rotary kilns have the advantage of incinerating liquids and solids independently or in combination, they also have relatively high capital costs compared to liquid injection systems.

Figure 2.1 - Generalized Incineration System on Land



2.2.3 Ocean Incineration

The Vulcanus ships employ vertically mounted liquid injection incinerators, each having three rotary cup vortex burners, firing into a cylindrical, refractory-lined combustion chamber. The Vulcanus I has two incinerators mounted on its stern, and the Vulcanus II has three incinerators. All five incinerators were designed and constructed by the same firm (H. Saacke KG) and are very similar in size and shape, although the incinerators on the Vulcanus II are slightly larger than those on the Vulcanus I (151 cubic meter volume versus 130 cubic meters). Each incinerator is capable of burning approximately 7 1/2 tonnes/hr. (1650 gallons) of liquid waste. The Vulcanus I has a cargo capacity of approximately 800,000 gallons (3500 tonnes), and the Vulcanus II a capacity of approximately 724,000 gallons (3200 tonnes).

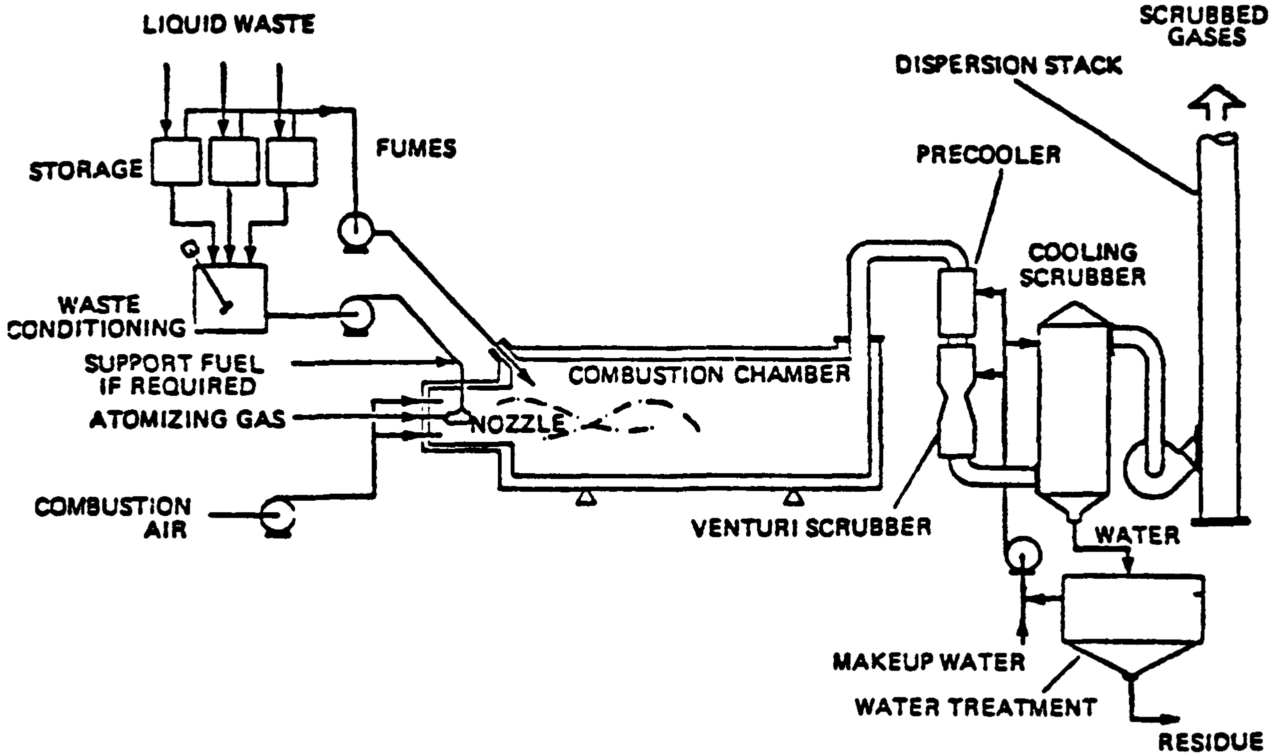
Two additional incinerator ships are under construction by the Tacoma Boatbuilding Company for At-Sea Incineration (also known as the Apollo ships). At-Sea Incineration has applied to EPA for a permit for the first of these vessels. Each will be equipped with two vertically mounted liquid injection incinerators in the stern. The cargo capacity of each ship will be somewhat larger than the Vulcanus ships (1.3 million gallons or 6,000 tonnes) and each will be able to burn about 25 tonnes/hr (5500 gallons) of liquid hazardous waste (12 1/2 tonnes/hour per incinerator).

An ocean incineration plan proposed by SeaBurn Inc. would make use of an oceangoing barge, towed by a tug, and carrying 144 mobile stainless steel tank containers located above the main deck in vertical cells. This would provide a total capacity of approximately 720,000 gallons. This operation would permit standard containers to be loaded with waste at the generator's site, transported by trailer or rail, and lifted on board by container cranes. Incineration would be provided by two horizontally mounted liquid injection incinerators equipped with seawater scrubbers to cool and dilute the exhaust plume and quicken the mixing of acidic and particulate emissions with the sea. Environmental Oceanic Services has also proposed an ocean incineration plan using stainless steel containers to collect and transport wastes. They propose using a smaller, self-propelled supply vessel, modified to carry an incinerator and containers of hazardous wastes.

In general, the waste burning rate for ocean incineration is greater than that for most land-based systems. For example, each incinerator on the Vulcanus burns about 1650 gallons of waste an hour. In contrast, the median capacity for land-based liquid waste incinerators is 150 gallons per hour. In an offshore 1982 EPA survey, only 8 land-based incinerators reported a capacity greater than 2000 gallons an hour.

Figure 2.2

LAND-BASED
LIQUID INJECTION INCINERATOR



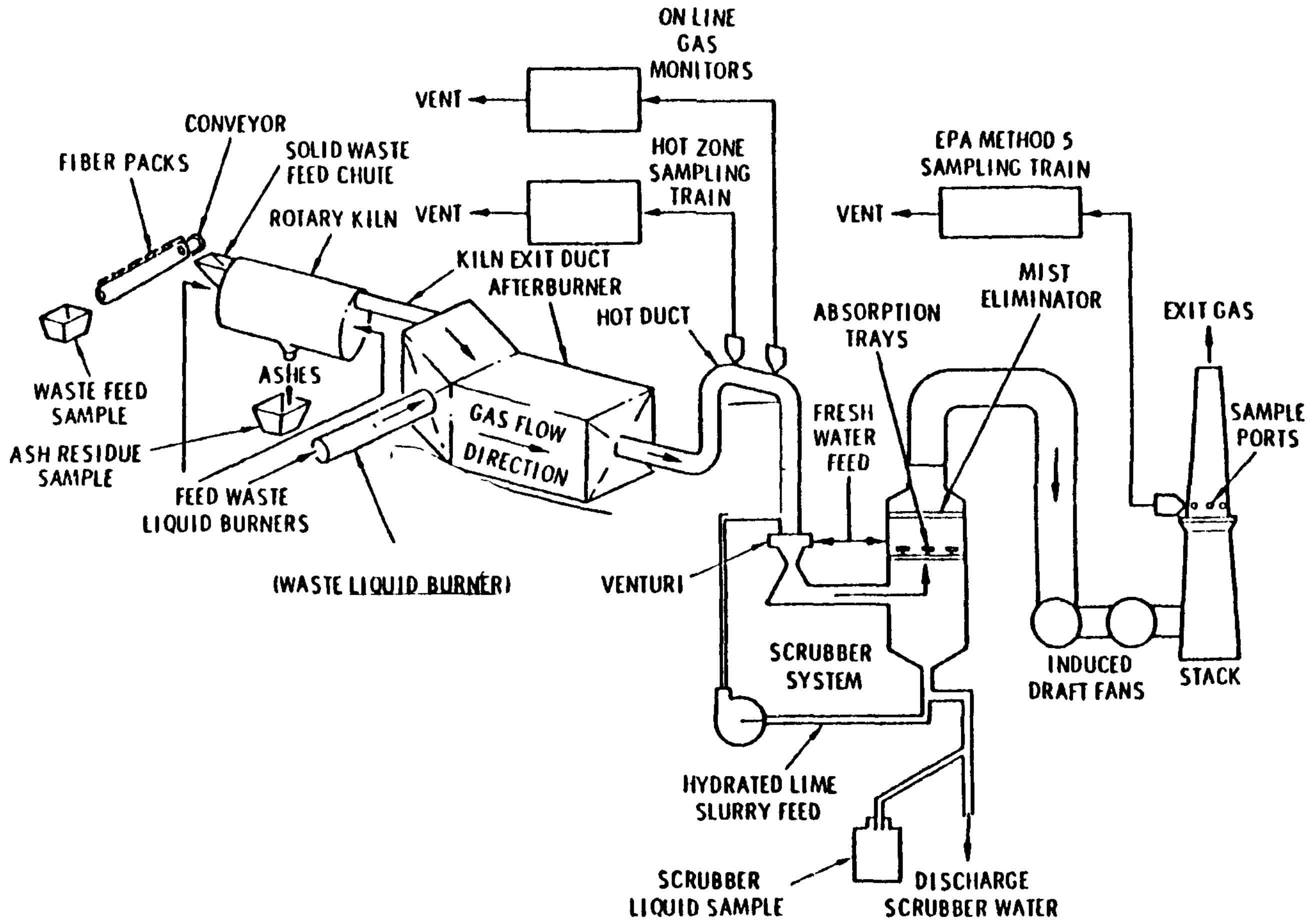


FIGURE 2.3

Rotary Kiln Incinerator
With Liquid Injection Capability

2.3 The Atomizing Burner

2.3.1 Land-based Incineration

One of the major design factors affecting the performance of a liquid hazardous waste incinerator is the operation of the waste burner. The functions of a properly designed and operated burner are to atomize the fuel and waste, position the flame, maintain continuous ignition, and help ensure the correct supply and proportions of fuel and air. Good atomization is particularly important to ensure complete burning and prevent the escape of unburned droplets of waste.

A variety of atomizer nozzle designs have been employed in incinerator burners, and the designs are usually classified by the source of atomizing energy: whether the flowing waste itself, a second fluid such as air or steam, or an external mechanical device, such as rotating cups. Although some experimental information is available on burner operating characteristics, sufficient data does not exist to correlate liquid injection hazardous waste burner performance with the destruction and removal performance achieved by the incinerator system. The diversity of burner operating characteristics, combustion chamber geometries, and other incinerator operating conditions has led EPA to focus on the existing destruction and removal efficiency performance standard rather than a design standard for burners.

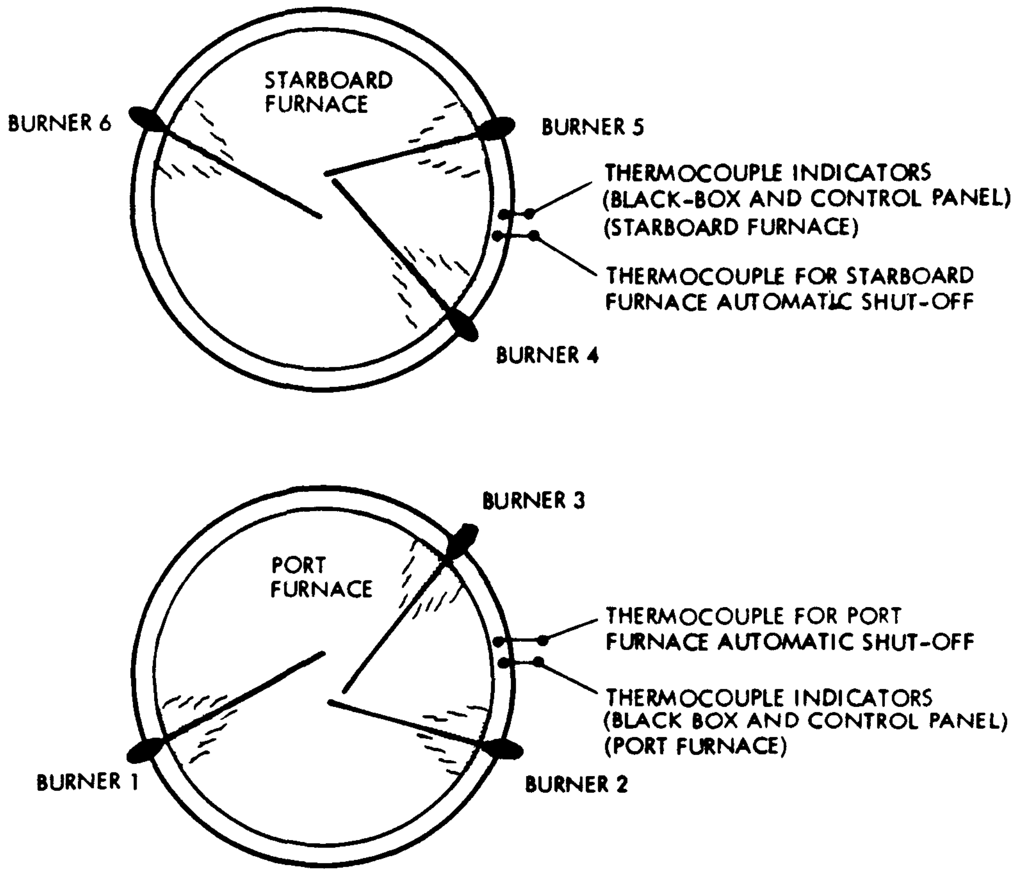
2.3.2 Ocean Incineration

Each Vulcanus incinerator provides atomization and flame control with three rotary cup burners located about 3 meters from the base (Figure 2.4). The rotary cup consists of an open cup mounted on a hollow shaft, which is spun rapidly (6000 rpm) as the liquid waste is delivered through the shaft. Rotational velocity spreads the liquid into a thin sheet as it forces the liquid to the rim of the cup where it is torn from the rim as a thin film. Surface tension causes the film to break into tiny droplets while high velocity air provides thorough mixing of the droplets with combustion air and shapes the flame. Combustion air is provided by one large fixed-speed fan for each incinerator, with a metered air flow rate controlled by an adjustable damper.

2.3.3 Issues

Maintaining atomizing burners in good operating condition is an issue for both land and ocean incinerators. In normal operation, atomizing burners in liquid injection incinerators are subject to corrosion and plugging which may impede atomization, change the spray angle, or produce uneven flow rates. The best protection against these mishaps is (1) selection of a design appropriate to the specific incinerator geometry and waste characteristics, and (2) frequent visual inspection, monitoring of feed pressure, and cleaning and replacement when necessary

Figure 2.4 Vulcanus I Burner and Thermocouple Locations



Some commenters have criticized the design of the rotary cup burners used on the Vulcanus ship, questioning the ability of the burners to provide adequate atomization, especially on a moving ship. They also contend that the design has been widely discontinued and is not the best technology available.

In fact, most of the land-based incinerators in the United States that EPA has studied do not use the European-style rotary cup atomizers, but have adopted pressure spray nozzles using air or steam to assist atomization. However, burner designs are extremely variable, and EPA has measured acceptable incinerator performance for a wide range of burner designs, including the rotary cup burner observed throughout the Vulcanus monitoring activities. Therefore, EPA has focused regulation on incinerator performance rather than burner design.

2.4 The Combustion Chamber

2.4.1 Land-based Incineration

In land-based incinerators, combustion takes place in a refractory-lined chamber that is designed to promote mixing of the waste and air and to allow sufficient residence time for the reactants to complete combustion. In some systems where liquid and solid wastes are incinerated, a secondary combustion chamber or afterburner is used to assist the combustion process.

2.4.2 Ocean Incineration

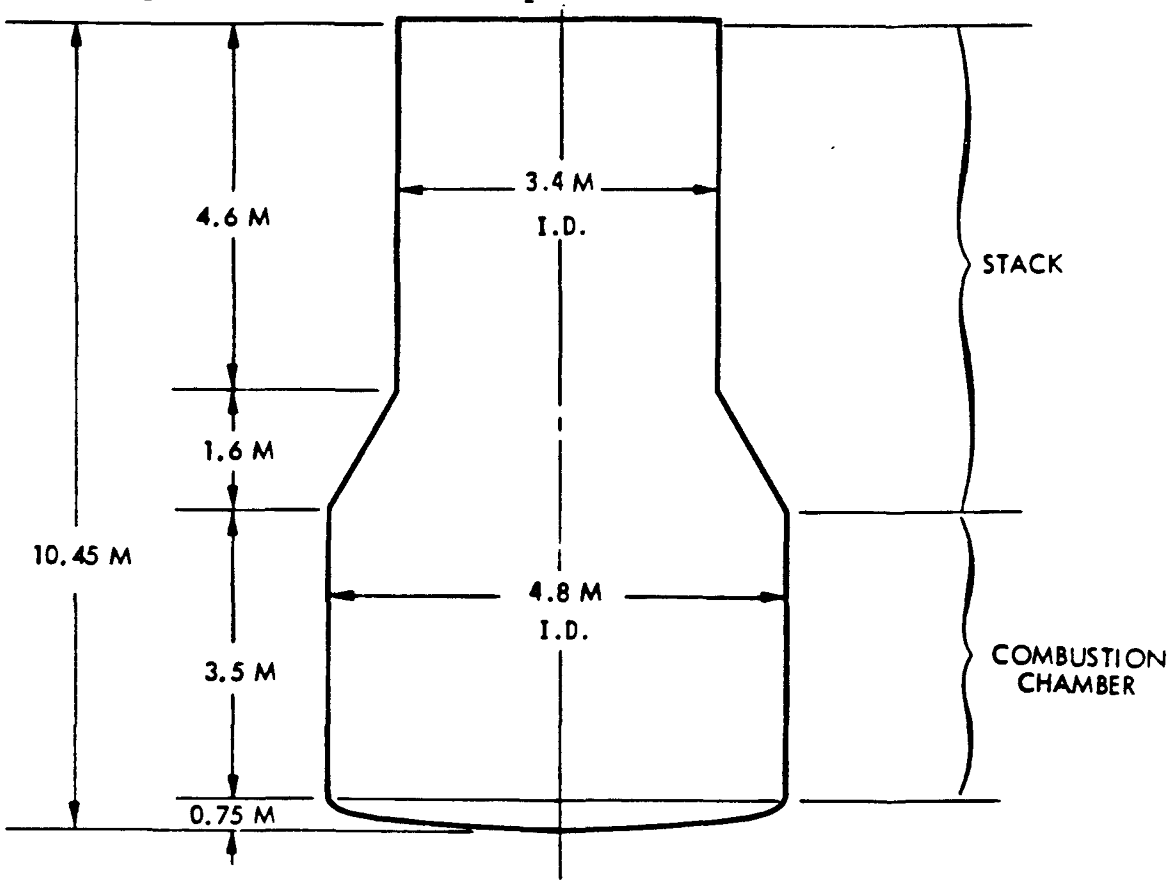
The combustion chambers for the Vulcanus ships are large vertically fired cylinders with a brief converging section which connects directly to the exit stack. The dimensions of the chamber are indicated in Figure 2.5. Burners are oriented tangentially to the vertical sides of the incinerators to provide swirling and mixing of combustion gases. Ocean incinerator design does not include an afterburner because only liquid wastes are incinerated.

The Apollo incinerators are similar in size and shape to those on the Vulcanus. Although the overall heights and diamemeters are approximately the same, the Apollo has a shorter stack and taller combustion chamber.

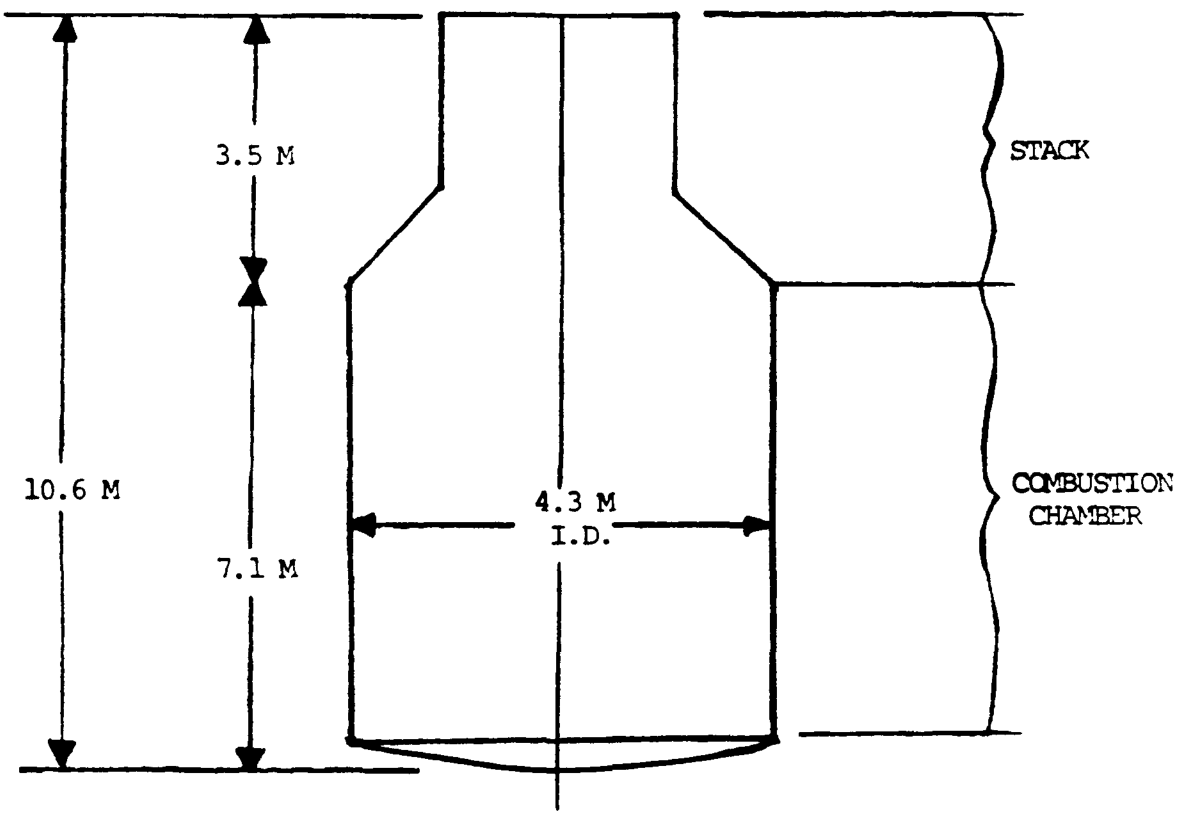
2.4.3 Issues

A few critics of the Vulcanus have argued that the incineration chamber design is inadequate because it does not provide sufficient turbulence for mixing of the waste with oxygen or enough residence time for complete combustion. The Office of Water believes that the appropriate test of the incinerator system is its performance characteristics rather than the design features. Although chamber design effects performance, no clear formula exists for linking chamber design to destruction efficiency.

Figure 2.5 Vulcanus and Apollo Combustion Chambers



Vulcanus



Apollo

The RCRA program also focuses on performance rather than chamber design. Most currently used land-based incinerators have been designed based upon estimation, engineering judgments, individual preferences, and trial and error procedures. EPA has evaluated a wide range of designs and has found that most of them will perform satisfactorily with proper operating temperatures, feed rates, and maintenance.

2.5 Pollution Control Technology

2.5.1 Land-based Incineration

Regulations for incinerators under RCRA and TSCA require controls on air emissions, scrubber water disposal, and ash disposal. Therefore, land-based hazardous waste incinerators include air pollution control devices for acid gases and particulates, as well as systems for treating or disposing of scrubber water and any ash residues. The installation of specific control technology depends, of course, on the type of incinerator used, the properties of the waste being incinerated, and the regulations applicable to the incinerator's location. Generally, however, air pollution control equipment will contain most, if not all, of the following components:

- Quench chamber or heat exchanger to cool the flue gas in order for downstream air pollution controls to operate more effectively.

- Device to collect particulates, such as venturi scrubber, baghouse, electrostatic precipitator, cyclone, or ionizing wet scrubber.

- Device to remove gaseous pollutants such as packed tower, plate, or spray tower scrubbers.

- A mist eliminator to separate water droplets from the flue gas.

- Flue gas handling equipment including ducts, dampers, blowers, and a stack.

2.5.2 Ocean Incineration

EPA does not require air pollution control equipment on ocean incinerators. Neither the Vulcanus nor the Apollo ships use air pollution control equipment, so there is no need to treat or dispose of scrubber water. The proposed SeaBurn vessel would be equipped with seawater scrubbers, but only to dilute the plume and cause it to descend to the sea more rapidly.

2.5.3 Issue

The primary issue for both land-based and ocean incineration is the impact on human health and the environment of emissions of HCl and particulates. For land, the question is whether current controls are adequately protective; for the ocean, it is whether the absence of control technology results in undue risk to the environment. We will defer discussion on this issue until section 4, which includes a full description of performance characteristics and emissions.

An additional issue for land-based incineration is the handling of scrubber water or solid material captured in the air pollution system. Under RCRA regulations, these products of incineration must be treated or disposed of as hazardous waste.

2.6 Energy Recovery Equipment

2.6.1 Land-based Incineration

In recent years there has been increasing interest in recovering the heat generated by the incineration of hazardous wastes. According to a 1982 EPA study, about one-fourth of the incinerators burning liquid hazardous waste employed heat recovery. Incinerator vendors reported, however, that about ninety percent of recent price quotations requested by prospective customers specified energy recovery equipment.

Energy is most often recovered as steam, which may be used for electricity generation, driving machinery, heating, or to raise the temperature of incoming combustion air. Steam generation usually involves boilers using firetubes (flue gases flowing through tubes heat surrounding water) or water tubes (water flowing through tubes is heated by surrounding hot flue gases). A major limiting factor in the use of heat recovery is the strong corrosive impact of hydrogen chloride which results from the combustion of chlorinated wastes.

2.6.2 Ocean Incineration

The Vulcanus and Apollo ships and the SeaBurn proposal do not include mechanisms for heat recovery because the energy that would be generated could not be utilized at-sea and because the high concentration of HCl in ocean incinerator emissions could damage heat recovery equipment.

2.6.3 Issue

Because the Vulcanus does not involve heat recovery, a concern was raised about the potential loss of energy from ocean incineration. EPA has not required heat recovery on land-based or ocean incineration because it does not directly affect human health and the environment, and because incinerator operators will, in their own economic interest, choose to recover heat when it is technically and economically feasible.

3. WASTE HANDLING ASPECTS

This section provides an overview of the steps involved in the waste handling aspects of incineration from the point at which wastes are transferred to the incinerator operator to the point of final disposal of residual wastes resulting from the incineration process. Issues raised concerning these aspects are also covered. This section does not examine the potential risks associated with waste transport pathways, as these are covered in the comparative risk assessment paper.

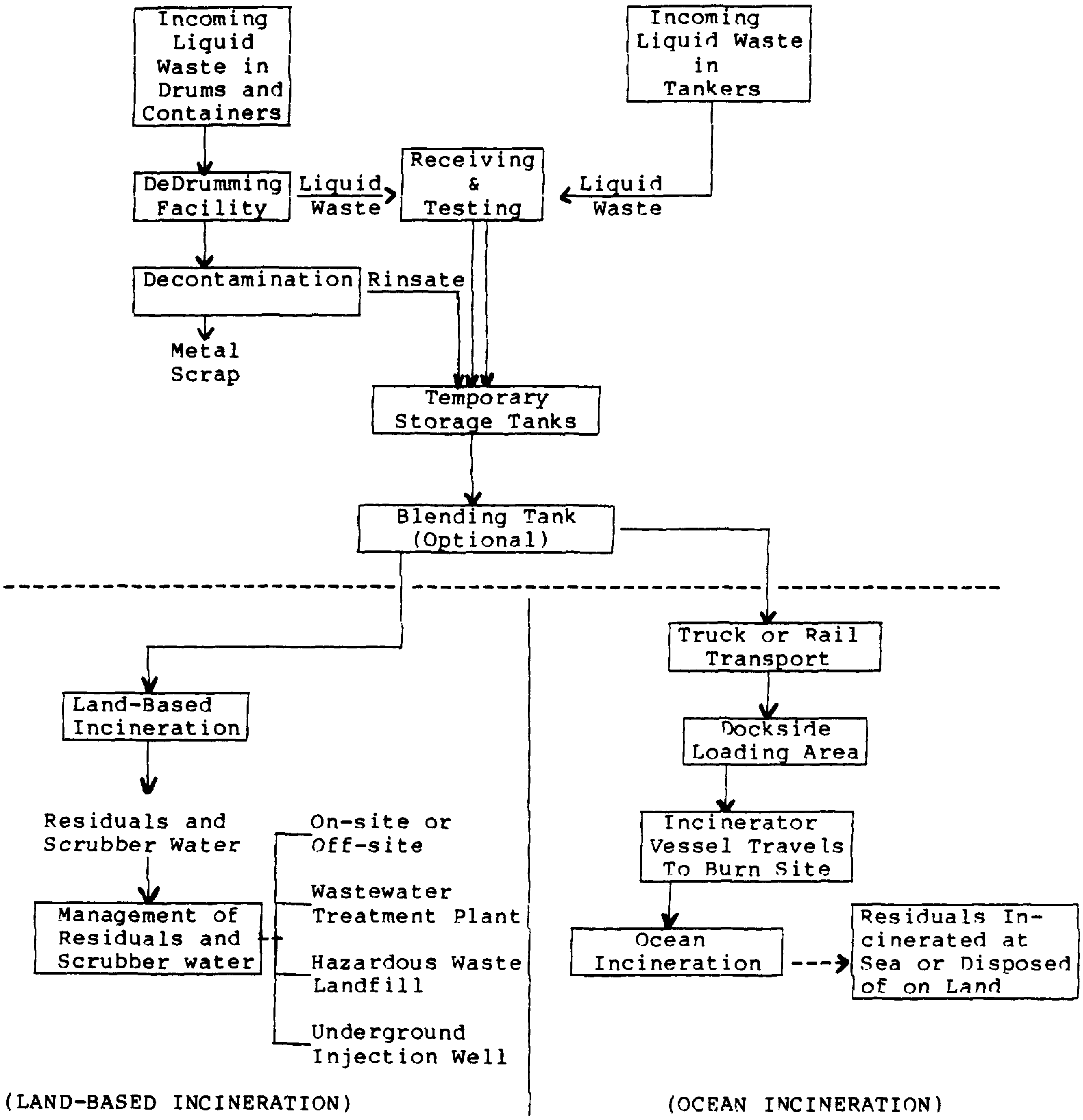
3.1 Waste Handling Aspects of Land-Based Incineration

Figure 3.1 illustrates a typical process flow for a land-based commercial incinerator. In practice, many variations occur, especially among on-site and smaller facilities. In this illustration, incoming wastes are delivered to the facility either as liquids in tank trucks or in drums and other types of containers. Currently, most land-based facilities utilize truck fleets to transport wastes, but some facilities also rely on transport by rail and barge. If the wastes have not been previously identified, they are tested to determine content, viscosity, and combustion value. Then the wastes are pumped into temporary storage tanks which are set up to accommodate compatible waste streams.

Some incinerator operations may utilize a blending tank to prepare an optimal mixture for burning. Other facilities simply pump wastes from different storage tanks directly to the incinerator, thus mixing the wastes during the actual burning. When incineration begins, wastes are pumped from the storage tanks or the blending tank to the incinerator at feed rates which provide for optimum combustion and which do not exceed the maximum thermal input (Btu per hour) allowed by the permit. If necessary, supplementary fuel may be fed into the incinerator to enhance combustion.

Following incineration, scrubbers are employed to remove acid gases and particulates before they can be released from the stacks. This process creates scrubber water which is classified as a hazardous waste. One option for managing the scrubber water is to channel it into a settling pond for removal of the sludge and to recirculate the water for subsequent use in the scrubbers. The remaining sludge is then disposed of in a hazardous waste landfill on or off site.

Figure 3.1 Simplified Process Flow for a Land-Based Incinerator and an Existing Infrastructure Ocean Incineration System



Another option simply involves disposing of all scrubber water in underground injection wells. A third option is to treat scrubber water in a National Pollutant Discharge Elimination System permitted unit. After treatment, the effluent water is no longer considered to be hazardous and may be discharged into sewers or waterways, subject to NPDES permit limitations. The sludge, however, is still considered hazardous, and must be disposed of accordingly.

3.2 Waste Handling Aspects of Ocean Incineration

Three categories of logistical systems have been described as options for managing waste handling aspects of ocean incineration. These are no-infrastructure, integrated, and existing infrastructure systems.

- No-Infrastructure Systems: This system minimizes the use of fixed facilities. Wastes accumulate at their sources and are stored in truck or rail tanks or portable liquid containers. Filled containers are transported to an existing port transfer facility which is not dedicated solely to incinerator ship operations. The wastes are then pumped or the containers lifted directly onto vessels. There is no blending of wastes from different sources prior to loading aboard ships although different waste streams may be segregated on board. During actual incineration, wastes are fed to the burners from different storage tanks to provide the best burning mixture.

  Variations of the no-infrastructure system have been proposed by Seaburn Inc. and Environmental Oceanic Services. They call for the use of stainless steel tank containers to be collected at generator sites and shipped to port. The sealed containers themselves are loaded on an incinerator vessel. Since each container has a direct feed to the incinerator, the wastes never leave the container until actual incineration of the wastes begins at sea.

- Existing Infrastructure Systems: An existing infrastructure system is similar to a no-infrastructure system in that it makes use of port transfer facilities which are not dedicated solely to incinerator ship operations. It differs from the no-infrastructure system primarily in that it allows for blending, preparation, and storage functions to be performed at existing, centralized facilities which are separate from the port facility.

Chemical Waste Management Inc. (CWM) proposed to employ an existing infrastructure system to support its Vulcanus incinerator vessels. Liquid wastes would be transported from generators to CWM's testing, storage, and blending facility at Emelle, Alabama. Blended waste streams would be truck transported to an existing port facility at Chickasaw, near the port of Mobile, Alabama, and wastes would be pumped directly onto the Vulcanus. Figure 3.1 illustrates a process flow for ocean incineration using an existing infrastructure system.

EPA's proposed permits for the Vulcanus ships required that, following incineration of the wastes at the designated burnsite, any ash resulting from the process, solvents used to wash tanks, contaminated shipboard waters, or other hazardous materials must be incinerated at sea, or upon return to port disposed of in accordance with EPA regulations.

o Integrated Systems: An integrated system involves the siting of a specialized port facility dedicated primarily to incinerator ship operations. The facility receives waste from generators and has the capacity for analyzing, blending, and storing them. Additionally, the facility is equipped to handle both containers and tanked liquids, and incorporates safety features to prevent leakage of wastes to the surrounding environ-environment. Variations on this concept have been proposed in the past by the Interagency Ad Hoc Work Group for the Chemical Waste Incinerator Ship Program and by At-Sea Incineration, Inc.

3.3 Key Differences in Waste Handling

As indicated in Figure 3.1, a typical process flow for land-based and ocean incineration may involve the same steps up through the waste blending operation. Following blending, the key difference between the two forms of incineration is primarily in subsequent transport of the wastes and disposal of residuals.

On land, the wastes are pumped directly from the blending tanks or temporary storage tanks to the incinerator. In contrast, an existing ocean infrastructure system, such as that proposed for the Vulcanus, would require an additional transfer and transport leg to haul wastes from the blending site to the port site (CWM's Chickasaw port transfer site is approximately 140 miles from its Emelle blending and storage facility).

The other key handling differences are in the disposal of residuals. Land-based facilities must handle scrubber water resulting from their processes. Current ocean incineration operations are not faced with managing scrubber water, since they do not use scrubbers. Even under the proposed SeaBurn system, there is still no scrubber water residual, since seawater used in the quench system would be returned directly to the ocean.

3.4 Key Waste Handling Issues

Critics are concerned that the mixing of incompatible wastes could lead to runaway chemical reactions, fires or explosions and therefore poses potential problems for both land and ocean incinerators. However, tests for waste compatibility are a routine part of system safeguards for commercial incinerator operations.

For ocean incineration, CWM routinely tests incoming wastes for blending compatibility at its facility in Emelle, Alabama. Only after the wastes are found to be compatible are they blended. CWM reports that blended wastes are held in storage tanks for a minimum of several days before loading into tank trucks for transport to the Vulcanus. Any reaction that could occur would occur by this time. No further blending of wastes is done once the wastes are removed from the storage tanks at Emelle. However, batches of blended waste from Emelle could be loaded into the same tank on the vessel.

For land-based incinerators, permits indicate the scope and frequency of sampling of incoming waste to determine whether it is within permit-specified physical and chemical composition limits, and in order to prevent the mixing of incompatible wastes. In general, it is in the best interest of land and ocean incinerator operators to ensure that adequate testing of incoming waste is done as a safeguard to protect their own investments and the safety of their employees. However, because of the many variations in waste handling practices on land, waste incompatibility could be a potential problem if normal safeguards are not consistently applied.

An additional concern involves the potential for spills and fugitive emissions during the collection, transport, pumping, and storage of the wastes. In the absence of concrete data, the SAB and others have speculated that releases from handling and storage might be large. The risk assessment conducted for this study, however, indicates that such releases are probably very small compared to stack emissions.

Neither the MPRSA nor the Ocean Dumping Regulations specifically addresses the issue of siting of transfer and loading facilities. However, the transfer facilities are subject to comprehensive control under U.S. Coast Guard regulations, which address conditions which must be met for the designation of a waterfront facility for handling and loading hazardous substances (33 CFR Part 6, 125, 126). EPA's proposed regulations require incineration companies to develop a contingency plan which outlines safety precautions to prevent accidents during loading and provides a workable plan for responding to any accidents that may occur.

4. PERFORMANCE CHARACTERISTICS

4.1 Overview of Trail Burns, Performance Standards, and Operating Parameters

This section outlines regulatory requirements and permitting procedures to place in context the subsequent technical discussion of performance characteristics.

4.1.1 Land-Based Incineration: Trial Burns and Performance Standards

In order to obtain a RCRA permit for operating a hazardous waste incinerator, the applicant must demonstrate the incinerator's ability to comply with EPA performance standards. Compliance with the standards for incineration of hazardous wastes (40 CFR 264.340 through 264.351) is generally established through conducting a trial burn. Initially, waste streams most likely to be treated at the facility are selected for the trial burn and analyzed for:

- o Heating value of the waste;
- o Viscosity;
- o Concentrations of hazardous constituents listed in 40 CFR 261, Appendix VIII, expected to be present in the waste;
- o Organically bound chlorine content (established during trial burn and listed in the permit);
- o Ash content (established during trial burn and listed in the permit).

During the trial burn, the incinerator must achieve the following performance levels:

- o Destruction and removal efficiency (DRE)- 99.99% for Principal Organic Hazardous Constituents (POHCs);

- Hydrogen chloride (HCl) emission - 99% removal or less than 1.8 kilograms per hour;

- Particulates- 0.08 grain per dry standard cubic foot (dscf) when corrected for amount of oxygen in the stack.

If the incinerator operator plans to burn PCBs, he must receive a separate approval from the Assistant Administrator of the Office of Pesticides and Toxic Substances in order to comply with TSCA. For liquid PCBs, regulations generally require:

- A combustion efficiency of 99.9%, and

- Either of the following operating conditions:

  - 1200°C ± 100, 2-second residence time, and 3% excess oxygen, or

  - 1600°C ± 100, 1.5-second residence time, and 2% excess oxygen.

However, EPA will allow other than specified temperature and residence times if equivalent DRE can be demonstrated.

4.1.2 Land-based Incineration: Operating Parameters

Once the trial burn has been conducted on the selected waste streams and adequate performance demonstrated, routine operations can begin. The final permit designates a set of operating requirements based upon the results of the trial burn which are specific to each waste feed burned and reflect the range of operating conditions shown to achieve acceptable performance levels. Operating requirements are specified in the permit for the following parameters:

- Carbon monoxide (CO) level in the exhaust stack gas (indicator of combustion upset and combustion efficiency)

- Waste feed rate

- Combustion zone temperature (although the exact location of the temperature sensor will vary in each case, a location should be specified in the permit which insures that temperature is always monitored at the same point during routine operation)

- Combustion gas flow rate (indicates residence time in combustion zone)

- Air pollution control device operating conditions.

4.1.3 Ocean Incineration: Performance Standards, Trial Burns, and Operating Requirements

EPA is proposing a trial burn procedure similar to that used under RCRA in permitting land-based incinerators to ensure that ocean incinerator vessels can achieve acceptable destruction efficiencies. This method calls for the applicant to submit a trial burn plan to EPA for approval as part of its overall application for an Operating Permit.

During the Trial Burn the incinerator vessel must do three things:

- o Demostrate that a Destruction Efficiency (DE) of at least 99.99% on POHCs, a DE of at least 99.9999% on PCBs chosen as POHCs, and a Combustion Efficiency (CE) in excess of 99.9% is achieved.

- o Define or qualify the range of wastes that can be burned by the system to achieve 99.99% DE and 99.9% CE.

- o Determine the optimum operating conditions under which acceptable DE and CE can be met.

Additionally, the trial burns may also be used to test the DE and CE of the system on the five wastes specified by the London Dumping Convention (LDC) for which doubts exist as to the thermal destructability and efficiency of destruction. These wastes are: polychlorinated biphenyls (PCBs), polychlorinated terphenyls (PCTs), tetrachlorodibenzo-p-dioxin (TCDD), benzene hexachloride (BHC), and dichlorodiphenyl trichloroethane (DDT). If the incinerator will be burning any of these wastes, they must be tested in the trial burn.

To summarize, trial burns are conducted primarily to demonstrate the destruction efficiency and combustion efficiency of the system on POHCs, and to establish operating conditions under which the DE can be met for a range of wastes.

After EPA determines that the trial burn adequately demonstrates the ability of the incinerator vessel to comply with the performance standards at a determined set of key operating parameters, operations could begin. Operating conditions under the Operating Permit are oriented towards ensuring that the CE performance standard is achieved which indicates acceptable DE. Continuous monitoring and recording would be required for the following operational parameters:

- o Wall temperature;

- o Oxygen concentration in combustion gases;

- Carbon dioxide and carbon monoxide concentrations in combustion gases;

- Waste flow rates and/or auxiliary fuel (if used) feed rates to the incinerator;

- Status of the flame;

- Air flow to the incinerators; and

- Amount of wastes incinerated.

In addition, operating requirements are specified for the three key parameters of incinerator wall temperature, and carbon monoxide and oxygen concentration in the stack gases.

4.2 Key Parameters for Measuring Destruction of Hazardous Constituents

4.2.1 Destruction Efficiency and Destruction and Removal Efficiency

Performance of hazardous waste incinerators is normally measured in terms of destruction efficiency (DE) or destruction and removal efficiency (DRE). Destruction efficiency refers to the percentage of hazardous constituents destroyed in the combustion chamber, while destruction and removal efficiency accounts for both the destruction in the combustion chamber and removal of remaining original hazardous constituents by air pollution control equipment. The RCRA regulations require a DRE for principal organic hazardous constituents (POHCs) of 99.99%, based on the following formula:

$$DRE = \frac{(W_{in} - W_{out})}{W_{in}} \times 100$$

Where: Win = mass feed rate of a constituent in the waste stream feeding the incinerator.

Wout = mass emission rate of the same constituent in the exhaust emissions prior to release to the atmosphere.

4.2.2 Combustion Efficiency

Combustion efficiency (CE), another indicator used to measure incinerator performance, is an indirect measure of an incinerator's ability to achieve a high level of waste destruction. It measures the extent to which carbon in the waste is oxidized to form CO_2 rather than CO, an indication of complete rather than partial combustion. Combustion efficiency is defined as:

$$CE = \frac{C_{co2}}{C_{co2} + C_{co}} \times 100$$

Where:

CE = combustion efficiency
C_{co2} = concentration of CO_2 in exhaust gas
C_{co} = concentration of CO in exhaust gas

RCRA regulations do not require measurement of CE, although permits specify maximum CO levels in the stack gas on a case by case basis. PCB regulations continue to specify a 99.9 percent CE, which the Office of Toxic Substances believes to be an indicator of a DRE of 99.9999 percent. EPA requires 99.9% CE for ocean incineration.

There is still some uncertainty within EPA as to whether a precise relationship can be determined between CE and DE or DRE in incinerators, other than the usual finding of good DE or DRE with good CE. The Office of Research and Development's (ORD) current thermal destruction program is conducting research at the lab/pilot scale to better understand these relationships.

4.2.3 Principal Organic Hazardous Constituents

Because many of the liquid hazardous wastes to be incinerated are complex mixtures of many different compounds, the RCRA program developed a system whereby the overall performance of an incinerator is measured by tests on a small number of waste constituents or individual hazardous compounds. The Office of Water has also adopted this approach for the ocean incineration program.

The testing system uses a small number of principal organic hazardous constituents (POHCs) to represent the many compounds found in a complex waste. In order to use POHC surrogates to represent many compounds, EPA developed a system to rank compounds on the basis of how difficult they are to burn. Incinerability is measured by "heat of combustion," a theoretical calculation of energy released when waste molecules are combusted. Compounds with a lower heat of combustion are presumed to be more difficult to burn than those with a higher heat of combustion.

Using the incinerability ranking, the test designer selects a few compounds, the POHCs, on which to measure destruction efficiency. Generally, constituents which are most difficult to destroy and most abundant in the waste mixture are selected. When a trial burn demonstrates that an incinerator can achieve a destruction efficiency of 99.99 percent for a particular POHC, the constituents with higher heats of combustion (less difficult to burn) burned in that incinerator under comparable conditions are also presumed to be destroyed.

4.2.4 Performance of Land-Based Incinerators

During the 1970's, EPA conducted or identified 54 test burns of hazardous wastes in which destruction efficiency was measured. The tests involved not only liquid injection and rotary kiln incinerators, but also hearth incinerators and newer technologies such as molten salt, fluidized bed, and pyrolysis. All but nine of the tests achieved a destruction efficiency of at least 99.99 percent, and many of the lower destruction efficiencies could be traced to extreme test conditions or identifiable and correctable problems. These test burns became the basis for the selection of the 99.99 percent DRE standard in the RCRA regulations.

In order to develop further information on incinerator performance in conjunction with an incinerator Regulatory Impact Analysis (RIA), EPA conducted case studies of 51 incinerators at 34 sites. Test burns were performed at 8 of the facilities. All eight incinerators with test burns had liquid injection devices, but some also had rotary kilns to burn solids. The tests involved a wide variety of incinerator designs, control devices, waste types, and operating conditions.

In general, the test burn results provide additional support for the capability of achieving DREs of 99.99 percent. Of 240 DREs calculated (for each test run for each compound), nearly two thirds were greater than 99.99 percent. Of the remainder, seventy percent were above 99.9 percent. Most of the cases below 99.99 percent DRE occurred when (1) there was a very low concentration of the POHC in the waste feed, or (2) when the compound was one which had been identified as a product of incomplete combustion at other facilities.

ORD reported that the tests were done while the incinerators were performing at their best, with close and careful maintenance and attention. Poor visual stack emissions were observed on occasion with careless or inept operators, and while these emissions were not measured or quantified, ORD felt that the emissions would have been unacceptable under RCRA. Overall, ORD reported that the tests reinforced their appreciation for quality of operations and its impact on performance.

4.2.5 Destruction of PCBs on Land

Data from many test burns of polychlorinated biphenyls (PCBs) provide evidence that the thermal destruction of PCBs in incinerators, in accordance with PCB regulations, can be accomplished with high efficiency and minimal emissions of undestroyed PCBs. The information in Table 4.1 shows data from PCB test burns in six incinerators of varying design and operating conditions. All but one burn achieved at least 99.9999 percent DRE, with the lowest value reported as 99.9971 percent.

4.2.6 Performance of the Vulcanus

EPA's conclusions regarding the performance capabilities of the Vulcanus ships are based on evaluations of data recorded during a number of test burns. Tables 4.2 and 4.3 summarize information on the test burns where destruction efficiencies were reported.

The Background Document on the Tentative Determination to Issue Permits made use of only three of these burns in considering the capability of the Vulcanus ships and proposing limits on wastes to be burned for the proposed special permits. (See tables).

- o The July-September 1977 burn of Agent Orange by the Vulcanus I in the Pacific is cited as evidence of at least 99.99 percent destruction efficiency of three compounds, including dioxin (TCDD). The actual calculated DE for dioxin of greater than 99.93 percent was judged to be a low estimate because: (1) chemicals with a lower heat of combustion achieved DEs greater than 99.99 percent, and (2) low concentrations of dioxins in the waste mixture challenged the capabilities of the analytical methodology.

- o The August 1982 Vulcanus I burn of a PCB mixture showed DEs greater than 99.99 percent for several POHCs, and greater than 99.999 percent for PCBs. The POHC with the lowest heat of combustion was hexachlorobenzene (1.79 Kcal/gram), and this was chosen as the limiting waste for the Vulcanus I permit.

- o The February 1983 Vulcanus II burn showed DEs greater than 99.99 percent for a variety of liquid organochlorines. The POHC with the lowest heat of combustion was tetrachloromethane (carbon tetrachloride, 0.24 Kcal/gram), and this was chosen as the limiting waste for the Vulcanus II permit.

- o Although the Vulcanus II did not have a test burn with TCDD or PCBs, EPA tentatively concluded that the Vulcanus II is capable of adequately incinerating these wastes based on the Vulcanus I tests, and the similarity of the Vulcanus II incinerators to those of its sister ship.

In the tentative determination on the special permits, EPA treated the August 1982 burn (Vulcanus I) and the February 1983 burn (Vulcanus II) as the definitive trial burns for determining compliance with the DE requirement, and establishing waste limitations and operating requirements. The Agent Orange burn of 1977 was also cited as specific evidence in support of sufficient incineration of dioxins.

Table 4.1 TEST BURNS OF PCBs IN INCINERATORS

Incinerator Type	Date of Test Burn	PCB Destruction & Removal Efficiency (%)	Temperature, Average (°C)	Residence Time (Sec)	PCB Feed Rate (kg/hr)
Rotary Kiln	10/1979	99.99998	760°	2	289[a]
+ Primary Combustion Chamber			1254°	2	
+ Secondary Combustion Chamber			1046°	2	
Liquid Burner	11/1979	99.99997	1304°	2.68	1102[b]
+ Afterburner			1183°		
Single Combustion Chamber	1/1980	99.9971	1347°	1.59	1[b]
Single Combustion Chamber	5/1980	99.99999	1316°	1.17	22[b]
Single Combustion Chamber	4/1981	99.9999	1271°	2.14	1.5[b]
Single Combustion Chamber	7/1981	99.999996	1180°	2.96	6[b]

a = WASTE FEED: Liquids + PCB-containing Capacitors

b = WASTE FEED: Liquids

Table 4.2 VULCANUS I TEST BURNS*

	(1)	(2)	(3)	(4)	(5)
DATE	October 1974 - January 1975	March 1977	July - September 1977	December 1981 - January 1982	August 1982
LOCATION	Gulf of Mexico	Gulf of Mexico	Johnston Atoll, Pacific Ocean	Gulf of Mexico	Gulf of Mexico
WASTES AND COMPOUNDS BURNED	Chlorinated hydrocarbons	Chlorinated hydrocarbons	Herbicide Orange (2, 4-D; 2, 4, 5-T; 2, 3, 7, 8 TCDD)	PCBs, TCDF chlorobenzenes	PCBs, TCDF chlorobenzenes
QUANTITY BURNED	16.8K metric tons	12.3K metric tons	10.4K metric tons	3.5K metric tons	3.5K metric tons
DEs CITED IN TENTATIVE PERMIT DETERMINATION	No	No	Yes	No	Yes
DEs REPORTED	"Organochlorides" >99.9%	Trichloropropane (C_3Cl_3) 99.92% - 99.98%	Dioxin (TCDD) > 99.93% 2, 4 - D >99.999% 2, 4, 5 - T >99.999%	EPA calls results inconclusive due to inadequate amount of valid data obtained.	PCBs >99.999% TCDF >99.93% Hexachlorobenzene >99.99%
LIT REFERENCE	8	2	1	33	3

* Sponsored by EPA. Other test burns have been conducted in the north sea.

Table 4.3 VULCANUS II TEST BURNS

	(1)	(2)
DATE	January 22-30, 1983	February 14-19, 1983
LOCATION	North Sea	North Sea
WASTES BURNED	Liquid Organochlorines	Liquid Organochlorines
QUANTITY BURNED	Not stated	1000 metric tons
CITED IN PERMIT DETERMINATION	No	Yes
DEs	EPA determines published DES are unusable since approved analytical protocol was not followed	CCl_4 >99.99% $CHCl_3$ >99.99% 1,1,2-TCE >99.99% 1,2-DCE >99.99% 1,1-DCE >99.99%
LIT REFERENCE	29, 24	20

4.2.7 Issues

A large number of individuals and groups challenged EPA's findings regarding the performance capabilities of the Vulcanus incinerators. Many of the concerns focus on the sampling practices and analytical methodologies used in the test burns. These concerns and the recommendations contained in the proposed regulations for dealing with them are summarized later in this paper in the section on sampling and monitoring. Five additional issues related to performance are discussed here.

o Destruction Efficiency for PCBs

Although the Vulcanus I demonstrated a destruction efficiency of greater than 99.999 percent for PCBs and met the TSCA requirements for liquid PCBs, it did not meet the 99.9999 percent DE which EPA has required for burning liquid PCBs on land as a matter of permitting practice.

Based on operating requirements and measures of combustion efficiency, EPA scientists believe that the Vulcanus routinely achieves the "six nines" level of destruction. The problem is that insufficient volumes of the combustion gases were sampled on the Vulcanus to demonstrate conclusively DEs of 99.9999 percent during previous burns. For this reason, EPA anticipates that required testing during future trial burns will collect a larger sample volume and effectively demonstrate whether a DE of greater than 99.9999 percent is achieved.

o A Trial Burn Waiver for PCBs

In the Tentative Determination, EPA proposed to authorize the incineration of PCBs in the Vulcanus II based upon trial burns by the Vulcanus I and the close similarity between the incinerators on the two ships. The TSCA regulations provide for a waiver of a PCB trial burn if a detailed comparison of two incinerator systems convinces EPA that they will have an equivalent destruction efficiency.

In permitting practice, however, the TSCA program has required a trial burn for all land-based facilities burning PCBs, and has never granted a waiver for a trial burn. In order to be consistent with TSCA permitting practice, the proposed regulations recommend that all vessels demonstrate 99.9999 percent DEs for PCBs, even if vessels with similar incinerator systems have already done so.

o Destruction of Dioxin

In the Tentative Determination, EPA stated that the circumstances of the 1977 Test burn indicated that the Vulcanus had achieved a DE greater than 99.99 percent for dioxin, even though the calculated DE was greater than 99.93 percent.

Some commenters questioned this determination. The proposed regulations include a higher destruction efficiency requirement for dioxins of 99.9999 percent. This can be demonstrated in a trial burn by achieving a DE of 99.9999 percent for compounds more difficult to incinerate than dioxins.

o The Impact of Scrubbers on Hazardous Organic Emissions

Some commenters expressed concern about the absence of scrubbers on the Vulcanus vessels, arguing that scrubbers provided an extra margin of safety by removing some of the hazardous organic compounds remaining in the flue gas. In EPA's opinion, scrubbers do not control hazardous emissions. Trial burns conducted by the RCRA program provide some data on this question. At five plants with wet scrubbers, EPA examined scrubber effluents for POHC contamination. Most hazardous constituents were undetected, or were present in very low concentrations (less than 20 ug/L). Generally, quantities found in the effluents were small compared to quantities emitted from the stack and did not significantly improve DRE.

o The Effectiveness of the POHC System

The POHC system is used by both the land-based and ocean incineration programs. A number of persons expressed concern that this system, and particularly the heat of combustion index, do not provide an adequate basis for determining the incinerability of a complex mixture of chemical compounds. EPA is continuing to assess the reliability of this system, but believes it to be the best system currently available. Recent data obtained by ORD does not substantiate the heat of combustion and concentration-based method for ranking compounds. Evidence seems to be mounting that any or all organics may be destroyed essentially equally under a given condition. However, the issue of selecting the appropriate measure for a POHC ranking system becomes less important when one considers that normal operating flame temperatures which organic compounds are subjected to in land and ocean incinerators are several hundred degrees higher than temperatures needed to destroy any compounds at the top of all investigated or considered hierarchies.

4.3 Hydrogen Chloride

4.3.1 Land-based Incineration

The combustion of chlorinated compounds in hazardous waste incinerators results in chloride emissions, principally in the form of hydrogen chloride (HCl). RCRA regulations limit HCl emissions to either 1.8 kilograms per hour or 99 percent removal. PCB regulations require the use of wet scrubbers or an approved alternate, with specific performance requirements to be specified by the Regional Administrator.

As indicated in the discussion of control technology, a wide variety of scrubber designs is used, with some using water as an absorbing medium and others using a caustic solution. In the incinerator test burn study conducted for the RCRA program, the effectiveness of HCl control was analyzed for the five incinerators with control systems. Scrubber systems were able to meet easily either the 99 percent removal efficiency or the 1.8 kilogram per hour criteria specified in the regulations.

4.3.2 Ocean Incineration

EPA does not require scrubbers for ocean incineration ships. Although the proposed regulations for ocean incineration include an environmental standard to limit HCl impacts, it is not expected that this standard will result in a need for scrubbers on ships. EPA's position is that ship personnel can be protected from any potential contact with HCl by setting appropriate rules about plume orientation and ship forward speed. In addition, HCl coming in contact with seawater will be rapidly neutralized.

Analysis of seawater collected under the Vulcanus' plume during the 1974-1975 test burn did not show a lowered pH due to the HCl. When the Texas Air Control board examined data from on shore monitoring for plume remnants during the August 1982 PCB burn, it found no evidence of HCl.

4.3.3 Issues

Generally, few concerns have been expressed regarding the impact of HCl on the ocean, based on the current level of burning. Two acid gas issues, however, were raised during the public comment period:

o HCl May Contribute to Acid Rain

EPA scientists believe that most direct HCl emissions from ocean incineration are mixed with ocean waters, and the remainder is too distant from land to contribute to terrestrial acid rain.

o The Release of Other Halogens

Some commenters on the ocean permits expressed concern about potential environmental problems if elements such as fluorine, iodine and bromine are released either as the free element or as the acidic gas, HF, HI and HBr. EPA intends to conduct environmental monitoring for these species during future permits, and as a result of further investigation may choose to limit the amounts of fluorine, iodine and bromine in wastes incinerated in the future. This decision will be based on evaluation of the atmospheric chemistry of these materials and their impacts on the marine environment.

4.4 Particulates

4.4.1 Land-based Incineration

Incineration of hazardous waste may result in particulate emissions from the waste feed, auxiliary fuels, and scrubbing liquids used in the air pollution control system. Ash from the waste feed or auxiliary fuel may be emitted as a particulate in the exhaust gas. Carbonaceous material can also be entrained in exhaust gases, condensed in air pollution control systems, and emitted to the atmosphere. Particulates may occasionally come out of water droplets evaporated in a quench chamber or scrubber and then be contained in the exhaust stream. RCRA incinerator regulations require particulates to be controlled to less than 0.08 grain/dscf when corrected to 7 percent oxygen in the stack gases. The PCB regulations have no specific limitations for particulates.

The actual particulate loading for directly discharged emissions will vary significantly as the characteristics of the waste vary. For instance, liquid waste incinerators would normally have smaller loadings than incinerators which burn solid wastes in conjunction with liquids.

The technology used to control particulate matter is well established and often features venturi scrubbers or ionizing wet scrubbers. The specific technology chosen depends upon the particulate loading, size distribution of particulates, acid gas removal needs, and regulatory requirements.

Test data on a variety of hazardous waste incinerators indicates that federal standards can be achieved with existing control technology. Test burns conducted for the OSW regulatory impact analysis indicated that three of the five systems examined with particulate controls achieved the federal standard. ORD reports that scrubbers and other forms of pollution control devices were found to be successful in meeting the particulate standard when sophisticated systems were used, less successful when low energy or less sophisticated systems were used.

4.4.2 Ocean Incineration

EPA does not require particulate emission controls for ocean incineration. Since only liquid wastes are burned, EPA expects the overall particulate loading to be very low. In addition, EPA proposes to limit particulates by limiting the amount of metals in the waste. A plume modeling exercise, assuming all metals in the waste enter the environment, will be used to set conservative limits ensuring that water quality criteria for the metals would not be exceeded.

4.4.3 Issue

In the past, EPA has not attempted to measure particulate loadings for the Vulcanus burns and has received some criticism for this. This issue is discussed further in section 5.2.3., on sampling.

4.5 Products of Incomplete Combustion (PICs)

4.5.1 Land-based Incineration

In the process of burning hazardous wastes, incinerators and other combustion devices may cause the formation and emission of potentially harmful substances that are not present in the initial waste stream. Concern about the creation of these substances, called products of incomplete combustion (PICs), became acute in the late 1970's with the discovery of chlorinated dioxins and furans in the emissions of many incinerators burning municipal refuse and hazardous wastes. A wide variety of other PICs has been found in incinerator test burns. Currently there is a great deal of uncertainty regarding the source of PICs or the mechanisms by which they are formed. As yet, PIC emissions are unregulated, although EPA proposed regulations on PICs under RCRA in 1981.

Because of the potential hazard from emissions of chlorinated dioxins or furans, EPA has studied this issue closely. In 1980, EPA sampled five municipal incinerators for dioxin emissions and found both the emissions and human health risk from the emissions quite low. At the same time, EPA evaluated the formation of dioxins and furans during the incineration of PCBs at the ENSCO and Rollins incinerators in El Dorado, Arkansas, and Deer Park, Texas. Although low levels of both PICs were found, a worst case risk analysis showed the incremental human health risk for cancer to be in the range from 0.1 to 0.8 per million population, based on the point of highest ambient air concentrations in a residential area.

Much uncertainty exists regarding how and why dioxins, furans, and other PICs are formed in high temperature incinerators and other combustion devices. The test burn report prepared for EPA as part of the Regulatory Impact Analysis suggests three mechanisms may account for the presence of PICs:

- o Actual products of combustion reactions, whether from specific organic precursors, or a complex series of reactions of oxygen, carbon, and chlorine atoms.

- o Compounds detected in the stack which were present in the waste feed at levels just below the cut-off used for waste feed analysis.

o Compounds introduced to the system from some outside source such as the scrubber water, in leak air, and auxiliary fuel.

For all of the incinerators tested, the combustion reaction alternative appears to account for the vast majority of PICs. In general, the report concluded that stack gas concentrations of PICs were typically as high as the concentration of POHCs detected in the stacks, but rarely exceeded 0.01% of the POHC input rate. Of the six sites tested for chlorinated dioxins and furans, dioxins were found at one site and furans at three. Maximum concentrations were 0.06 ng/L of furans and 0.02 ng/L of dioxins.

4.5.2 Ocean Incineration

In previous ocean test burns, EPA found only trace amounts of dibenzofurans, and in one instance, dioxin at 0.09 nanograms per cubic meter. Other potential PICs were not investigated.

4.5.3 Issue

The identification and measurement of potentially harmful PICs has become an issue for a wide range of combustion sources including land-based and ocean incineration. PIC emissions may be significant because, although they have been identified in very trace quantities, they are also some of the most toxic materials known; i.e., dioxins and furans.

Critics of the Vulcanus permits believe that the ocean program should pay greater attention to PICs. The ocean incineration regulations will address the issue by requiring that more research be done on identifying and analyzing PIC emissions during research burns.

The RCRA program and ORD are also continuing research into factors affecting PIC formation and control, and their impacts on the environment. Because studies to date indicate that reported levels of PICs from well operated hazardous waste incinerators present very low risks, EPA has not regulated PICs.

4.6 Variables Affecting Combustion

4.6.1 Land-based Incineration

Incineration theory traditionally identifies four factors critical for efficient incineration: sufficient oxygen, and the three "Ts" of time, temperature and turbulence. The wastes must be exposed to a temperature high enough to allow complete oxidation of the organic materials, they must have adequate time exposed to the hot temperatures, and they must be mixed well enough to ensure that each molecule is exposed to enough oxygen molecules to allow complete oxidation. Temperatures are usually measured by a thermocouple in the combustion wall or in the gas stream. Residence time is normally estimated based on combustion chamber volume, temperature, and combustion gas flow rate in the system. Turbulence is more difficult to measure, and practitioners have not reached general agreement on a turbulence parameter.

When EPA first began to regulate incinerators, it specified conditions, such as particular minimum values for temperature, residence time, and oxygen (measured by "excess O_2 in the stack"). This approach is reflected in the TSCA Annex I regulations (May 1979) for incineration of liquid PCBs, as well as the provisions of the London Dumping Convention technical guidelines. The RCRA incinerator regulations were originally proposed with specified operating conditions, but this approach was abandoned in favor of performance standards with operating conditions specified on a permit by permit basis. One of the major reasons for the performance standards approach under RCRA was the growing recognition that not enough is known about how design and operating parameters affect performance for EPA to specify those parameters in a definitive way.

4.6.2 Ocean Incineration

The Vulcanus incinerators operate in the temperature range of 1166°C to 1600°C, with a residence time on the order of one second, and excess oxygen in the 5-15 percent range. In establishing operating conditions in the proposed permits, EPA's Office of Water has relied primarily on the RCRA performance standard approach. However, minima for wall temperature, oxygen in the stack gas, and CE, a maximum for carbon monoxide in the stack gas, and residence time requirements are also established, as those are required under the London Dumping Convention Incineration Regulation and Technical Guidelines. Separate operating requirements and a DE performance standard are set for wastes containing PCBs.

4.6.3 Issue

In this area, the primary issue has been the adequacy of the one-second residence time achieved by the Vulcanus incinerators. Some commenters feel this provides inadequate combustion time for PCB wastes, which are subject under TSCA regulations to a 2 second residence time at Vulcanus operating temperatures. EPA's view is that the capability of the ocean incinerators is best measured directly through performance by destruction efficiency, under operating conditions established during trial burns as under the RCRA regulations. EPA believes its experience with a wide range of test burn data under the TSCA program shows that a residence time of two seconds is not necessary for adequate PCB destruction.

Under the RCRA program, permit operating conditions are based on actual conditions achieved during the trial burn, and therefore, are not a major issue. Under the TSCA program, minimum temperature and residence time are required, but the operating parameters may be waived if a 99.9999 percent destruction efficiency is achieved during a trial burn. In practice, the TSCA program has provided waivers for several incinerators achieving the required destruction efficiency, but with dwell times less than the 2 seconds specified in the regulation. All of the land-based waivers have been for existing on-site incinerators with low concentrations of PCBs in their waste feed; no commercial, off-site incinerators have received waivers.

5. SAMPLING AND MONITORING

This section provides an overview of sampling and monitoring requirements and procedures for both land-based and ocean incineration. Issues raised with regard to specific procedures are also covered.

5.1 Sampling and Monitoring Procedures for Land-Based Incinerators

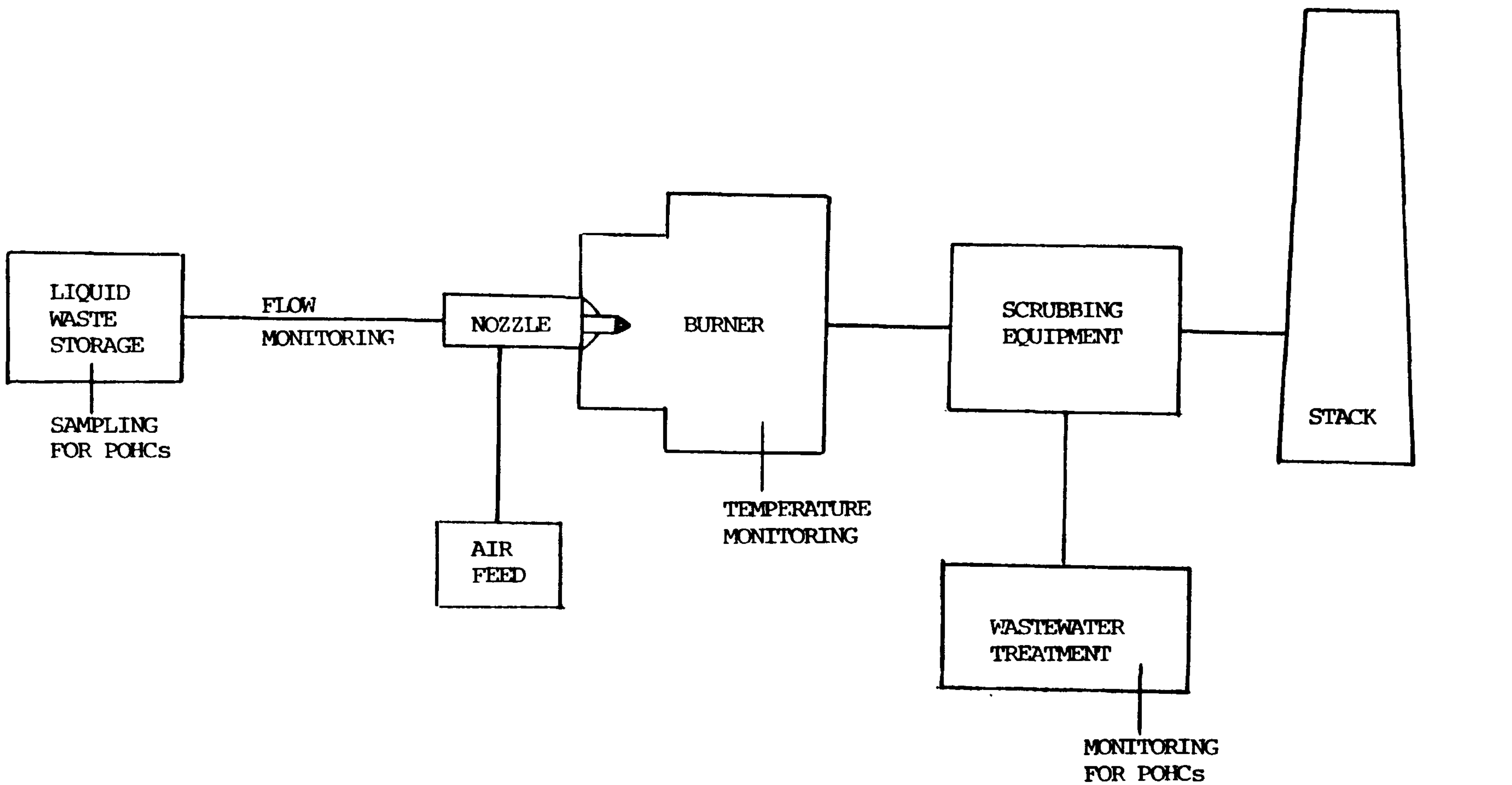
Sampling techniques and analysis methods for incinerator emissions used for the trial burn are generally taken from EPA recommended methods found in 40 CFR Part 60 Appendix A - Methods 1-5, and Test Methods for Evaluating Solid Waste: Physical/Chemical Methods (SW-846, Second Edition, July 1982), or in the EPA document, Sampling and Analysis Methods for Hazardous Waste Combustion (Arthur D. Little, Inc., EPA-600/ 8-84-002, February 1984).

Typical sampling and monitoring locations for a liquid injection incinerator are indicated in Figure 5.1. Comprehensive sampling and monitoring during the trial burn are essential for documenting compliance with the performance standards and developing the conditions of the permit. Sampling and monitoring data from the trial burn must be sufficient to provide for:

- o quantitative analysis of the POHCs in the waste feed to the incinerator;
- o quantitative analysis of the stack exhaust gas for the concentration and mass emissions of the POHCs
- o quantitative analysis of the scrubber water, ash, and other residues for the POHCs;
- o computation of destruction and removal efficiency (DRE);

Figure 5.1

SCHEMATIC DIAGRAM SHOWING TRIAL BURN MONITORING LOCATIONS FOR A LIQUID INJECTION INCINERATOR



- computation of HCL removal efficiency (if emissions exceed 1.8 kilograms per hour);

- computation of particulate emissions;

- identification of sources of fugitive emissions;

- average, maximum and minimum combustion temperature and gas velocity;

- continuous measure of carbon monoxide (CO) in the exhaust gas.

5.1.1 Routine Sampling and Monitoring

Following the trial burn, the facility receives a permit for ongoing operations which specifies waste analysis and monitoring requirements. Routine waste analysis requirements will vary for different facilities. For example, an incinerator that only burns wastes generated from one manufacturing process may have less stringent requirements than a commercial incinerator that burns wastes from a variety of sources. A waste analysis plan must be developed which allows for periodic verification that the waste feed is within permit-specified physical and chemical composition limits.

RCRA permits require continuous monitoring for temperature, carbon monoxide, waste feed rate and combustion gas velocity.

5.1.2 Automatic Waste Feed Cutoff

An automatic waste feed cutoff system is required to shut off waste feed to the incinerator whenever certain operating parameters deviate from the limits set in the permit. To accomplish this, the cutoff valves are interlocked to all of the required continuous monitoring devices (temperature, carbon monoxide, waste feed rate and combustion gas velocity). For each operating parameter, the permit should establish a range of operation and a level, somewhat beyond that range, at which the emergency waste feed cutoff system must be activated. The permit writer generally selects the ranges on the basis of trial burn data. At least weekly testing of the cutoff system is required.

5.1.3 Ambient Monitoring

Under RCRA and TSCA, no ambient monitoring is required for land-based incinerators. All routine monitoring is for stack emissions. In some cases, states may require ambient monitoring under the Clean Air Act.

5.1.4 Issue

The land-based hazardous waste incineration program does not require ambient monitoring. EPA's risk studies indicate that if stack emissions are verified to be within regulatory limits, human health and environmental impacts will be very small. Additionally, in many locations accurate and reliable testing for ambient air effects around land-based incinerators is not feasible due to extremely low concentrations and interference from other industrial activities.

5.2 Sampling and Monitoring Procedures for Ocean Incineration

During the ocean trial burns, sampling and analysis of stack gases to determine the DE on POHCs and in determining emission levels of PICs must be done according to EPA sampling and analysis methods described in 40 CFR part 60. Sampling techniques and analysis methods for wastes are taken from Test Methods for Evaluating Solid Wastes (SW-846, Second Edition, July 1982) or Sampling and Analysis Methods for Hazardous Waste Combustion (Arthur D. Little, Inc., EPA-600/8-84-002 February 1984). During routine burning operations, CE is used as the measure for gauging incinerator performance. Continuous monitoring of wall temperature, oxygen, carbon dioxide, carbon monoxide, waste flow, and air flow to the combustion chamber is required.

5.2.1 Automatic Waste Feed Cutoff

Automatic waste feed cutoff devices are linked to minimum wall temperature, flame-out, minimum oxygen in combustion gas, maximum carbon monoxide in combustion gas, and failure of monitoring devices for temperature, air flow, oxygen in combustion gas, carbon monoxide in combustion gas, carbon dioxide in combustion gas, and waste and auxiliary fuel flow. As with land-based incinerators, the ocean permits establish the level at which the cutoff system is activated.

Instrument calibration and testing according to manufacturer's specifications is required before each cruise for devices measuring carbon monoxide, carbon dioxide, oxygen, wall temperature, waste flow and auxiliary fuel, and air flow as well as for the waste feed cutoff system.

5.2.2 Ambient Monitoring

Environmental monitoring studies have been conducted to varying degrees during past ocean burns. In these studies, EPA has not been able to detect any increase in background levels of PCBs, dioxin, or POHCs in the ambient air, water or marine biota samples collected. Proposed regulations will require comprehensive environmental monitoring studies to be conducted by applicants prior to issuance of permits.

5.2.3 Other Monitoring

Other monitoring requirements include keeping records of times and dates of burns, wind speed and direction, and vessel position, course, and speed.

5.3 Issues

Table 5.2 recaps the issues that have been raised by critics of ocean incineration regarding sampling and monitoring procedures carried out during past ocean burns. The most significant issues are discussed in further detail in the following sections.

5.3.1 Stack Gas Sampling

In past burns EPA has required that stack gas be sampled using methods consistent with 40 CFR part 60 methods for sampling stationary sources. The best method is acknowledged to be the sample/velocity traverse. The traverse calls for a sampling probe to be inserted in the stack and moved horizontally along two perpendicular diameters. Samples are to be collected at twelve points along each diameter. Each sampling point is indicative of an equal cross-sectional area of the stack from the center of the stack outwards. Thus the time that the sampling probe collects from each point is equal.

Partial stack traverses have been done on two series of burns. Critics have pointed out several inadequacies in conducting them which they charge have resulted in inaccurate measures of incinerator performance. Moreover, the results of the traverses have been used by EPA as a basis for determining that a fixed point sampling method could be used in subsequent burns. This method calls for the sampling probe to be inserted at a single stack location thought to provide the most representative sample of stack gas. Again, critics charge that there is inadequate data from the traverses to select a fixed point, and, thus, measurements from the fixed point have not yielded data that is representative of emissions.

A constraint that has inhibited stack traversing on the M/T Vulcanus I is inherent in the method of sampling itself. The method was originally devised for stationary, land-based sources where the flow regime (i.e. laminar vs. turbulent) was unknown. For land-based incinerators with scrubbers, combustion gas is cooled and slowed down, making stack traversing an easier operation to carry out. Moreover, working conditions on a short stack emitting hot gases on a continuously moving vessel make it more difficult to physically carry out this method at sea.

TABLE 5.2 Issues Raised With Regard to Sampling/Monitoring Procedures of Ocean Burns

CATEGORY	ISSUE	EPA RESPONSE
1) STACK GAS SAMPLING	° Traversing procedures are inadequate because they have only been done on one diameter; probe hasn't sampled all points; some traverses not done in a horizontal plane resulting in ambient air diluting pollutant concentrations; and wall area not sampled in sufficient proportion to offset lower CE in that region.	° In proposed regulations, EPA will require that conclusive traverses be carried out.
	° One point sampling has shown wide range of gas composition data. Does not give an accurate representation of emissions.	° EPA believes that a conclusive traverse may provide justification for future fixed point sampling.
	° Flow disturbances within the incinerator are a factor in choosing location of fixed point probe.	° EPA believes flow disturbances not a factor in ocean incinerator design.
	° Stack gas sampling only conducted on one incinerator. Can't assume that all incinerators operate equally.	° EPA position is that for incinerators of equal design on the same vessel, it is only necessary to monitor one for DE. During routine operations however, all incinerators will be required to monitor for operating parameters.
	° Teflon tubing causes the loss of PCBs, thereby giving erroneously high destruction efficiencies.	° EPA believes Teflon as good as glass for PCB recovery.
2) SAMPLING FOR PARTICULATES	° Unburned POHCs and PICs may be in stack emissions adsorbed to solid minute particulate matter or to droplets. Should perform isokinetic sampling to measure for particulate matter.	° EPA believes that pure isokinetic sampling cannot be done in ocean incinerators because of non-laminar flow. EPA also believes that at elevated temperatures, POHCs and PICs are not attached to particulates, but rather exist as free vapors. To confirm this, proposed regulations will require isokinetic sampling which will be appropriately modified for consideration of ocean incineration charcteristics.

Cont'd

CATEGORY	ISSUE	EPA RESPONSE
3) WASTE FEED RATE MEASUREMENT	° Waste feed rate cannot be measured effectively by soundings in the vessel's tanks because of the ships motion, thus DE analysis is inaccurate.	° EPA believes that soundings provide at least as accurate a measure of waste feed rate as do flow meters, however proposed regulations would require continuous waste feed monitoring using flow meters in subsequent burns.
4) WALL TEMPERATURE	° Thermocouples to measure temperature are improperly located, have given erratic readings, have not shown that uniform heat distribution exists and don't give adequate measure of combustion zone temperature.	° Proposed regulations would require minimum incinerator temperature for purposes of automatic waste feed shutoff and accurate devices to measure and record. Permit writer will determine whether temperature and measurement devices are adequate.
5) MEASURING FOR PRODUCTS OF INCOMPLETE COMBUSTION (PICs)	° More emphasis should be placed on identification of possible organic compounds produced and emitted during ocean incineration.	° Proposed regulations would require a more complete identification and quantitative analysis on stack emissions for PICs during research burns.
6) AIR FLOW MEASUREMENT	° Air flow monitoring, which allows residence times to be measured, has not been adequate in several burns.	° EPA will require air flow to be measured but does not believe it is a critical factor in determining DE on POHCs.
7) AMBIENT MONITORING	° Past environmental studies were inadequate. More study is needed to determine effects of emissions on ambient air, water and marine biota.	° EPA will require comprehensive environmental studies in future permits to better determine effects of emissions.

Critics have also claimed that flow disturbances within the incinerator will affect measurements taken from a fixed point probe. EPA maintains that flow disturbances are irrelevant because of the turbulent gas swirl characteristic of ocean incinerator design.

After reviewing the public comments, EPA has concluded that the basis for choosing the fixed point sampling location was adequately demonstrated during previous stack traverses. However, because of the many comments received expressing concern on this issue, conclusive traversing of the stack would be required under the currently proposed regulations.

5.3.2 Sampling for Particulates

Critics have said that surviving POHCs and PICs may be emitted from stacks by adsorbing on minute solid particulate matter such as ash, metals or from thermal corrosion of firebrick. They claim that isokinetic sampling should be done to quantify particulates in order to provide a more complete measure of DE. EPA believes that at elevated temperatures, virtually all POHCs and PICs exist as free gaseous molecules or vapors, and as such are adequately monitored using standard traversing procedures. However, to confirm this to the extent possible, EPA proposed regulations would require that quantitative samples be collected using isokinetic sampling which will be appropr imately modified for consideration of ocean incineration characteristics.

* * * * *

This paper presents a comparison of the major technical features of land-based and ocean incineration. Our objectives are to provide a sound technical background summary and to illuminate areas of controversy by matching key issues with available technical information. The discussion encompasses major design elements, waste handling features, and characteristic emissions from each technology. It does not include an assessment of the human health or environmental impacts of the technologies because that is the primary work of the comparative risk assessment paper.

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