Chapter 8
Environmental Releases From Ocean Incineration

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Incineration is a technology primarily intended to *destroy* hazardous wastes. However, as with any hazardous waste technology, each phase of operation has at least the potential to release waste or waste products into the environment.

A full quantitative analysis of the magnitude and probability of releases from incineration is not possible, primarily because insufficient data exist on which to base such an analysis. This chapter first comments on these data limitations and then describes the nature of releases associated with ocean incineration. It then presents and analyzes available data on the probability of such releases occurring, and compares these risks with those from similar activities (i. e., land-based incineration, marine transportation of hazardous materials, and additional sources of marine pollution).

The chapter ends with a summary and comparative discussion of the total releases expected from land-based and ocean incineration. This summary ties together the large amount of information presented in the chapter and provides an overview that may suffice for readers who do not wish to explore the subject in detail.

DATA LIMITATIONS

Any discussion of risks arising from land-based and ocean incineration is greatly hampered by a lack of data on many key aspects. This chapter often refers to such data gaps, particularly those cited by EPA's Science Advisory Board. Significantly, our understanding of risks from both land-based and ocean incineration is comparably constrained by this lack of needed data. Indeed, many of these data gaps apply to many or all other hazardous waste management technologies as well.

Without sufficient data, a very large degree of uncertainty taints all of the risk calculations and some of the overall conclusions, as well. At the same time, given the truism that no method for managing hazardous wastes is risk-free, the most important information is that which provides for a comparative assessment of risks. Although this task is difficult and by no means free of uncertainties, an evaluation of relative risk can be developed now and subsequently refined as the information base improves.

For ocean incineration, data with which to assess the potential for both accidental and routine releases are particularly scant, in part because of the relative lack of experience with this technology (at least in the United States). This necessitates a reliance on indirect historical data for such releases (i.e., data collected for related activities such as hazardous materials transportation). In addition, the lack of experience has provided only limited opportunities to collect data on routine releases occurring under a wide range of operating conditions.

[1]OTA has examined the risks involved in transporta(;on of hazardous materials, including waste (19).

TYPES OF ENVIRONMENTAL RELEASES

Environmental release of waste from incineration operations can occur as a result of accidents, such as vessel or truck collisions, leaking tanks, or upsets in incinerator operation. Releases can also result from normal or routine operations, when, for example, small fractions of unburned waste are emitted from incinerator stacks or waste or residual ashes are handled. A full analysis of the envi-

ronmental effects of land-based and ocean incineration will ultimately require that both kinds of releases be characterized and quantified.

Several important distinctions can be drawn between these two types of events.

Accidental releases are not predictable with respect to time or place, although historical data can be used to develop estimates of their probability of occurrence. For events that occur relatively often, as do, for example, vehicle accidents, historical data can provide accurate risk estimates. However, for rare events such as ship grounding, or for events arising from unique aspects of a new technology, historical data either are nonexistent or produce much less reliable estimates.

Both the frequency and the magnitude of accidental releases are subject to influence by regulatory and technical factors. For example, use of containerized systems for transporting wastes can decrease the quantity of wastes released in the event of accidents, and restrictions on vessel transit during storm conditions should reduce the likelihood of accidents.

Routine releases are easier to predict and quantify. Although the magnitude of routine releases can be minimized through technological design and careful practice, some release is inevitable from essentially any system.

Routine releases resulting from incineration can involve either the waste itself or products generated as a result of the incineration. Accidental releases virtually always involve loss of the original waste itself.

This section describes the various types of environmental releases and, wherever appropriate, draws distinctions between land and ocean basing. The types of releases considered include the following: accidental releases from spills and incinerator upsets; and routine releases from fugitive emissions, normal stack emissions, and air pollution control device effluents.

Available data are discussed from two perspectives: First, the additional activities and risks specifically associated with ocean incineration are highlighted; and second, these risks are compared to risks associated with related activities, to provide a broad context in which to view ocean incineration.

Marine *Spills*[1]

Typically, handling and transport of hazardous waste to be incinerated involves many similar or identical steps for both land-based and ocean incineration. Figure 9 presents a schematic representation of such steps for land-based and ocean incineration. The potential for a spill to occur must be evaluated at each of these steps. For ocean incineration, an extra transfer and transport step is required to bring wastes to dockside, load them onto the vessel, and transport them to the incineration site. This factor tends to increase the risk of accidental release of wastes. (As discussed in ch. 6, implementation of the containership concept, in which wastes would be transferred directly from source to vessel in sealed containers, might substantially reduce this risk during handling on land and during vessel loading; increased handling of containers on board could increase the risk of a spill during the voyage.)

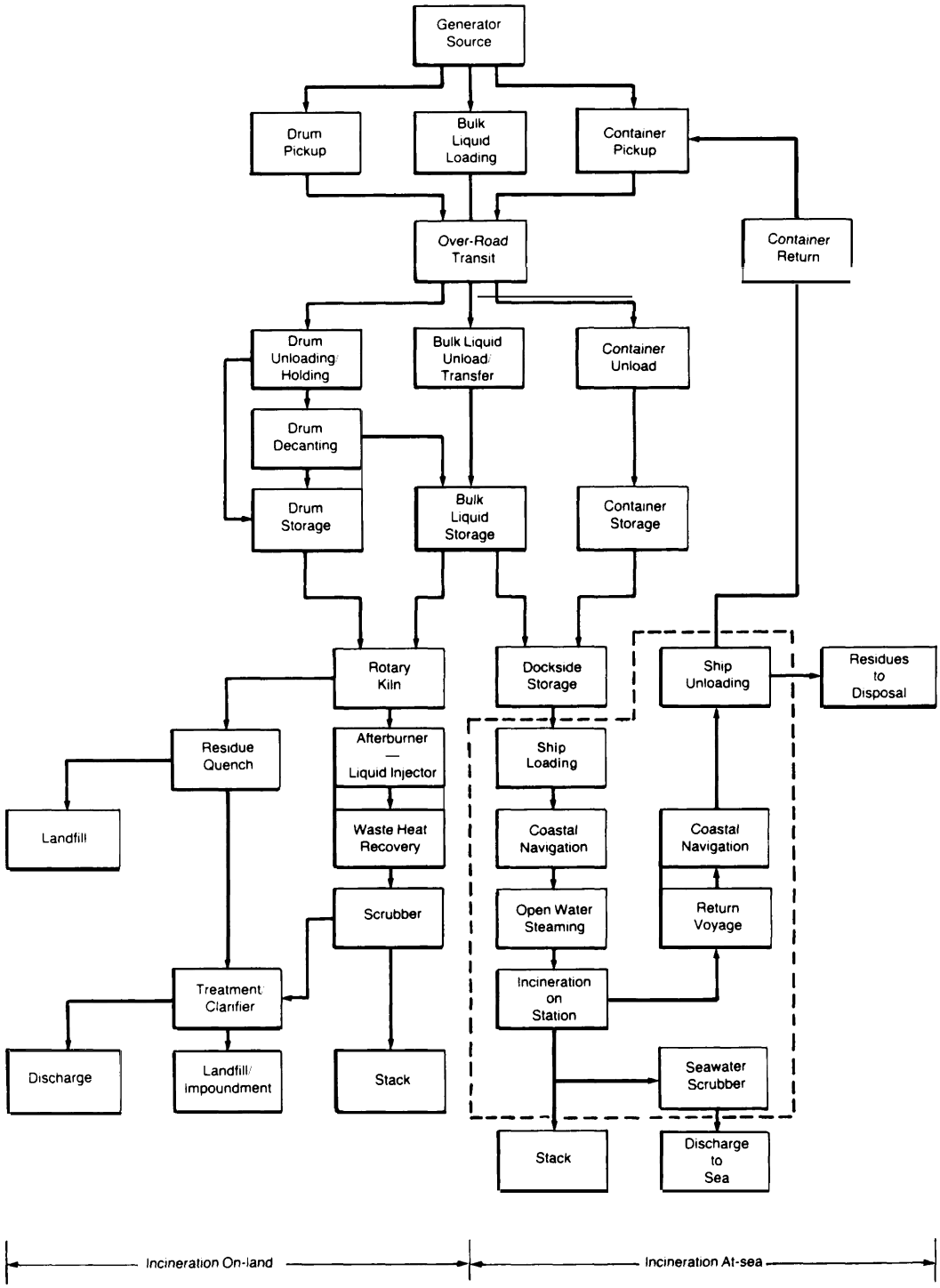
Table 13 summarizes steps in the waste flow where accidents can occur, and indicates the cause and type of, release in each case.

With respect to additional transportation and handling risks applicable to ocean incineration, EPA estimated the probability of release for a ship with characteristics similar to the *Vulcanus II*, operating in two locations: 1) out of Mobile Bay in Alabama and incinerating at the designated Gulf of Mexico Incineration Site (app. C in ref. 22); and 2) out of Philadelphia and Delaware Bay and incinerating at the proposed North Atlantic Incineration Site (8). These analyses were based on consideration of historical safety and engineering data for the maritime bulk chemical industry. Specifically, bulk chemical transport data for tank ships of comparable size operating worldwide between 1969 and 1982 formed the basis of the analysis. The data were adjusted to account for the following special circumstances and the somewhat stricter design and operational requirements applicable to incinerator ships:

- relative ease of maneuverin, and use of sophisticated navigational equipment;

[1]In this discussion, the term *spill* refers to a release caused by the breaching of a cargo tank. Other releases caused by leaking valves, etc., are considered later in the section on fugitive emissions.

Figure 9.— Step-by-Step Flowchart for Land-Based and Ocean Incineration



Note: Area within dotted line represents one cycle of the ship

SOURCE: Arthur D. Little, Inc., *Overview of Ocean Incineration*, prepared by J.R. Ehrenfeld, D. Shooter, F. Ianazzi, and A. Glazer for the Office of Technology Assessment (Cambridge, MA: May 1986).

Table 13.—Accidentai Releases From Land-Based and Ocean incineration

Activity	Cause of release	Type of release	Relevant mode
Waste pickup/loading/unloading:			
Drums	Mishandling	Spill on land	Land/ocean, bulk
Bulk liquids	Overfilling, line break	Spill on land	Land/ocean, bulk
Containers	Mishandling	Spill on land	Land/ocean, containerized
Road or rail transit	Vehicle accident, tank or valve leak	Spill on land Fire	Land/ocean, bulk/containerized
Storage:			
At dockside	Tank or container failure	Spill on land	Ocean
At incinerator	Tank or container failure	Spill on land	Land
Vessel loading	Overfilling, line break	Spill on land, water, or ship	Ocean, bulk
Vessel transit	Collision or grounding	Spill to water or on ship	Ocean, bulk
Incineration	Upset or malfunction	Increased emissions	Land/ocean, bulk/containerized
Bulk liquids or containers	Mishandling	Spill	

SOURCE: Arthur D. Little, Inc., Overview of Ocean ***incerneration,*** prepared by J.R. Ehrenfeld, D. Shooter, F. lanazzi, and A. Glazer, contract report prepared for the U.S. Congress, Office of Technology Assessment (Washington, DC: May 1986).

- segregated ballast design and dedicated ballast and cargo tanks;
- double-hull and double-bottom design;
- dedicated port facility;
- specially trained crew;
- weather restrictions during transit;
- U.S. Coast Guard transit requirements (e. g., moving safety zone); and
- routes to be used.

The probability of an accident occurring during various segments of the transit was separately assessed for four locations: the pier or harbor, Mobile or Delaware Bay, the coastal zone, and the burn site. Four types of accidents were separately addressed as well: collisions (ship/ship); rammings (ship/nonship); grounding; and nonimpact events (e. g., explosions, fires, structural failures, capsizing).[3] In addition, accident data were adjusted to account for the fact that not all accidents result in actual release of waste.

The resulting estimates are of two sorts: first, estimates of the probability of a spill (i. e., spill rate) of any size occurring at a given location or from a given type of accident; and second, a probability distribution that predicts the frequency of spills of various sizes.

Estimation of Spill Rates

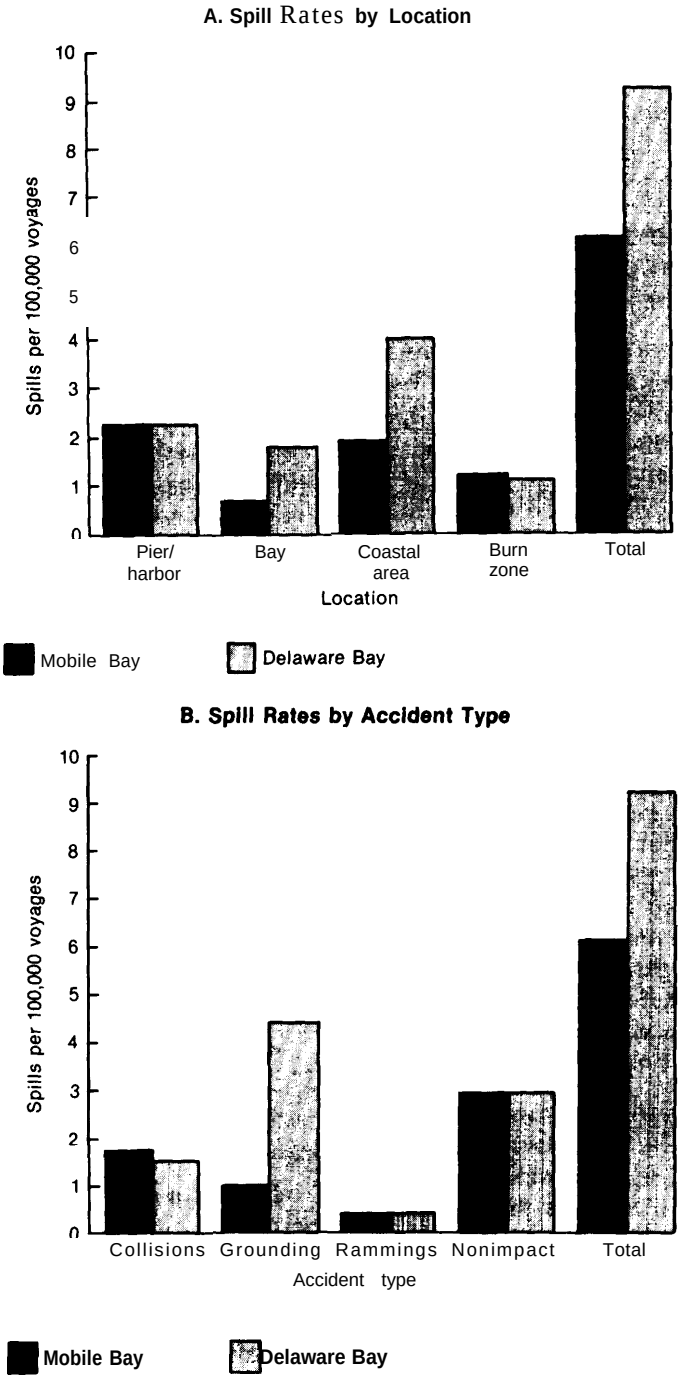
For a *Vulcanus* H-type ship, EPA's estimated spill rates for the Gulf of Mexico and for Delaware Bay are presented in figure 10. The total spill rates are the sum of those for the four locations or the four types of accidents. These data suggest that about half of all spills in both locations can be expected to occur at dockside or in the harbor or bay. Nonimpact casualties (e. g., explosions, fires, structural failures, capsizing) are predicted to account for almost half of all spills in the Gulf of Mexico, but less than a third of those in Delaware Bay. Spills due to grounding are over four times more likely in Delaware Bay than in the Gulf, largely because of differences in bottom conditions. Based on historical accident rates, a major fraction of spills in the pier/harbor area are expected to take place while the vessel is moored, rather than during transit.

Based on these data, EPA predicts that the overall spill rate for all accident types and locations would be 6 per 100,000 voyages for the Gulf of Mexico and 9 per 100,000 voyages for Delaware Bay. As can be seen from figure 10, most of the difference in these two estimates is because of the higher probability of grounding in the Delaware Bay, due to harder bottom conditions.

These estimated spill rates for the *Vulcanus* II are seven- to ten-fold lower than the historical spill

[3]Adjustments of the data were made where appropriate to account for conditions specific to a location and an accident type. For example, probabilities for vessel grounding in Delaware Bay were adjusted upward based on the higher rate of grounding in this region relative to that experienced worldwide; probabilities for grounding in the Gulf of Mexico were adjusted downward to account for soft bottom conditions. No adjustments of data for nonimpact accidents were made, due to lack of sufficient information.

Figure 10.—Spill Rates for the Vulcanus II in Mobile and Delaware Bays



SOURCES: Mobile Bay: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration," Assessment of *Incineration* as a Treatment *Method* for *Liquid Organic Hazardous Wastes* (Washington, DC: March 19S5); Delaware Bay: Engineering Computer Optecnomics, Inc., "Analysis of the Risk of a Spill During a Single Voyage of the *Vulcanus II* From the Port of Philadelphia to the Incineration Site in the Atlantic Ocean, " prepared for the U.S. Environmental Protection Agency (Annapolis, MD: Apr. 30, 1980).

rate for all tank ships of comparable size operating worldwide between 1969 and 1982 (61 per 100,000 voyages). Such a result is expected because of the adjustments made to account for the special safety features of incineration vessels and their operation.

Using EPA's assumption of an average of 14 voyages per ship per year, these spill rates indicate that one accident could be expected to occur every 800 years (Delaware Bay) to 1,200 years (Gulf of Mexico). These estimates *are per ship;* thus, if three ships were in operation, one spill would be expected every 270 to 400 years on average.

EPA's spill rate estimates are subject to a number of limitations. For example, spill rates only represent a *Vulcanus* II-type vessel operating in specific regions, and cannot be expected to apply to other vessel designs or locations. In addition, spills of hazardous material go unreported to a significant degree. No upward adjustment was made to account for the number of unreported accidents and spills. Such an adjustment would affect the *absolute* probability of a spill for the *Vulcanus II,* but not its safety *relative* to that of all tank ships operating worldwide. [4]

EPA's spill rate estimates are highly sensitive to the magnitude, reliability, and appropriateness of adjustments made to historical spill data. For example, if it is assumed that only a quarter of all marine spills are reported, then the actual spill frequency would be increased by a factor of 4. The resulting spill rates would now be 1 per 200 to 300 years (again *per ship).* If three ships were operating, a spill could be expected every 67 to 100 years; if a larger fleet of 30 ships were employed, a spill could be expected every 7 to 10 years.

Conversely, the downward adjustments made to historical spill data might be too conservative. For example, nonimpact accidents may well be affected by design and operational features that are employed (e.g., double-hull construction; sophisticated firefighting equipment). These factors were excluded from EPA's analysis due to a lack of quantitative information. Their consideration would result in actual spill rates that would be even smaller than EPA has estimated.

The factors listed above represent only some of the many inherent sources of uncertainty that affect the reliability of spill rate estimates. Even if only small uncertainties accompanied each of the individual factors that influenced the calculation of a spill rate, the combined uncertainties could lead to a highly questionable result. For this reason, the *absolute* magnitude of such risk estimates must be used with great caution.

Comparing the relative risks for activities that are subject to the same or similar uncertainties, however, can still be informative. Thus, a major conclusion that is clearly supported by EPA's spill rate analysis is that the operation of incineration vessels should result in a significantly lower per-ship rate of spills than the rate for tank ships in general.

Estimation of Spill Size

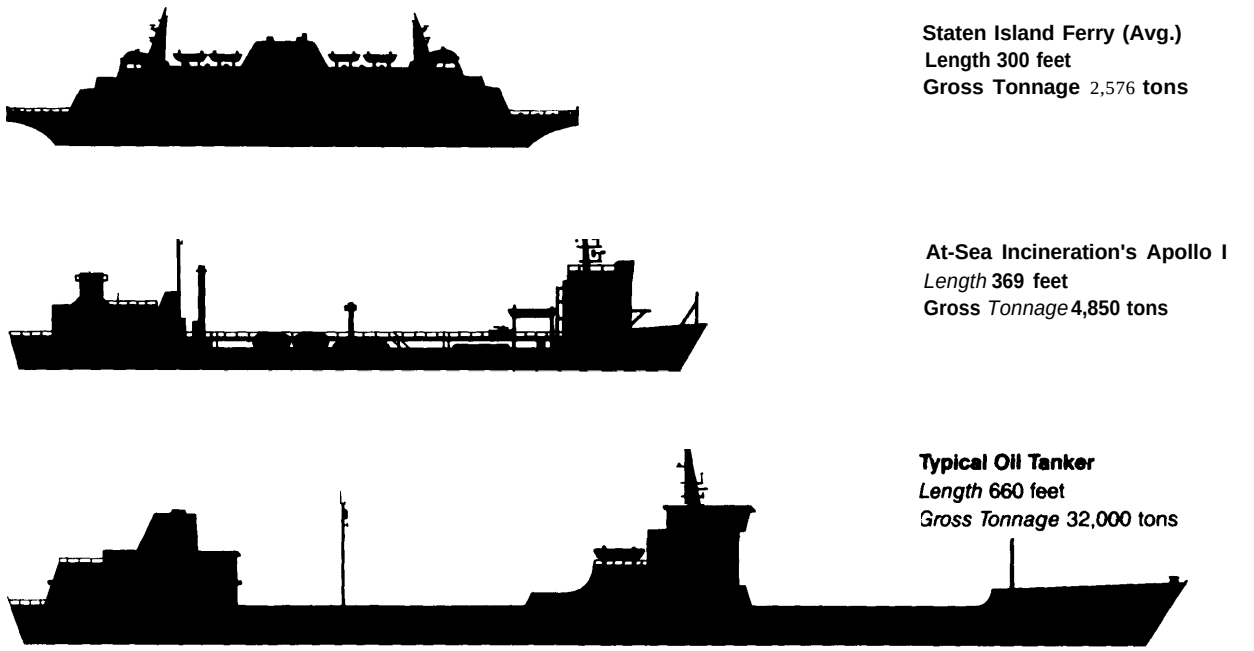
EPA rejected use of direct historical data on spill size for tank ships, because such data are skewed toward conventional single-hull tankers whose average *tank size* is comparable to the *entire cargo* of the *Vulcanus II.* Instead, historical data on the extent of damage caused by accidents were used to estimate the probability of occurrence of each of the following categories of events leading to cargo loss:

- involvement of a single cargo tank—80 percent of spill events,
- involvement of two adjacent tanks—15 percent of spill events, and
- involvement of three or more tanks—5 percent of spill events.

In each case, it was assumed that the entire contents of a tank involved in an accident were lost. Because the *Vulcanus II* is designed to remain afloat even after the loss of two of its tanks, cargo losses from events involving damage to one or two tanks would be limited to their corresponding volume (about 100,000 and 200,000 gallons, respectively). However, for events involving three or more tanks, loss of the entire cargo (about 800,000 gallons) was assumed. These assumptions are quite conservative because of the unlikelihood that all the con-

4A number of other criticisms of the EPA analysis have been raised (6), based primarily on U.S. Coast Guard data on polluting incidents in and around U.S. waters (20). However, most of these data are not relevant to evaluating the risk of a spill from an incinerator vessel, in that: 1) the incidents did not result in any release of waste; 2) the incidents involved sources other than vessels; or 3) the vessels involved were of significantly less safe design (e. g., river barges).

Figure 11.–Comparative Size Scale of an Incineration Vessel (the *Apollo I)* and Other Typical Commercial Ships



SOURCE: At-Sea Incineration, Inc

tents of a tank would be lost in all accidents. These ''worst-case' data suggest that an average spill from an incineration vessel would result in the release of 19 percent of the total cargo, which would correspond to about 150,000 gallons in the case of the *Vulcanus II.*

Unfortunately, essentially no data are available for vessels of comparable size and possessing the design and operational features of incineration vessels. Moreover, because historical data collected over only a few years may by chance include or exclude the very rare event that generates a very large spill, their reliability is highly questionable. These and the other limitations discussed above clearly illustrate the problems associated with using historical data to estimate the average magnitude of a low-probability, high-consequence event such as a marine spill.

Whatever its absolute magnitude or uncertainty, the average expected spill size from an incineration vessel can logically be assumed to be significantly smaller than that resulting from a typical tanker accident, where both tank and total cargo size tend to be much larger (see fig. 11).

Estimates of spill rate and size are certain to vary between vessels, port locations, and burn sites. Thus, an analysis based on any one operation is of limited applicability to others, whereas a generic analysis tends to obscure the potential for significant variation. This fact underscores the need for comparing various vessel designs and operation plans as an integral part of assessing the safety of ocean incineration (see ch. 6).

Comparison of Releases From Transportation on Land and At Sea

EPA estimated the magnitude of releases that would be expected to occur as a result of accidental spills during land and ocean transportation (21,22). Based on this comparison, EPA suggested that the ocean transportation phase would contribute about 20 percent of releases of waste caused by spills. Releases caused by spills during land transportation are estimated to be more than three times higher than releases caused by spills during ocean transportation. Releases caused by spills during transfer and storage operations would be slightly lower than releases caused by spills during ocean transpor-

tation. Because spill releases from land transportation, transfer, and storage are estimated to be identical for land-based and ocean incineration, EPA suggested that the total expected release due to spills for ocean incineration would be about 20 percent higher than that for land-based incineration.

Even if accurate, however, such estimates do not adequately reflect the relative environmental consequences of releases. To do so would require consideration of such factors as the ease of cleaning up spills, the transport and fate of spilled material, the nature of exposure to organisms and humans, and the actual health effects of the substances present in the waste. Compared to estimation of spill rate and size, far more uncertainty and absence of data accompany the estimation of these additional factors, which are considered in chapter 9.

Comparison of Marine Transportation of Hazardous Waste and Nonwaste Materials

Available data indicate that, with respect to number of transits, quantities and types of material carried, and expected releases, ocean incineration entails a very small incremental increase in risk over that routinely borne in the marine transport of hazardous materials. Even if a fleet of 30 vessels were employed, marine transport of hazardous materials would increase by about one-tenth of 1 percent; quantities of material spilled in the marine environment would increase by an even smaller fraction.

A discussion of the risks of accidental releases of wastes while at sea or dockside should consider both the types and quantities of hazardous *non waste* materials (e. g., petroleum products, raw chemical feedstocks) that are handled and transported by similar means and routes on a routine basis.

Types of Material Carried.—Critics of ocean incineration argue that transport of hazardous waste poses a greater risk than transport of hazardous nonwaste materials for two reasons: first, that waste materials are more toxic or concentrated; and second, that incineration vessels would carry complex mixtures of different substances, whereas tank ships carry pure substances, which are easier to clean up if spilled.

Typical liquid cargoes carried by tank ships include crude oil, petroleum products, petrochemicals, liquefied gases, and nonpetroleum-based chemicals. Thus all of the major categories of ocean-incinerable wastes are represented among materials routinely transported in raw form. In addition, many tank ships are designed and authorized to carry numerous substances in various combinations, for example, petroleum products and nonpetroleum-based chemicals. These materials, however, are segregated in separate tanks, reducing the likelihood that a mixture of substances would be released in a tank ship spill.

With respect to toxicity and concentration, the majority of waste suitable for incineration at sea is derived from industrial processes that use a wide variety of chemicals in pure form. The composition of waste generated by a given industrial process, therefore, tends to reflect rather closely the composition of the feedstocks initially used.

However, industrial processes can alter the composition of subsequent waste products in at least three respects. First, contaminants can be introduced; for example, solvents used for cleaning and decreasing may contain dirt, grease and oil, and metals not originally present in the feedstocks. Second, water content can be increased, diluting the original material. Third, different substances can indeed become mixed in the process that generates the waste.

Thus, contamination or mixing can render wastes resulting from industrial processes more complex than the nonwaste materials from which they were derived; at the same time, the concentrations of particular toxic constituents may well be less than those of the raw materials. Because environmental toxicity is a function of *both* concentration and composition, any generalization about relative toxicities of wastes and raw materials is impossible; rather, analysis on a case-by-case basis is required.

Much public attention has focused on the transport of PCBs, which are no longer routinely produced or transported for industrial or other commercial purposes. Although PCBs are a small fraction of ocean-incinerable wastes, they are among the most environmentally persistent of all toxic materials transported at sea, and have considerable potential to be accumulated by exposed organisms and introduced into the food chain. For this reason, special regulatory attention is warranted for PCBs. (See box B in ch. 3.)

Quantities of Material Carried.-EPA has estimated that the amount of hazardous waste that would be transported by the six existing or planned incinerator ships would be 0.03 percent of the total volume of hazardous substances handled by U.S. ports in 1983 (50 FR 8226, Feb. 28, 1985). This calculation was based on U.S. Army Corps of Engineers data reporting a total of 1.38 billion metric tons[5] of hazardous materials passing through U.S. ports in 1983.

Table 14 provides a summary of U.S. Army Corps of Engineers data on the annual tonnages of hazardous materials and petroleum passing through various U.S. ports in 1984, These amounts are compared to the quantities that would be carried by 1 or 30 incineration vessels similar in size to the *Vulcanus* ships or the significantly larger *Apollo* ships.

Gulf of Mexico and Mobile Bay. —EPA has examined data on shipments of petroleum and hazardous substances in Mobile Bay and the Gulf of Mexico. The data distinguish between crude petroleum, petroleum products, and hazardous chemicals. Table 15 presents data for shipments in and out of Mobile Bay between the years 1977 and 1981. Table 16 presents similar data for the Gulf of Mexico in 1983 and indicates the total number of shipments made.

The data in tables 15 and 16 provide the basis for the following conclusions:

- Each incineration vessel with an annual capacity of 65,000 metric tons operating full time out of Mobile Bay would increase total carriage there by the following amounts:
  —for all commodities listed: 0.8 percent, and
  —excluding crude petroleum: 1.6 percent.
- Each such vessel would increase carriage in the Gulf of Mexico by the following amounts:
  —for all commodities listed: 0.01 percent, and
  —excluding petroleum: 0.02 percent.
- Assuming that each such vessel made 14 transits annual] y, the number of *hazardous material shipments* in the Gulf of Mexico would

[5]The quantity cited by EPA is 8.70 billion barrels of hazardous substances; this is roughly equivalent to 1.38 billion metric tons.

Table 14.—Annual Tonnages of Hazardous Materials and Crude Petroleum Passing Through Various U.S. Ports in 1984

Location	Quantity Transported in 1984 (millions of metric tons) Hazardous materials	Crude petroleum	Total	Quantity normalized to one *Vulcanus* vessel
Total for all U.S. ports (1983)[b]	—	—	1,364	21,290
Port of New York	104	8	112	1,723
Delaware River/Bay	26	46	72	1,108
Port of Mobile, AL	3	3	6	92
Port of Lake Charles, LA	20	7	27	415
Houston Ship Channel, TX	46	11	57	877
San Francisco Bay, CA	25	26	51	785
			Annual quantity[c]	
One incineration vessel				
Vulcanus			0.065	1
Apollo			0.100	1.5
30 incineration vessels				
Vulcanus			2.0	30
Apollo			3.0	46

[a]Includes the following commodities:

Sodium hydroxide	Basic chemicals	Jet fuel
Crude tar, oils, gas	Paints	Kerosene
Dyes, pigments	Gum, wood chemicals	Distillate fuel oil
Alcohols	Insecticides, disinfectants	Residual fuel oil
Benzene and toluene	Miscellaneous chemicals	Lubricating oil and grease
Sulfuric acid	Gasoline	Naptha, petroleum solvents

[b]This 1983 quantity is cited in the preamble to EPA's proposed Ocean Incineration Regulation, 50 FR 8228, Feb. 28,1985. The data are originally derived from the Waterborne Commerce Statistics of the U.S. Army Corps of Engineers. A national total for 1984 was not available at the time of publication of this report.
[c]Estimates based on information obtained from vessel owners.

SOURCE: Office of Technology Assessment, based on U.S. Army Corps of Engineers, *Waterborne Commerce of the United States,* Freight Traffic Tables for Calendar Year 1984.

Table 15.—Average Annual Tonnages of Petroleum Products and Chemicals in Mobile Bay
(thousands of metric tons)

Commodity	Tonnage[a]
Crude petroleum	3,848
Gasoline, jet fuel, kerosene, fuel oil, and solvents	4,018
Benzene, toluene, and basic chemicals	155
Total	7,821

[a]Annual averagea for the period 1977-81.

SOURCE: U.S. Environmental Protectlon Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Baaed Incineration, " *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

Table 16.—Shipments of Petroleum and Hazardous Substances in the Gulf of Mexico, Fiscal Year 1983

Commodity	Volume of shipments (mmt)	Number of shipments
Petroleum	270	44,917
Hazardous substances	274	14,978
Total	544	59,895

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Baaed and Ocean-Baaed Incineration," Assessment of *Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

increase by about 0.09 percent, or less than 1 per 1,000. If petroleum were included, the increase would be 0.02 percent, or 2 per 10,000.

EPA argues that stricter design and operational requirements applicable to incineration vessels would decrease actual *releases* of hazardous material to the environment even further. Design factors include the smaller tank and total cargo size, double hull, greater maneuverability, and shallower draft of incineration vessels. Operational requirements include weather restrictions and U.S. Coast Guard controls on vessel transit. If such factors are taken into account, EPA expects releases from each incinerator ship operating in the Gulf to be less than 0.002 percent (or one fifty-thousandth) of those from routine transport of petroleum and hazardous material in the Gulf.

Incinerator Upset

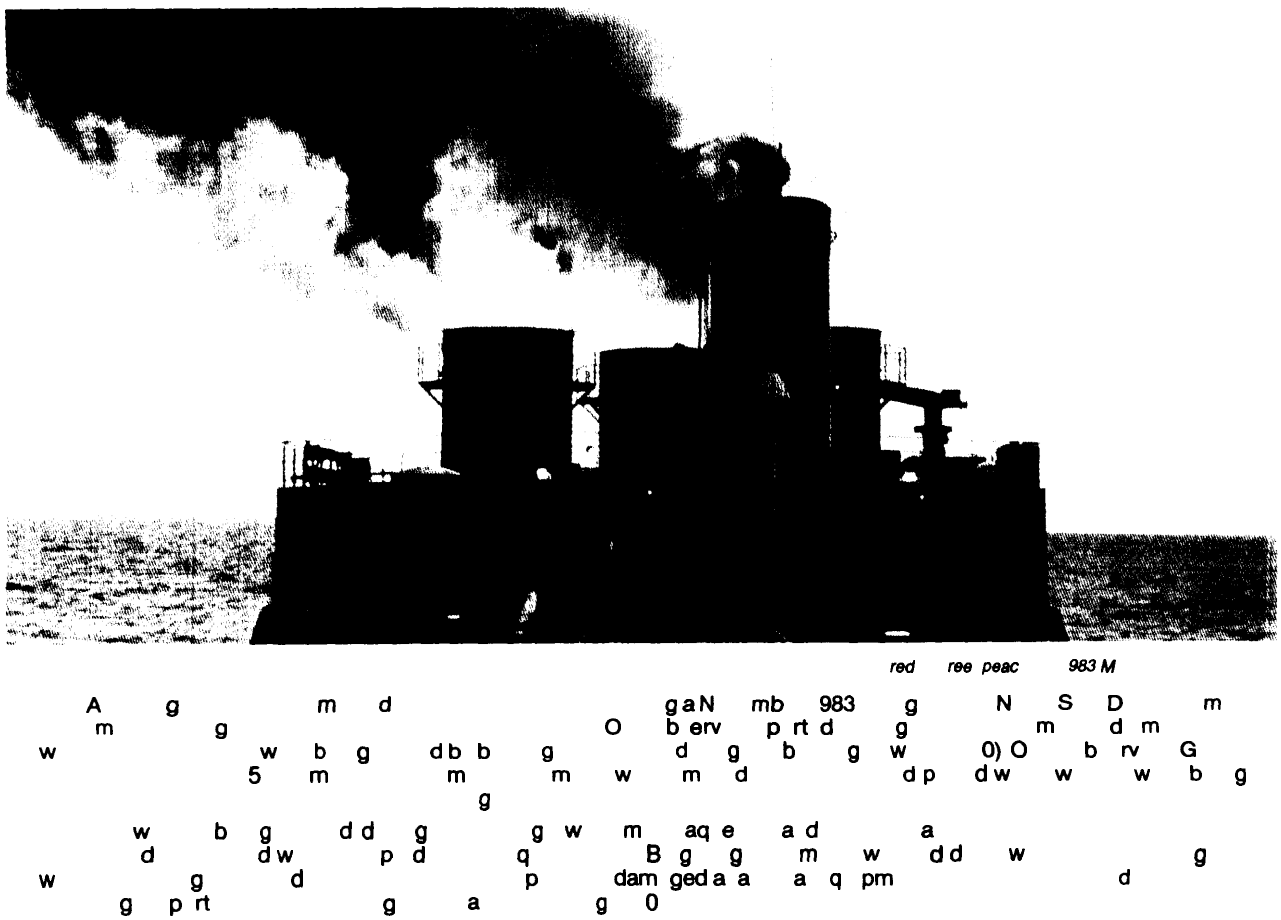
A second category of accidental release involves any malfunction of the incinerator that results in the release of undestroyed or partially destroyed waste. The expected duration of an incinerator upset would be limited because of the requirement for automatic shutoff of waste to the incinerator in the event of a malfunction. Nevertheless, during this time waste could be expected to enter—and exit—the incinerator under conditions that deviated from permit requirements. A significant amount of combustion would continue to occur because of the remaining heat in the combustion chamber, although the degree of combustion would almost certainly be lower than the efficiency standard.

The amount of additional release would depend on both the length of the upset and the destruction efficiency attained under upset conditions. To illustrate the magnitude of the expected additional release, a worst-case scenario might involve a 10-second delay in waste feed shutoff (see ref. 23; the proposed Ocean Incineration Regulation would allow only 4 seconds). Assuming that during this 10 seconds the destruction efficiency (DE) fell (in the worst case) to 90 percent, the quantity of unburned waste released would be equivalent to 2.8 hours of operation at a DE of 99.99 percent, or 280 hours at a DE of 99.9999 percent. [6]

For a PCB burn requiring a DE of 99.9999 percent, about 10 such upsets during a 12-day (288-hour) burn would reduce the average DE by a factor of 10, to 99.999 percent. If a DE of only 99.99 percent were required (i.e., for incineration of non-PCB wastes), about 1,000 such upsets would be needed to reduce the DE by a factor of 10, to 99.9 percent.

This calculation highlights the fact that the higher the desired DE is, the more sensitive the system is to temporary incinerator upsets. Unfortunately, data are not available on the expected frequency of upsets associated with either land-based or ocean incineration. Nor does evidence exist showing that ocean and land-based incineration technologies experience different frequencies of upset. This issue of variation in operating conditions during extended incineration is one area identified by EPA's Sci-

[6]A reduction in DE from 99.99 percent to 90 percent would increase the *rate* of emissions a thousand-fold; if the lower DE lasted for 10 seconds, the *amount* of emissions would be equivalent to that normally released in a period 1,000 times longer, or 10 seconds X 1,000 = 10,000 seconds = 2.8 hours. Similarly, if the reduction in DE were from 99.9999 percent to 90 percent, emissions would be equivalent to that normally released in 10 seconds X 100,000 = 1,000,000 seconds = 280 hours.



ence Advisory Board (23) as warranting further study and attention. [7]

Fugitive Emissions

Fugitive emissions, which are commonly associated with the transfer and storage phases of incinerator operation, are typically small, slow, or sporadic releases of waste from a variety of sources, including leaking seals, pumps, pipes, valves, and storage tank vents. Unlike spills, most fugitive emissions are released to the atmosphere through volatilization; only rarely are fugitive emissions of a nature or magnitude that would lead to the contamination of marine waters. Such releases can be largely controlled through design modifications and good operating practices.

With respect to estimating magnitude, some fugitive emissions (e. g., small, intermittent pump or valve leaks) are probabilistic (random) in nature. Others (e.g., breathing losses from storage tanks and working losses during the filling and emptying of tanks) are continuous, at least during a particular activity. EPA has estimated fugitive emissions for an ocean incineration operation using an integrated port facility of the type that Chemical Waste Management, Inc., had proposed to build at Chickasaw, Alabama. The calculation assumed that one of the following two wastestreams was incinerated: an annual throughput of 56,000 metric tons of waste containing 35 percent PCBs, or 68,000 metric tons of waste containing 50 percent ethylene dichloride (EDC).[8]

[7]The Science Advisory Board has suggested that operation on rolling and pitching seas may conceivable affect operating conditions. Opponents contend that there would necessarily be an inherent reduction in the performance of a moving incinerator, while proponents argue that such effects would be negligible and draw an anology to the fuel injection system of a sports car.

[8]Fugitive emissions from these wastestreams would probably be composed largely of volatile waste components, rather than PCB or EDC themselves (app. B in ref. 22).

Under this scenario, EPA calculated that the release of either waste through fugitive emissions would be about 0.7 metric tons annually, or about one-thousandth of 1 percent (0.001 percent) of the total amount of waste handled (22). In each case, storage tanks, not waste transfer and handling, were the major source of emissions, accounting for over 80 percent of the total release.

EPA also estimated fugitive emissions from an ocean incineration system using an intermediate waste storage facility of considerably older design (Chemical Waste Management's facility in Emelle, Alabama). EPA found that fugitive emissions could be expected to increase because of two factors: first, the extra transfers of waste to and from the Emelle facility; and second, the less airtight design of the Emelle storage tanks. Total fugitive emissions under this scenario would be 4.9 and 5.5 metric tons annually for the PCB and EDC wastes, respectively (app. B in ref. 22). These levels would be seven to eight times higher than those resulting from the more modern, single-step operation in an integrated port facility like the one that was proposed for Chickasaw.

Fugitive emissions calculated under each of these scenarios represent the largest of all sources of releases for the handling and transfer phases of ocean incineration. Table 17 compares the various sources of releases for three systems: ocean incineration using a modern integrated port facility (e. g., the one planned for Chickasaw); an equivalent land-based incineration system; and ocean incineration using an older intermediate storage facility requiring a two-step transfer procedure (e. g., the existing facility at Emelle). Total expected releases range from 0.002 percent (Chickasaw and land-based) to 0.01 percent (Emelle) of waste throughput.

Table 17.—Average Expected Annual Releases From Storage and Transfer Operations (metric tons per year)

Release source	Planned Chickasaw facility	Existing Emelle facility	Land-based equivalent
Truck unloading/ loading (spills). . . .	0.03	0.1	0.03
Transfer/storage (spills)	0.5	0.4	0.5
Fugitive emissions . .	0.7	5.2	0.6
Total	1.2	5.7	1.1

[a]An annual waste throughput of 59,000 metric tons is assumed.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Baaed Incineration: Appendix B," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 19S5).

Comparison to Land-Based Incineration

Using an approach similar to the one outlined above, EPA has estimated the amount of fugitive emissions that could be expected from the additional waste storage and handling that ocean incineration would entail. This analysis indicated that, after accounting for all phases of operation, releases due to fugitive emissions would be about 15 percent higher for ocean incineration than for land incineration (22).

Comparison to Other Sources of Fugitive Emissions

Data to compare levels of fugitive emissions from ocean incineration to levels from other sources are generally lacking. Numerous other sources exist at U.S. ports, given the very large quantities of hazardous materials handled by such ports. For example, in the Port of Mobile, about 30 waterfront facilities are currently licensed to handle or store hazardous substances (22). In addition, there are, of course, thousands of other facilities located throughout the United States that handle such substances.

Normal Stack Emissions

Because incineration cannot completely destroy wastes, stack emissions have at least the potential to contain harmful levels of hazardous substances and to convey them to the environment. These substances include:

- unburned waste;
- products of incomplete combustion (PICs);
- toxic metals; and
- acid gases (hydrochloric acid, sulfur oxides, and nitrogen oxides).

The following discussion addresses the quantities of each of these classes of emissions that could be expected to be released to the environment through ocean incineration.

Unburned Waste

This category of wastes is defined (in a regulatory sense) through the selection of a few compounds considered to be representative of the entire waste. The selection is based on one of two criteria: the compounds are present in the waste in high concentration or are judged to be particularly difficult to destroy through incineration. These compounds are termed principal organic hazardous constituents, or POHCs. The regulatory advantage of such a system is that destruction efficiency need only be measured for a small set of POHCs, because their destruction to a particular level is assumed to indicate equal or greater destruction of all the unmeasured components of the waste. Potential shortcomings of this definition are discussed at length in chapter 2.

If the assumptions behind the definitions of POHCs and DE are accepted, and if the desired DE is actually achieved, then the quantity of unburned waste released through stack emissions can be calculated in a straightforward manner. The quantity is simply the product of the unburned fraction of the waste ([100— DE]+ 100) and the total quantity of waste burned. Thus, if an incineration vessel burned 50,000 metric tons of a waste containing 35 percent PCBs in a given year, and if the burns met the DE standard of 99.9999 percent, the quantity of unburned PCBs released would be:

$$\frac{100 - 99.9999}{100} \times 50{,}000 \times 0.35 = 0.0175 \text{ metric tons, or } 17.5 \text{ kilograms (38.5 pounds) annually}$$

The magnitude of such releases would be extremely sensitive to changes in the DE. For example, if a DE of only 99.99 percent were achieved, almost 2 metric tons of PCBs would exit the stack annually.

The unburned waste emitted by an incineration vessel would be released over a rather large area, because of the movement of the ship during incineration and the dispersion of the plume after release. This material would be further dispersed upon entry into the sea, due to currents and wave action, although there is potential for concentration of emissions in the surface microlayer (see ch. 9).

The significance of releases of unburned waste to the environment is unresolved. One approach commonly used for evaluating significance is to compare expected releases from ocean incineration with releases from other sources. Ocean incinerator emissions are typically released to the atmosphere (unless a seawater scrubber is employed), but they generally settle over the ocean surface, so the contributions of other sources to both the atmosphere and marine waters are germane. Available data for each of these environments are discussed below, using the example of PCBs.

Releases to the Atmosphere.—In the Gulf of Mexico, ambient (i.e., background) concentrations of PCBs in the atmosphere have ranged between 0.05 and 0.5 nanograms per cubic meter (ng/m^3) (app. I in ref. 22). This atmospheric concentration is estimated to result in 7 to 70 grams of PCBs being annually deposited onto each square kilometer of the Gulf's surface (g/km^2 per year). Using this rate of deposition, EPA has estimated that each year between 10 and 100 metric tons of PCBs enter the waters of the Gulf from the atmosphere (app. I in ref. 22).

Using this range as a measure of the background flux of PCBs entering the waters of the Gulf from the atmosphere permits an estimation of the increase that could be expected to occur because of ocean incineration. The area of the ocean surface affected by the incinerator plume is estimated to be about 90,000 square kilometers (app. I in ref. 22). Assuming a throughput of 50,000 mt of 35 percent PCBs and a DE of 99.9999 percent, the estimated flux of unburned PCBs from ocean incineration would be about 0.2 g/km^2 per year.[8] This would yield an increase above background flux of 0.3 to 3 percent over the affected area.

Averaged over the entire Gu]f these data indicate that each incineration vessel operating at a DE of 99.9999 percent would cause a 0.02 to 0.2 percent increase in the quantity of PCBs entering the water from the atmosphere. At the upper end of this range, an increase in the number of vessels operating in the Gulf or a decrease in the DE achieved could result in a significant increase above background.

[8] 17.5 kg/yr ÷ 90,000 km^2 = 0.2 g/km^2 per year.

Releases Directly Entering Marine Waters.—PCBs also enter marine waters from a variety of other sources, including waste discharges, dumping, and rivers. For comparative purposes, table 18 lists several estimates of direct PCB inputs to various marine waters from various sources.

The data indicate that ocean incineration employed on a modest scale would cause an incremental increase in the total input of PCBs to marine waters. Clearly, the relative magnitude and significance of such an increase would also vary with respect to location. For example, in contrast to most of the inputs from sources shown in table 18, the emissions from ocean incineration would be expected to enter marine waters at considerable distances from the coast. At these deep ocean sites, the emissions could represent a greater fractional input of PCBs, but would be dispersed over a much larger volume and have less adverse impact on marine life or humans. Unfortunately, few data are available with which to assess the absolute significance of the consequences of the incremental increase in PCBs that would be caused by ocean incineration (see ch. 9 for a discussion of one study).

Table 18.—Estimated Inputs of PCBs to Various Marine Waters

Affected waters: source	Annual PCB loading (kg/yr)
New York Bight:[a]	
Sewage sludge dumping	800-2,000
Dredge materials dumping	3,500
POTW discharges	200-1,000
Upstream sources	3,100
Southern California Bight:[b]	
Sewage	2,000
One incineration vessel at 99.9999% DE[c]	18
One incineration vessel at 99.99% DE[c]	1,800

[a] J. O'Connor, J. Klotz, and T. Kneip, "Sources, Sinks and Distribution of Organic Contaminants In the New York Bight Ecosystem," *Ecological Stress and the New York Bight*, G. Mayer (ad.) (Charleston, SC: Estuarine Research Federation, 19s2), pp. 931453.

[b] M. Connor, "Statement on Incineration of Hazardous Waate At Sea," In Hearing Before the Subcommittee on Fisheries and Wildlife Conservation and the Environment and the Subcommittee on Oceanography of the House Committee on Merchant Marine and Fisheries, 98th Cong., 1st sess., Dec. 7, 19S3, Serial No. 9S-31 (Washington, DC: U.S. Government Printing Of fice, 19S4).

[c] Assumes a throughput of 50,000 metric tons per year of 35% PCB-laden waste. EPA haa proposed the higher DE of 99.8999% for ocean incineration of PCBs.

SOURCE: Office of Technology Assessment.

Products of Incomplete Combustion (PICs)

Data on the formation of PICs are scant for both land-based and ocean incineration. Indeed, EPA's Science Advisory Board has identified the lack of data on the formation of PICs as a major gap in our understanding of incineration, one that precludes an accurate assessment of the full extent of exposure and the impacts of incinerator emissions.

Emissions of PICs were studied in each of the previous U.S. ocean burns, and in a number of land-based incineration trials. Many questions remain regarding the adequacy of sampling and analysis undertaken during the trials, especially with respect to identifying and detecting PICs. The most glaring shortcoming, which was common to virtually all such measurements, was that only a small fraction of all compounds in the emissions (both parent compounds and PICs) was actually identified and individually measured (app. E in ref. 22). Thus, the fraction of emissions that is actually PICs, as opposed to residual parent compounds, is unknown.

This factor alone can lead to underestimation of PIC emissions by several orders of magnitude. For example, in past burns the sum of the amounts of individually identified and measured PICs typically accounted for about 1 percent of the total unburned hydrocarbons present in emissions (app. E in ref. 22).

Moreover, in most past trial burns, measurements were attempted for only a few PICs. In the ocean incineration trials involving PCBs, for example, analysis was performed for only a single PIC: tetrachlorodibenzo-p-dioxin (TCDD).

Other sources of uncertainty in estimating PIC emission rates from existing data include the following (app. E in ref. 22):

- inconsistency in definitions of what constitutes a PIC;
- variations in sampling procedures and detection limits for PICs;
- inconsistency in lists of compounds for which sampling and analyses were undertaken;
- variations in waste feed, which is thought to be a partial determinant of PIC composition; and
- variations in incinerator type and operating conditions.

What is needed is a systematic examination of PICs to provide a consistent and comparative set of data for evaluating both land-based and ocean incineration. Currently, both the quality and quantity of existing data are insufficient to provide the basis for any sound scientific conclusions.

Toxic Metals

Because ocean incinerators would be expected to burn only liquid wastes with low solids content, metal emissions would be directly proportional to the quantity of metals present in the waste feed. Essentially all metals present in the waste would exit the stack during the course of the burn.

EPA has proposed placing a regulatory limit on allowable concentrations of metals in *wastes accepted for incineration at sea (see* ch. 7). Each of 14 specified metals would be limited to no more than 500 parts per million (ppm) in such wastes. At a throughput of 50,000 metric tons annually, a maximum of 25 metric tons (ret) of each of these metals would be released through incineration.

In addition, the proposed Ocean Incineration Regulation would further limit the concentrations of certain of these metals in the *final blended waste* to be incinerated. This further limitation would be accomplished through compliance with an environmental performance standard based on water quality criteria for each metal (see ch. 7). EPA has calculated the maximum quantity of particular metals that could be emitted without exceeding applicable water quality criteria, using a model for plume dispersal and surface water mixing. For 3 of the 14 specified metals, the model requires a waste concentration of less than 500 ppm. Allowable concentrations of these three metals, along with resultant annual emissions (again assuming an annual throughput of 50,000 metric tons), are shown in table 19 (50 FR 51363, Dec. 16, 1985).

Because EPA would not limit the *aggregate* quantity of metals allowable in waste to be incinerated at sea, each individual metal could theoretically be present up to its individual limit, This would place a maximum theoretical limit on total emissions for all 14 metals, calculated as follows: 1.1 mt (silver) + 0.5 mt (mercury) + 17.5 mt (copper) + 275 mt (11 other metals at 25 mt each) = 294 metric tons/year.

Table 19.—Maximum Concentrations of Three Metals Allowed in Wastes To Be Incinerated At Sea

Metal	Allowable concentrations (parts per million)	Expected emissions (metric tons/year)
Silver	21.3	1.1
Mercury	9	0.5
Copper	350	17.5

[a]Assumes an annual throughput of 50,000 metric tons.

SOURCE: U.S. Environmental Protection Agency, 50 FR 51363, Dec. 16, 1965.

This calculation greatly *overestimates* total metal emissions, because no waste would be likely to contain all 14 metals at concentrations even approaching the maximum levels indicated above. The few available data that quantify the metal content of wastes likely to be incinerated at sea indicate that the concentration of individual metals in liquid organic wastes is typically one to three orders of magnitude lower than the 500 ppm standard (3). The metal content of wastes actually incinerated at sea in Europe and the United States is comparably low (1 ,9, 14).[10] Nevertheless, *in the following comparisons, emissions of metals at the theoretical maxim urn are used as a means of considering* worst-case *conditions.*

Comparison With Other Releases of Metals to Marine Waters. —Metal emissions expected from ocean incineration may be compared with inputs of metals into marine waters from other sources.

Coastal Waters. —Resources for the Future (16) developed a database that estimates marine discharges of seven different metals (arsenic, cadmium, chromium, copper, lead, mercury, and zinc) from land-based sources. Table 20 indicates their estimate of the total amount of these metals discharged annually to the Gulf of Mexico. These inputs can be compared to the theoretical maximum input of the same seven metals that would result from the operation of an incineration vessel.

The data indicate that land-based sources annually deposit about 5,600 metric tons of these seven metals in the Gulf of Mexico. In contrast, based on the proposed limits for ocean incineration, the

[10]The PCB waste that Chemical Waste Management, Inc. (4), proposed to incinerate in the recently canceled EPA research burn contained four metals at detectable levels: chromium (35 ppm), lead (61 ppm), nickel (16 ppm), and zinc (61 ppm).

Table 20.—Comparison of Inputs of Seven Metals to the Gulf of Mexico From Incineration and Land-Based Sources (metric tons)

Metal	Annual land-based loading to Gulf[a]	Maximum annual incinerator emission[b]	Maximum percent increase due to incineration
Mercury	27	0.5	1.9
Copper	628	17.5	2.8
Cadmium	645	25.0	3.9
Arsenic	757	25.0	3.3
Lead	828	25.0	3.0
Chromium	1,317	25.0	1.9
Zinc	1,405	25.0	1.8
Total	5,607	143.0	2.6

SOURCES: [a]Resources for the Future, Renewable Resources Division, Pollutant Discharges to *Surface Wafers for Coastal Reg/ens,* prepared for the U.S. Congress, Office of Technology Assessment (Washington, DC: February 1988).
[b]EpA proposed Ocean Incineration Regulation 50 FR 8222, Feb. 28, 1985.

theoretical maximum on incinerator emissions would be 143 metric tons per ship per year.[11] Thus, even if incinerated wastes contained the maximum allowable amounts of these metals, each incineration vessel operating in the Gulf would increase the input of these seven metals by about 2.6 percent.

Adding estimates for a number of metals obscures the fact that significant variation commonly exists in the amount of various metals in wastes. This is true for both incinerable wastes and the other sources of metal inputs discussed above. The variation takes on greater significance in light of the fact that metals differ significantly with respect to human and environmental toxicity.

To illustrate this variation, table 20 indicates the quantities of individual metals contributed by land-based sources and (in the worst case) by operation of an incineration vessel. The data indicate that mercury and zinc are discharged in the smallest and largest amounts, respectively, from land-based sources; inputs of zinc into the Gulf are more than 50 times greater than inputs of mercury.

Also shown in table 20 is the maximum percent increase in inputs of each of the seven metals that would result from the operation of an incineration vessel. Interestingly, despite the fiftyfold difference in the actual *quantity* of mercury and zinc entering the Gulf, the predicted *relative* increases in the inputs of these two metals resulting from incineration are almost identical (1.9 percent for mercury versus 1.8 percent for zinc). This similarity is due to the fact that the proposed limitation on incinerator emissions specified for zinc is fiftyfold higher than that proposed for mercury.

Finally, the data in table 20 indicate that, even in the worst case, the incremental increase in metal inputs caused by incineration would be small for all seven metals, ranging between 1.8 percent (zinc) and 3.9 percent (cadmium).

Other available data on toxic metal inputs to coastal marine waters include estimates for six metals in the New York Bight (13) and eight metals in the Southern California Bight (24). The sources considered in these studies included municipal and industrial wastewaters, atmospheric deposition, and storm runoff. These data indicate annual metal inputs of about 3,500 metric tons (in the Southern California Bight) and 24,500 metric tons (in the New York Bight). Using maximum emissions limits calculated for these metals, one incinerator ship could theoretically contribute about 4 percent (Southern California) and 0.5 percent (New York) of the respective metal burdens already entering these marine waters.[12]

Open Ocean Waters.—Currently some 300,000 metric tons of acid and alkaline wastes are directly dumped into the ocean each year (7). This practice is expected to continue for the foreseeable future. The maximum quantity of five toxic metals

[11] 117.5 mt (copper) + 0.5 mt (mercury) + 125 mt (5 × 25 mt for the other five metals) = 143 mt per ship per year.

[12] The emissions from ocean incineration, in contrast to these coastal inputs, would be expected to enter marine waters at considerable distances from the coast. At these ocean sites, they might be a greater fraction of total inputs, but also could be expected to disperse over a much larger volume and to cause less adverse impact on marine life or humans.

(cadmium, chromium, copper, lead, and zinc) present in this waste is estimated to be about 630 metric tons (7). Relative to the maximum theoretical limit on incinerator emissions for these five metals (1 17.5 metric tons annually), the amount dumped directly into the ocean is about five times greater than the amount an incinerator vessel would emit in the worst case.

As a final comparison, metal emissions from ocean incineration can be compared to the quantity of metals present in sewage sludge that is dumped in the ocean. An estimate for the concentrations of the five predominant metals (cadmium, chromium, copper, nickel, and zinc) present in New York City's sewage sludge was developed for the City's Department of Environmental Protection (ref. 12, cited in ref. 17).13 The ocean dumping of New York City's sewage sludge is estimated to contribute approximately 540 metric tons annually of these five metals, or almost five times the maximum theoretical quantity of these same metals that one incinerator ship could emit in a year. Because New York City's sewage sludge represents only about half of the total amount currently dumped in the ocean (1 1), this source of metals to the marine environment is even larger than the above comparison indicates.

Comparison With Land-Based Incineration. —Land-based incinerators that would otherwise exceed the particulate standard specified under the Resource Conservation and Recovery Act (RCRA) (see ch. 7) are required to be equipped with stack scrubbers designed to control particulate emissions, Because most metals are strongly bound to particulate matter, scrubbers should significantly reduce metal emissions from hazardous waste incineration.

EPA (22) compared expected emissions of metals from land-based and ocean incineration, using a model liquid wastestream containing 100 ppm of each of four metals (arsenic, cadmium, chromium, and nickel). Arsenic is the most volatile of these, and EPA estimates that scrubbers remove only about 50 percent of it; the other three metals are assumed to be removed at 90 percent efficiency. Using these assumptions, EPA predicts that total metal emissions from land-based incineration of this model wastestream would be one-fifth of those from ocean incineration.

EPA's estimates of the scrubbers' removal efficiencies might be too high for the incineration of *liquid* wastes, because resulting particulate would fall at the low end of the particulate size range and would be removed at a lower efficiency than average (2). Nonetheless, incineration of waste at sea would clearly result in greater emissions of metals than incineration of the same waste on land at facilities equipped with scrubbers.

Comparison With Background Metal Concentrations in the Open Ocean.—EPA used an atmospheric plume/ocean transport model to estimate the rate at which metals would be deposited and how large an area would be affected by emissions from ocean incineration. For the model (4-metal) wastestream described in the previous example, the total amounts of each of the four metals deposited per unit area were calculated. The subsequent mixing of metals in seawater was explored under three scenarios and the resulting metal concentrations were calculated. Table 21 presents these scenarios and concentrations (app. I in ref. 22).

Some limited field data provide estimates of background metal concentrations in the open ocean. Background concentrations were calculated for the upper 60 meters, allowing a direct comparison to the estimated input from ocean incineration under Scenario 3. Table 22 presents the results of this comparison (App. I in ref. 22).

These data indicate that, for mixing to 60 meters,[14] three of the four metals would be well below background. Only cadmium could be expected to exceed its very low background concentration; its level in the affected area would roughly double

[13] New York City's sewage sludge, as well as that from several other sewerage authorities in New York and New Jersey, is currently dumped at a site in the New York Bight. Under current regulations to be completely in effect by the end of 1987, all of this sludge, as well as that from two newly constructed treatment plants in New York City, is to be dumped at the 106-mile Sewage Sludge Dump Site, located immediately adjacent to the proposed North Altantic Incineration Site.

[14] EPA's proposed Ocean Incineration Regulation (50 FR 8245, Feb. 28, 1985) would define the release zone for incinerator emissions as comprising the upper 20 *meters* of surface water; this represents an estimate of the depth of the surface thermocline, above which the initial mixing would be expected to occur. Initial mixing would be defined as "dispersion or diffusion of incinerator emissions into the receiving water which occurs within four hours after release from the incinerator" (50 FR 8258, Feb. 28, 1985).

Table 21.—Metal Concentrations Resulting From Ocean Incineration, Under Three Different Scenarios for Mixing of Emissions in Seawater

	Resulting concentration [a]	
Scenario 1:		
All metals are deposited within the surface microlayer, represented by the upper 0.1 millimeter of the ocean surface in the affected area	*320,000*	ppt[b]
Scenario 2:		
All metals are evenly mixed in the upper 1 meter of the affected area	32	ppt
Scenario 3:		
All metals are evenly mixed in the upper 60 meters[c] of the affected area	0.53	ppt

[a]Assumes that four metals (arsenic, cadmium, chromium, and nickel) are present in the incinerated waste at 100 ppm each.
[b]ppt = parts per trillion.
[c]EPA's proposed Ocean Incineration Regulation (50 FR 8245, Feb. 28, 1985) would define the release zone for Incinerator emissions as comprising the upper 20 meters of surface water; this represents an estimate of the depth of the surface thermocline, above which the Initial mixing would be expected to occur.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration: Appendix I," *Assessment of Incineration as a Treatment* Method *for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

under this scenario. Even if metals from emissions were confined to the upper 1 meter of water, only cadmium could be expected to exceed its background level; in this case, however, the cadmium level would be about 100 times its background concentration.

In contrast, if all emissions were somehow entirely confined to the microlayer, all four metals would far exceed background levels. This would be true despite the fact that background levels of metals measured in the surface microlayer exceed those measured in surface waters by a factor of anywhere from 1 to 50 (app. I in ref. 22). The significance of the microlayer is an area of considerable controversy, and is discussed in chapter 9.

Acid Gases

Because ocean incineration is not expected to employ scrubbers to remove acid gases, the level of acid emissions can be calculated directly from the chlorine (or other halogen) content of the waste feed. Almost all of the organic chlorine content of wastes would be converted through incineration to hydrogen chloride (HCl) gas, with much smaller amounts exiting in the form of other chloride salts, elemental chlorine gas, or organic chlorine (i. e., as residual POHCs and PICs).

To examine the possibility that incineration of highly chlorinated wastes at sea might exceed the proposed environmental performance standard for HCl (see ch. 7), EPA (50 FR 8245, Feb. 28, 1985) developed a worst-case scenario by assuming the following:

- pure carbon tetrachloride, 92 percent chlorine content, is incinerated at a rate of 25 metric tons per hour;
- all chlorine exits as HCl at a rate of 23.7 metric tons per hour; and
- all HCl is deposited within 100 meters of the ship and mixed to a depth of 20 meters (the estimated depth of the thermocline defining the 4-hour mixing zone), which makes the total volume of the mixing zone 22 billion liters.

Under these extreme conditions, EPA estimated, the resulting decrease in alkalinity of seawater in the mixing zone would be only about 1.3 percent,

Table 22.—Comparison of Metal Inputs From Ocean Incineration to Background Metal Concentrations in the Upper 60 Meters[a] of the Open Ocean

Metal[b]	Upper 60 meters background level (ppt)[c]	Upper 60 meters Scenario 3 level (ppt)	Ratio of background to Scenario 3
Arsenic	1,100	0.53	2,075
Cadmium	0.3	0.53	0.57
Chromium.	268	0,53	506
Nickel	146	0.53	275

[a]EPA's proposed Ocean Incineration Regulation (50 FR 8245, Feb. 28, 1985) would define the release zone for incinerator emissions as comprising the upper 20 meters of surface water; this represents an estimate of the depth of the surface thermocline, above which the initial mixing would be expected to occur.
[b]Assumes that these four metals are present in the incinerated waste at 100 ppm each.
[c]ppt = parts per trillion.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Baaed Incineration: Appendix I," *Assessment of /incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

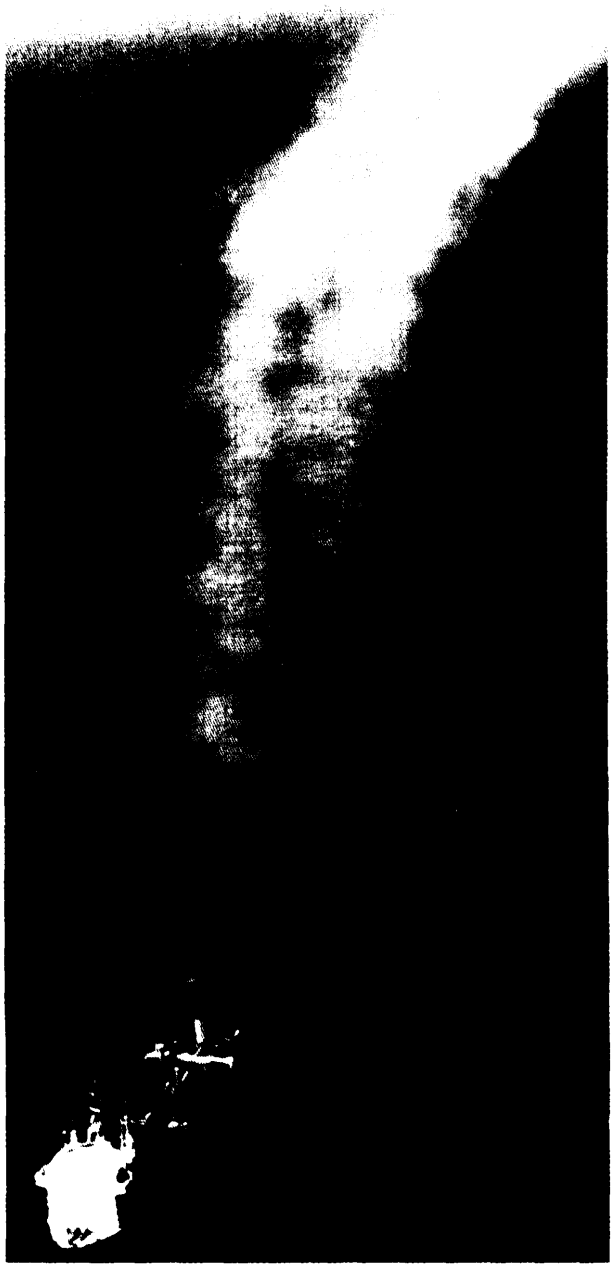


Photo credit: Fred Ward © 1985 National Geographic Society

The Vulcanus // incinerator ship, now owned by Chemical Waste Management, Inc., operating in the North Sea. The plume from the ship is composed mostly of steam and hydrochloric acid.

well below the 10 percent change allowed by the proposed standard.

This scenario has been challenged on the basis that it ignores potential impacts that could occur at the higher concentrations of acid that would exist before initial mixing was achieved (i. e., before 4 hours had elapsed). In particular, regions of the surface microlayer that came in direct contact with the incinerator plume might well be exposed to very high (though transient) HCl concentrations. In that event, a large proportion of the organisms in this area could be impaired or possibly killed.

However, given the intermittent nature of ocean incineration, the relatively small size of the affected area, and the high renewal rate of the surface microlayer resulting from new growth and replenishment from adjacent areas, the long-term net loss of biomass would probably be small or non-existent. A more extensive discussion of the nature and significance of the surface microlayer is presented in chapter 9.

Acid wastes are currently directly dumped into the ocean at two sites in the North Atlantic Ocean (7), The rate of dumping of this waste and the size of the dumping area are such that the concentration of acid entering surface waters greatly exceeds that expected from an incineration vessel, by a factor of about 250 (9). In some cases, transient (1 to 4 hours) perturbations in the alkalinity of seawater have been observed following the dumping of acid waste, although no significant effects on marine life have been observed. In contrast, extensive monitoring of past ocean incineration burns has not detected any change in seawater alkalinity (see ch. 11).

Air Pollution Control Device Effluents

This waste, which is generated in very large quantities by land-based incinerators equipped with scrubbers, contains all of the particulate, metals, and acid gases removed from incinerator emissions. EPA (app. Fin ref. 22) calculated the following annual composition and quantity of scrubber effluent from a land-based incinerator burning 50,000 metric tons of PCB waste annually and complying with all RCRA standards (waste metal content was assumed to be 100 ppm each of arsenic, cadmium, chromium, and nickel):

- *total quantity*— 1.34 million metric tons (more than 99 percent wastewater);
- chlorine content—9,300 metric tons (0. 7 percent of the total), mostly dissolved salts; and
- *metal content*—4. 5 metric tons each of cad-

mium, chromium, and nickel and 2.5 metric tons of arsenic.

Scrubber effluents are typically neutralized, treated to remove particulate matter, and discharged under a Clean Water Act permit as nonhazardous waste. Sludges generated through treatment are normally considered hazardous under RCRA, and must be disposed of as such.

SUMMARY AND COMPARISON OF TOTAL RELEASES FROM LAND-BASED AND OCEAN INCINERATION

This section summarizes and compares estimates of the total amounts of waste released by land-based incineration and by ocean incineration. The comparison highlights major differences between these technologies with regard to their potential to cause exposure and adverse impacts.

The EPA incineration study (21) attempted to quantify releases from each phase of operations for both land-based and ocean incineration. The study evaluated the incineration of two different wastestreams: a PCB-contaminating waste typical of existing stockpiles; and an ethylene dichloride (EDC) waste representing a common (though simplified) industrial chlorinated wastestream. Table 23 presents estimates of how much of each of these wastes would be released during various phases of incineration operations. For a full discussion of the derivation of these estimates and the assumptions and uncertainties involved, the reader should consult the EPA study.

The absence of reliable data, particularly for PIC emissions, and the need to invoke numerous assumptions that are difficult to verify, cast considerable doubt on the estimates and greatly limits their use for setting policy. In particular, the *absolute* quantities probably do not accurately reflect releases from any actual operation.

The following discussion uses the data presented in table 23 for *comparative* purposes only, to identify substantial differences between the releases expected from land-based and ocean incineration.

Within the limits of accuracy of EPA's release estimates, land-based and ocean incineration appear to pose comparable hazards with respect to the overall quantities of wastes and waste products released into the environment. However, the nature and location of the releases also play major roles in determining the potential for humans and the environment to be exposed to or harmed by the releases. By highlighting these differences, chapter 9 compares risks to humans and the environment posed by land-based and ocean incineration.

As an aside, data presented on the last line of table 23 underscores the general advantage of incineration (on land *or* at sea) over land disposal as a means of managing hazardous waste. Expressed as a percentage of total throughput, releases of waste from incineration are minute, indicating the tremendous potential for incineration to reduce both the quantity and degree of hazard associated with these wastes.

Ocean incineration can be expected to release somewhat greater quantities of waste and waste products to the environment than land-based incineration. Increased releases are expected from several phases of ocean incineration operations.

Transfer and Storage.—Ocean incineration would entail at least one extra step, namely the transfer of wastes to the vessel itself. This additional activity would slightly increase the expected quantity of fugitive emissions and the likelihood of a spill occurring.

Ocean Transportation.—Ocean transportation of hazardous waste, which would obviously occur only for incineration that took place at sea, would increase the risk of waste being released through spillage. Assigning an annual average quantity to such an event is highly problematic, because it does not adequately reflect either the probability of a spill occurring or the size of the spill. Available data strongly suggest that a marine spill from an ocean incineration vessel represents a very low-probability event; however, it is equally clear that the consequences of such an event could be catastrophic (see ch. 9).

Table 23.—Summary of Annual Incineration Releases for Two Model Wastestreams

	PCB wastes		EDC wastes	
Assumptions:				
Concentration of PCB or EDC	350/0		50 "/0	
Metal content (As, Cd, Cr, Ni)	100 ppm each		100 ppm each	
Annual throughput	50,000 mt		68,500 mt	
Destruction efficiency	99.99990/0		99.99 "/0	
Use of modern transfer facility	Yes		Yes	
	Ocean	Land	Ocean	Land
Estimated releases (mt/yr)[a]:				
Land transportation	2.1	2.1	*2.7*	*2.7*
Transfer and storage	1.2	1.1	*1.2*	1.1
Ocean transportation	0.6	—	*0.8*	—
Subtotal	3.9	3.2	*4.7*	*3.8*
Normal stack emissions:				
Unburned wastes	0.1	0.1	*6.8*	*6.8*
PICs[b]	<<0.1	<<0.1	*20.6*	*0.6*
Metals	22.4	4.5	*27.4*	*5.5*
Stack subtotal	22,5	4.6	*54.8*	*12.9*
Scrubber effluent metals	—	17.9	—	*21.9*
Total releases (mt/yr)	26.4	25.7	*59.5*	*38.6*
(as percent of throughput)	0.053	0.051	*0.087*	*0.056*

[a]The releases from land ocean transportation and from transfer and storage include both routine (e.g., fugitive emissions) and accidental releases. For releases due to accidental events such as spills or incinerator upset, theestimates presented here must be interpreted with caution since they represent long-term averages; actual releases from such events are probabilistic, and in a given year could range from zero to avery large amount.
All estimates have been rounded up to the nearest 0.1 metric ton for ease of calculations. Use of a scrubber is assumed for land incineration.
[b]Estimates of PIC emissions are far more uncertain than the other rough estimates presented here, and are of questionable use even in the crude comparison for which these data are intended. See text for a discussion of the variation in these values between land and ocean modes and between PCB and EDC wastestreams.
The symbol "<<" indicates that the estimated value is much less than 0.1 metric tons.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Summary and Conclusions," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

For these reasons, comparing the risks of spills from incineration vessels to the risks of spills from marine transportation of hazardous substances in general is more appropriate than comparing them to transportation risks from land-based incineration. This more appropriate comparison is presented earlier in this chapter.

As expected, table 23 indicates a somewhat larger (20 percent) release from transporting and handling waste for ocean incineration than for land-based incineration, primarily because of the additional marine transportation that would be involved. The slightly larger releases expected for the EDC waste relative to PCBs is due mostly to the higher assumed throughput.

Incineration. —For both land-based and ocean incineration, and for both types of wastestreams, the incineration process itself would be the major source of expected releases. Each of the three major categories comprising total incinerator emissions is discussed below.

Unburned Waste. —More unburned EDC waste than PCBs would be released because a lower destruction efficiency and a higher annual throughput apply to the EDC waste. Under the assumptions employed, no differences in quantities of undestroyed waste released from land-based and ocean incineration are expected.

PICs. —All of the estimates for PIGs are based on extremely limited field data, and cannot serve as the basis for sound generalizations. Thus, EPA's estimates that much higher PIC emissions would be expected from ocean incineration of EDC waste than from land-based incineration, and from burning EDC waste than from burning PCBs, cannot be considered reliable (see previous section on PICs). The only possibly valid generalization is that achievement of a higher DE should logically lead to lower PIC emissions. However, even this straightforward prediction must await further field verification for both land-based and ocean incineration.

Metals. —The quantity of metals resulting from burning the same type of waste is not expected to differ between land-based and ocean incineration. However, the use of air pollution control equipment on some land-based incinerators (which rep-

resents a major regulatory distinction between these technologies) is expected to alter the final disposition of such metal emissions. For both the PCB and EDC wastestreams, the sum of metals present in stack releases and scrubber effluents from land-based incineration would be equal to the stack releases of metals from ocean incineration.

The data in table 23 suggest that metals account for the great majority of releases from land-based and ocean incineration. These estimates, however, depend entirely on the assumptions made about metal content, which appear to have been substantially overestimated (see previous section on estimating releases of metals).

As is the case with PIC emissions, our present understanding of metal emissions, both qualitative and quantitative, is far from adequate for both land-based and ocean incineration. This major data gap limits our ability to accurately assess the potential for exposure to and harm from incineration of hazardous wastes.

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