Chapter 6
Ocean Incineration Technology

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EXISTING AND PLANNED VESSELS

Ocean incineration technology has been used on a much smaller scale than has land-based incineration or any other major technology for managing hazardous wastes. Two incineration vessels are currently operating, primarily in Europe;[1] two more are fully or partially built but not yet employed; and plans for constructing others have been offered by several companies. The combined waste handling capacity of all of these vessels could accommodate only a small portion of the hazardous waste generated in the United States.

Generally speaking, a single technology has been used or proposed for ocean incineration. All existing or planned ocean incineration vessels use liquid injection technology, and are intended to incinerate only liquid organic wastestreams. Table 11 summarizes relevant data for all existing, under-construction, and planned incineration vessels. Of these, the only foreign-owned vessel is the German *Vesta,* which operates in the North Sea.

Although all of these vessels share features intended to respond to the unique needs and constraints of ocean incineration, they differ in several important respects. This chapter examines ocean incineration technology and wastestreams, as well as associated aspects of operations, such as requirements for port facilities. The chapter also compares and contrasts the various existing and proposed technologies for ocean incineration. For a comparison of land-based and ocean incineration technologies, see chapter 7.

[1]The two vessels are the Vulcan *us II* and the *Vesta;* the Vulcan us *I* is operational but not currently active.

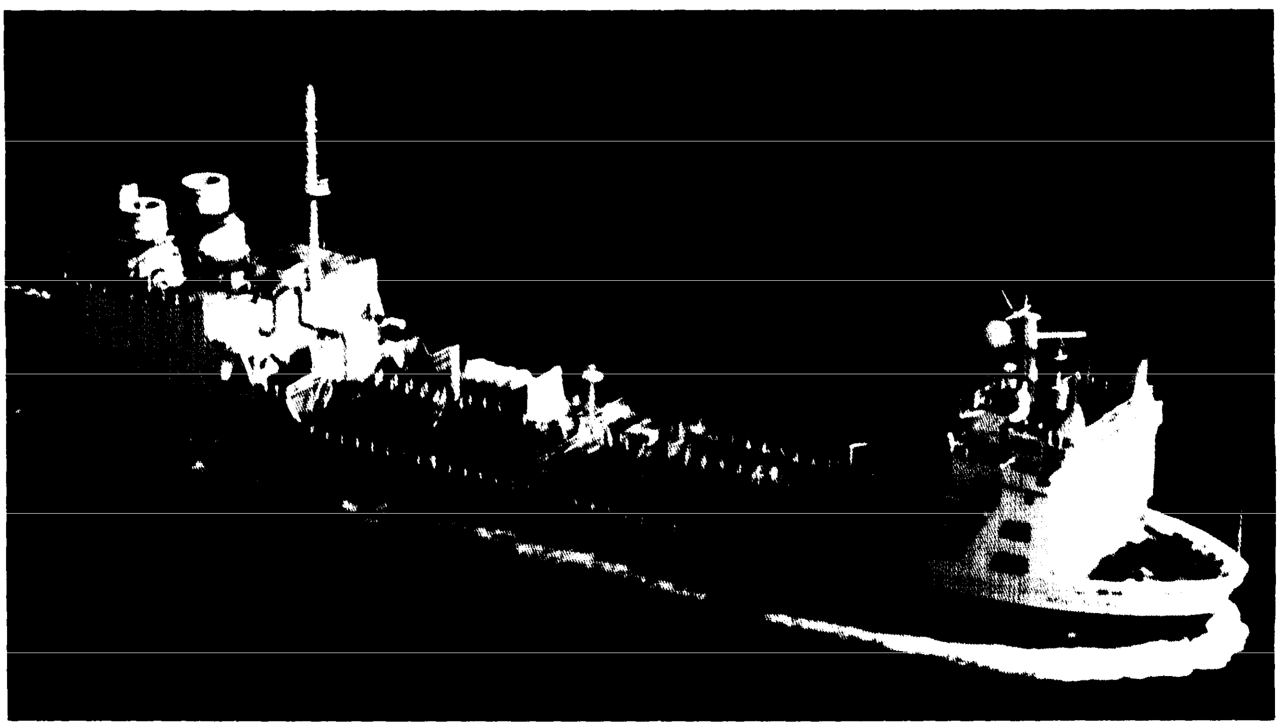

Photo credit: At-Sea Incineration, Inc.

The *Ape//o /* incinerator ship, launched in 1985 but never used for incineration of hazardous wastes.

Table II.-Characteristics of Existing and Proposed incineration Ships

	Vulcanus I	*Vulcanus II*	*Apollo I*	*Apollo II*	SeaBurn vessel	EOS vessel	*Vesta*
Owner/operator	Waste Management, Inc./ Ocean Combustion Services		Tacoma Boat/ At-Sea Incineration, Inc.[a]		SeaBurn, Inc./ Stolt-Nielsen	Env. Oceanic Services Corp.	Lehnkering AG
Current status	Operating in Europe	Operating in Europe	Completed	Under construction	Planned	Planned	Operating in Europe
Type of vessel[b]	Converted cargo ship type II	Incinerator ship type II	Incinerator ship type II	Incinerator ship type II	Oceangoing barge and tug type I	Small supply ship type II	Incinerator ship type II
Number of incinerators	2	3	2	2	4	1	I
Incinerator orientation	Vertical	Vertical	Vertical	Vertical	Horizontal	Horizontal	Vertical
Burner type	Rotary cup	Rotary cup	Air nozzle	Air nozzle	Steam nozzle	Steam nozzle	Rotary cup
Cargo mode	8 tanks below deck	8 tanks below deck	12 tanks below deck	12 tanks below deck	144 containers (stainless steel intermodal containers stored above deck)	16 containers	9 tanks below deck
Total capacity (× 1,000 gal)	800	800	1,300	1,300	720	80	290
Waste feed rate (gal/hr)	3,300	4,950	5,500	5,500	3,240	?	≈ 2,640
Full load burn time (days)	10.1	6.7	9.9	9.9	9.3	?	4.6
Emission controls	—	—	—	—	Seawater quench/scrubber		—
Required infrastructure	Existing	Existing	Integrated	Integrated	None	None	Existing

[a]Tacoma Boat is currently reorganizing under Federal Bankruptcy Laws; At-Sea Incineration, Inc., defaulted on payment of guaranteed loans initially granted and recently paid off by the U.S. Maritime Administration.

[b]Type II chemical tankers must have double hulls and double bottoms, and must store wastes in several different compartments to reduce cargo loss in the event of an accident. Design standards for type I vessels include these and additional requirements. The proposed Ocean Incineration Regulation (50 FR 8225, Feb. 28, 1985) and U.S. Coast Guard regulations (46 CFR 172) require that incineration vessels be at a minimum type II.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report 1: Description of Incineration Technology," *Assessment of Incineration as a Treatment for Liquid Organic Hazardous Wastes* (Washington, DC: 1985); and W. Lankes, "Incineration At Sea: Experience Gained With the M/T Vesta," in Wastes *in the* Ocean, vol. 5, D.R. Kester, et al. (eds.) (New York: John Wiley & Sons, 1985), pp. 115-124,

WASTESTREAM CHARACTERISTICS

Typical liquid hazardous wastestreams are complex mixtures of many chemical compounds. For ocean incineration in particular, most shiploads are expected to consist of heterogeneous mixtures derived from several or many sources and processes. Wastestreams are usually characterized with respect to a number of parameters. The viscosity of the waste must be sufficiently low to allow it to be pumped and introduced into the incinerator in small droplets. The heating value (i. e., energy content) of the waste feed must be sufficiently high to heat incoming waste to its ignition temperature, to provide the energy needed for oxidation, and to maintain combustion. The heating value of a waste generally decreases as water content increases and as the proportion (percent by weight) of chlorine present in organic compounds increases. Therefore, liquid wastes are usually blended to produce optimum values for energy content, chlorine and water content, and viscosity. Virtually all wastes, even relatively homogeneous ones, require some blending before incineration to ensure proper consistency and flow.

INFRASTRUCTURE AND LOGISTICAL SUPPORT SYSTEMS

The various ocean incineration vessels differ in how much they rely on waste preparation, storage, handling, and transfer facilities on shore. Three general categories of logistical systems have been identified (7,8).

No-Infrastructure System

Under this system, waste handlers make minimal use of fixed facilities. Wastes accumulate where they are generated or handled, stored in truck or rail tanks or in portable containers. When full, the tanks or containers are transported to existing port transfer facilities not dedicated solely to ocean incineration operations. Wastes are pumped or are lifted in containers onto the vessel. Any blending of wastes from different sources occurs only on board, as they are fed to the incinerator. Wastes from different storage tanks are fed sequentially or simultaneously, to provide the best burning mixture.

SeaBurn, Inc., and Environmental Oceanic Services Corp. plan to use a variant of this design. They would use the sealed 5,000-gallon stainless steel intermodal containers (see discussion of containerization below) to transport wastes from their sources to the the vessel, avoiding the need for any dockside handling of uncontainerized wastes.

Existing Infrastructure System

Under this system, waste handlers use port facilities not dedicated solely to ocean incineration. Blending, preparation, and storage functions are carried out at existing, centralized facilities that are entirely separate from the port facility.

Waste Management, Inc., plans to employ such a system (or to develop an integrated system; see below) to support *Vulcanus* operations in the Gulf. Under the existing system, liquid wastes would be transported from generators to its testing, blending, and storage facility at Emelle, Alabama. Blended wastes would be loaded onto trucks for transport to dockside, and then pumped directly from the trucks to the vessel.

Integrated System

Under this system, waste handlers use specialized port facilities designed primarily for ocean incineration. The facility receives wastes directly from generators and maintains onsite testing, blending, and storage capability for both containerized and tanked wastes.

At-Sea Incineration, Inc., proposed using such an integrated port facility to support operation of its *Apollo* vessels. Waste Management, Inc., is considering developing such a facility, in lieu of or in addition to its existing facility at Emelle, Alabama.

TECHNICAL COMPARISON OF DESIGNS FOR OCEAN INCINERATION

One major theme of the debate over ocean incineration is whether a *best-available-technology* (BAT) approach is needed or desirable and, if so, whether existing vessels represent BAT (see ch. 2). The various designs for ocean incineration vessels differ in several respects that directly bear on the nature and potential safety of their operations. The Environmental Protection Agency has not yet thoroughly evaluated the various designs; such an evaluation must be undertaken if the BAT question is to be resolved.

Given its limited mandate in this study, OTA has *not* attempted to develop a comprehensive comparative evaluation. Rather, the following discussion identifies particular design and performance features that would probably be central issues in such a comparison. By reference to table 11, the specific vessels to which this discussion applies can be identified.

Containerization Versus Bulk Storage and Transfer

The most obvious difference between existing and proposed designs for ocean incineration systems is how cargo is handled and transferred. Two companies have proposed systems based on a containership concept that would employ 5,000-gallon stainless steel intermodal tank containers. Intermodal (IM) containers are increasingly used for all types of cargo throughout the world. An estimated 20,000 IM tank containers designed specifically to carry liquid commodities are in use worldwide (3). As the name implies, IM containers can be transported via rail, truck, barge, and ship. Standardized twistlock mechanisms on containers and on vehicle chassis are designed to ensure that containers are adequately secured during transport.

In specifically applying the containership concept to ocean incineration, waste generators or handlers would fill and seal tank containers and would transport them by truck or rail to port facilities for loading onto barges or ships. No blending or other handling of waste would occur at the ports. IM tank containers would be mounted on or above deck and their wastes individually pumped to a feed tank directly connected to the incinerator. Following cleaning, tank containers would be returned to generators for further use.

The containership concept differs from existing ocean incineration systems, which use more conventional tank trucks and tank farms for land transportation and storage, and large bulk tanks (about 100,000 gallons each) to hold waste onboard the vessels. As described above, waste blending and transfer facilities on land are an essential link in such systems.

The relative advantages and disadvantages of these two approaches need to be evaluated for all phases of incineration operations, beginning with waste generators and ending with handling during and after shipboard incineration. Advantages and disadvantages of IM containers are discussed below, for each of several phases of incinerator operation: land transportation, handling, and transfer; marine transportation; and waste incineration. First, however, the reader must recognize several assumptions that apply to this analysis.

In the following discussion of advantages and disadvantages, the intermodal approach is implicitly compared with the more conventional bulk handling system used by all existing incineration vessels. It is important to recognize that particular features of an individual company's operation may greatly affect the extent to which these advantages or disadvantages are applicable. The discussion is therefore oriented towards a ''generic' operation, and wherever possible, relevant information specific to a particular operation is also presented.

In addition, both the bulk and intermodal tank approaches to handling hazardous cargoes are already widely used. The U.S. Coast Guard believes that both approaches can be, and are being, carried out safely under appropriate regulation. The Coast Guard has further indicated that solutions are available to the problems that are identified below, and can be addressed through proper regulation, thereby rendering both approaches fully viable.[2] The intent of the discussion, therefore, will

[2]These comments were received through the review of a draft of this report by the U.S. Coast Guard.

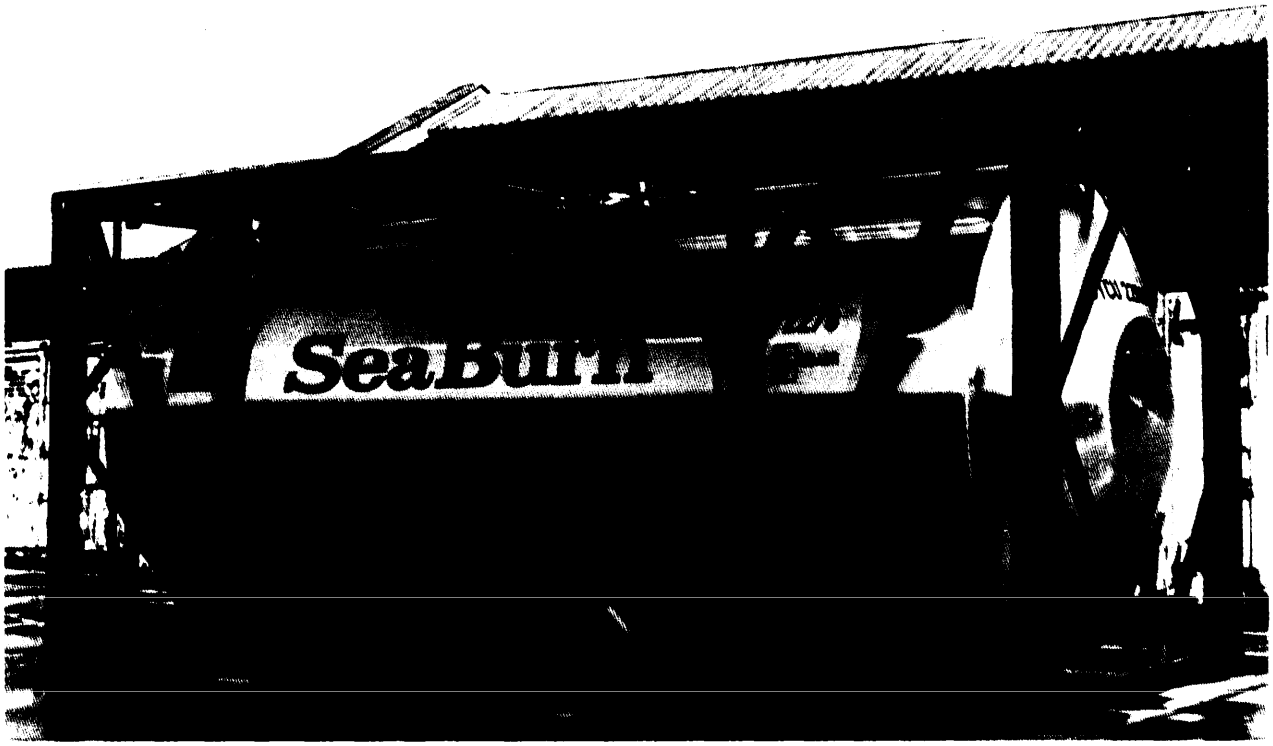

Photo credit: SeaBurn, Inc.

Stainless steel intermodal tank containers, which typically carry about 5,000 gallons, can be transported via rail, truck, barge, or ship. The supporting framework reduces the risk of breaching the tank in the event of an accident and provides for securing of the tank to specially designed chassis during transport.

be to point out features of each approach that are advantageous or that may require additional regulation in order to ensure safe operation.

Land Transportation, Handling, and Transfer

Advantages:

- Tank containers are sealed at the site of generation and before any transportation, so that wastes do not need to be transferred later on land or at the port.
- The intermodal nature provides for flexibility in transport, because IM tank containers can travel to port facilities by truck, rail, or barge.
- No special facilities are required at the port, and individual IM tank containers can be stored still attached to their chassis while awaiting the arrival of the incineration vessel, facilitating their movement in the event of an emergency.
- The IM tank container is encased in a rigid metal protective frame that substantially reduces the risk of breaching the tank in the event of a rail, highway, or terminal accident.
- A large and growing international network for handling and transporting IM containers is available.
- Wastes from different generators are not mixed or blended before they are incinerated, allowing the identity and source of a waste to be traced in the event of a spill.

Disadvantages. —Although there appear to be several clear advantages with respect to the IM tank container itself, transport of these containers, particularly by truck, poses several problems.[3] These problems are related primarily to the fact that there is an insufficient number of chassis designed to

[3]Another OTA assessment (9) examines hazardous materials transportation in detail and evaluates the relative safety, performance, and regulation of intermodal and other bulk liquid containers. Much of the discussion of land transportation using IM tank containers presented here is drawn from that analysis.

transport IM tank containers in a manner that maximizes over-the-road stability and complies with bridge laws that limit the vehicle weight per axle and per wheelbase.

- The chassis most commonly used today that is designed specifically to carry IM containers is 20 feet in length and equipped with corner twistlocks; however, for most liquids, a fully loaded IM tank container mounted on such a chassis violates bridge laws in most States. The option of partially filling the tank is not viable, since it can lead to sloshing of the liquid contents and instability on the road. Use of a 40-foot chassis with the IM tank container centrally mounted using twistlocks solves these problems; however, the number of such chassis (estimated to be only about 400 in the entire United States) is far less than the number of IM tank containers currently in use.
- The size, shape, and height of IM tank containers are such that, even when mounted legally on the standard 20- or 40-foot chassis, they can be inherently unstable: the high center of gravity greatly increases the potential for roll-over. A specially designed IM chassis called a "low boy' addresses this concern, and is widely used in Europe, but fewer than 100 of these chassis (40-foot, center-mount, and low boy) are in use in the United States.
- Although the number of standard 20-foot chassis possessing twistlock mechanisms is sufficient to accommodate the IM tank containers currently in use in the United States, their use on the highway violates bridge laws in many States. This situation commonly results in the transport of IM tank containers on flatbed trucks, "secured' by wrapping with chains. This practice is entirely legal under current Department of Transportation regulations, even though it has been denounced by some trucking industry representatives and has resulted in a number of accidents involving hazardous materials (for example, see ref. 2).

These problems appear to have a straightforward technical solution: required use of 40-foot low boy chassis for over-the-road transport of loaded IM tank containers. Indeed, SeaBurn, Inc., has indicated that it plans to use the 40-foot low boy chassis. SeaBurn intends to have a sufficient number of these chassis manufactured to support its operation, and to dedicate these chassis exclusively to such use in order to preclude unauthorized methods of handling its IM tank containers.

Marine Transportation

The containership concept appears to offer several advantages over bulk transport in the marine transportation phase of ocean incineration. The advantages include the following:

- The relatively small volume of waste in each container should limit the size of a spill in the event of an accident. Many individual tank containers would have to rupture to approach the size of a release that could be expected from the rupture of one large bulk cargo tank.
- Because individual IM tank containers could be relatively easily salvaged, they would facilitate the retrieval of waste lost overboard.
- IM tank containers would be stowed above deck, and hence above water line. In addition, an on-deck spill collection system will be utilized, These features would facilitate inspection and leak detection and would reduce the likelihood that leaks would contaminate bilge water or the marine environment. The greater ventilation above deck would reduce the possibility of explosions caused by buildup of reactive gases.

Waste Incineration

In contrast to the advantages of using IM tank containers with respect to marine transportation, their use may pose significant disadvantages relative to bulk storage when considering the incineration operation itself. These disadvantages are all related to the large number of individual tanks involved:

- Because wastes are not blended before being loaded onto the vessel, a potentially enormous burden of waste analysis maybe involved. Under the proposed Ocean Incineration Regulation, separate sampling and analysis will be required for each of the many individual tanks, before they are accepted by the permittee and again before they are incinerated. Verification by EPA that only permissible wastes are accepted for ocean incineration will become equally burdensome.

- The potential exists for incompatible wastes to come into contact when tank containers are switched. Accurate information regarding the contents of each container and constant control over the sequence in which tank containers are connected for pumping to the incinerator will be essential, to a much greater degree than would be required of the bulk storage approach.
- The reduction in the need for waste handling on land offered by the IM mode is reversed during the incineration operation itself. Frequent container switching (on the order of every few hours) will be required, increasing the potential for spills or exposure of the crew to waste materials.
- Whether and how the frequent switching of containers would affect incinerator performance or necessitate greater surveillance has not been adequately investigated. For example, ensuring consistency in waste destruction efficiency when switching from a high-energy waste to a low-energy waste would probably require adjustments in waste feed rate, use of auxiliary fuel, air flow, and other parameters.

Despite the clear differences between the bulk and containerized modes with regard to handling and incineration, the proposed Ocean Incineration Regulation contains no provisions specifically addressing containerized wastes. Provisions governing tank containers have been developed internationally and are incorporated into the London Dumping Convention's Technical Guidelines for Ocean Incineration.

Again, it is important to acknowledge that technical and regulatory solutions exist, or can be developed, to address the potential problems associated with both the bulk and containerized approaches, and to provide for their use to full advantage. The above discussion is intended to highlight areas where further attention may well be needed, rather than to detract from the merits of either approach. Based on OTA's limited analysis of the containership concept in relation to bulk transport, further study will be necessary to determine whether either approach provides a clearly superior technology for waste handling.

Self-Propelled Versus Barge Vessels

One company has proposed using an ocean-going barge-tug combination for ocean incineration. A total of one hundred and forty-four 5,000 - gallon IM tank containers and up to four incinerators would be mounted on the barge. Such a vessel would have a shallow draft, which would allow it access to virtually any port facility.

Concerns have been raised about the relative safety and maneuverability of a barge system. Unfortunately, data that can be used to evaluate the safety of the type of ocean-going barge proposed for use in ocean incineration are largely unavailable. The U.S. Coast Guard maintains a database that records all reported hazardous materials spills to U.S. waters (10). Data for 1982 and 1983 indicate an accident rate for tank barges double that for tank ships. These data include barges of all types used to carry oil or hazardous substances, however, including those operating on rivers or other inland waters. Indeed, with respect to both the number of accidents and the quantities of material released, the vast majority involved oil released to inland waters. For spills involving *hazardous* substances rather than oil, the number of releases was two-fold higher for tank barges, but the quantities released were actually slightly higher for tank ships.

Several features of the ocean incineration barge proposed by SeaBurn, Inc., should greatly reduce the risk of a release of waste in the event of an accident, and are not reflected in the above statistics. First, the barge would be a Type I chemical tanker, which exceeds the *Type II* cargo containment requirements applicable to ocean incineration vessels.[4] According to SeaBurn, Inc., no other such barges currently exist in the world's fleet. Second, the proposed barge is ocean-going and has a ship's bow, unlike the barges involved in the vast majority of reported accidents. Given these and other features, SeaBurn, Inc., argues that its barge will be in a safety class all its own.[5]

'Coast Guard regulations for chemical carriers specify three levels of cargo containment systems, Type I affording the highest degree of containment. See 46 CFR 172 for a description of these construction requirements.

'V. G. Grey, President, SeaBurn, Inc. , personal communication, May 16, 1986.

As proposed, the SeaBurn barge would be towed behind an ocean-going tug, a feature which somewhat reduces its maneuverability relative to existing ocean incineration vessels possessing bow thrusters. However, the U.S. Coast Guard indicates that a barge-tug system can be operated safely, even in confined areas, particularly when accompanied by the other navigational controls (e. g., a moving safety zone) that are to be applied to ocean incineration vessels.[6]

Despite the factors discussed above, regulations governing construction, inspection, and other aspects of an ocean incineration system employing a towed barge should be carefully examined to ensure that the requirements are adequate and commensurate with those applicable to self-propelled systems.

Seawater Scrubbers

Existing ocean incineration systems are designed to vent combustion gases directly upwards into the atmosphere, which raises concerns about the potential for subsequent adverse impacts on the marine environment and at least the nearest shorelines. As an alternative, two companies have proposed a system in which combustion gases would pass through a scrubber-like device prior to discharge. A deluge of seawater would physically wash the exhaust stream. In contrast to a true scrubber, however, the seawater scrubber would immediately discharge the untreated scrubbing effluent into the ocean. Thus, the scrubber would alter the location and nature, but not the quantity, of the discharge to the marine environment.

A seawater scrubber would alter incinerator emissions in two major respects, by affecting both the partitioning and the temperature of emissions. Each of these differences offers potential advantages and disadvantages (see below).

Although a seawater scrubber would greatly affect the nature of incinerator emissions, data are currently insufficient for determining whether the addition of seawater scrubbers to ocean incineration vessels would provide any improvement over the technology presently employed. Further study may provide a basis for such a determination in the future.

Partitioning of Emissions

A seawater scrubber would divide emission components into two parts: those discharged in the scrubbing effluent; and those not removed through scrubbing and therefore emitted to the atmosphere. Acidic gases (typically hydrogen chloride) would be expected to be mostly neutralized during the wash, because of the natural buffering capacity of seawater. Any residual acid would be rapidly neutralized after the effluent was discharged to the ocean. In addition, during the scrubbing, some of the particulate and organic components of the emissions would become dissolved or become suspended in the effluent.

A seawater scrubber would significantly reduce the quantity of contaminants emitted to the atmosphere, but would discharge contaminants into the ocean at much higher concentrations than those resulting from contact of an unscrubbed plume with the ocean surface (12).

Plans call for the scrubbing effluent to be discharged directly into the wake of the vessel to maximize mixing and dispersion of trace contaminants. Being warmer than ambient seawater, however, the scrubbing effluent would tend to remain at, or rise to, the surface (12). The potential for these concentrated and heated discharges to affect surface-dwelling organisms (including the so-called microlayer; see ch. 9) has not been examined.

In contrast, emissions from vessels not employing seawater scrubbers would disperse and settle out over the ocean surface, affecting a larger area, but introducing contaminants at lower concentrations.

Temperature of Emissions

Seawater scrubbers would also quench (i.e., cool) exhaust gases, reducing their exit temperature from about 2,5000 F to below 3000 F. This would have two practical effects on incinerator emissions. First, the plume would be less buoyant and would, therefore, not rise as far above the ocean surface. This effect would tend to decrease the time required for the plume to settle on the ocean surface, thereby decreasing the size of the affected area, but also in-

[6] These comments were received through the review of a draft of this report by the U.S. Coast Guard.

creasing concentrations at the surface. As indicated previously, this increase in the concentration of incineration products would be expected to exert relatively greater effects on surface organisms residing in the smaller affected area.

Second, because sampling of stack gases is complicated by the high exit temperatures as well as by the corrosivity typical of ocean incineration emissions, a scrubber might help to simplify emissions monitoring and reduce damage to sampling devices. On the other hand, sampling of emissions for particulate (see ch. 7) could become more difficult or impossible, because particulate might be washed out of the plume before they could be sampled. Significant quantities of unburned wastes or products of incomplete combustion (PICs) can be bound to such particulate after exhaust gases hav'e cooled or condensed (1). In the absence of corrective measures, this effect could significantly compromise the reliability of sampling for the purposes of calculating a destruction efficiency.

Clearly, further research into the advantages and disadvantages of seawater scrubbers will be necessary to determine whether they represent best available technology. As discussed in chapter 1, based on available information, there appears to be little need for scrubbers on ocean incineration vessels if proper controls are placed over waste content and operating conditions.

Combustion Chambers

Existing and proposed technologies also differ with respect to the design and orientation of the combustion chamber itself. Existing vessels carry vertically mounted single-chamber incinerators, whereas two proposed designs would use horizontally mounted two-chamber units.

Proponents of the horizontal orientation argue that it is the only design that could accommodate a seawater scrubber and two combustion chambers, and that the design would also help to reduce plume altitude. Passage of wastes through two combustion chambers should at least theoretically increase residence time and enhance destruction efficiency. However, confirmation of these claims must await the development and testing of such an incineration vessel. Moreover, because two chambers are not considered necessary to achieve high destruction efficiencies of liquid wastes in land-based incinerators (see ch. 2), requiring their use in ocean incineration appears premature. Although EPA's reliance on performance rather than design standards does not negate the need for further investigation into combustion chamber design, it represents a reasonable regulatory approach at the present time.

Burner Types

Incinerator burners serve several important functions, including atomization (i. e., fine droplet formation) of wastes. The degree of atomization can be an important determinant of overall destruction efficiency because it affects the mixing rate of waste and air in the combustion zone. The ocean incineration vessels that are currently operating employ a traditional European-designed burner that atomizes incoming waste using a mechanical device (rotary CUP or vortex). Those vessels recently built or planned for construction in the United States would use a U.S.-designed spray nozzle injection system for atomization. According to EPA, most land-based incinerators in the United States also employ the spray nozzle design (11).

Although the mechanical design for atomizing wastes is allowed by EPA, considerable controtersy exists over the adequacy of its performance. Critics argue that the use of rotary cup burners is being discontinued or even prohibited because of' insufficient atomization and excessive .sensitivity to operating conditions like waste feed rate and vibration (see refs. 4 and 5, and other references therein). Proponents argue that studies specifically designed to assess the performance and degree of atomization of mechanical burners have found them comparable to other designs (1), and that the very short flame length generated by mechanical burners yields high combustion efficiencies (6).

According to EPA, insufficient data exist to correlate burner design with incinerator performance. Because burner design is only one of many factors (e. g., operating conditions, combustion chamber geometry) that affect incinerator performance, EPA has chosen to rely on performance rather than design standards in formulating both land-based and ocean incineration regulations (1 1). Thus, although further study of this issue is warranted, no consensus currently exists as to the best available technology for atomizing waste.

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