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Project Summary

Report of the Interagency *Ad Hoc* Work Group for the Chemical Waste Incineration Ship Program

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This publication summarizes two complete project reports: "Design Recommendations for a Shipboard At-Sea Hazardous Waste Incineration System," and "Design Requirements for a Waterfront Facility to Support Chemical Waste Incinerator Ships."

These two engineering studies assess the key aspects of at-sea incineration of hazardous chemical wastes. Included are evaluations of (1) several alternative shipboard incineration systems, (2) requirements for a full-service waterfront support facility, and (3) all phases of waste disposal, from waste selection to final disposition of any effluent, ash, or residues produced. A preliminary evaluation was made of generic incinerators potentially applicable to shipboard operation. As a result, liquid injection incinerators were selected for destruction of pumpable wastes, and a rotary kiln was recommended for experimental evaluations of shipboard incineration of solid hazardous wastes. Fluidized-bed, molten salt, multiple hearth, multiple chamber, and starved-air incinerators are all limited in operating temperatures and/or waste type capability compared with the rotary kiln.

Cost of each liquid injection incinerator is estimated to be $2.5 million (or $3.8 million installed). Estimated cost of rotary kiln incinerator proposed for shipboard application is $900,000 (or $1.1 million installed). One rotary kiln and three liquid injection incinerators are recommended for the ship under consideration, which has a waste capacity of approximately 8,000 metric tons. Required sampling, monitoring, and analysis equipment is estimated to cost approximately $261,000. These estimates are in 1980 dollars. The Maritime Administration of the U.S. Department of Commerce has estimated the total cost of a new incinerator vessel (including installed incineration equipment) to be $75 to $80 million for delivery in 1985.

Capital costs for a dedicated, full-service waterfront support facility (excluding dock rental and land costs) are estimated to be $19 million in 1980 dollars. Operating costs (including labor, maintenance, depreciation, power, and ash disposal) are estimated to be $4 million annually, excluding undetermined insurance costs.

A review of existing U.S. terminal facilities found that 139 ports and 1,221 terminal docks, piers, or wharves on the East, Gulf, and West coasts of the continental United States have sufficient water depth and space to receive the conceptual design incinerator ship. These terminals are concentrated primarily in the states of

Texas, New Jersey, Louisiana, California, and New York.

This Project Summary was developed by EPA's Industrial Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

An estimated 57 million metric tons of industrial hazardous wastes were produced in the United States during 1980. Many of these wastes, particularly the organic chemicals, are incinerable; but only a limited number of commercially available, land-based hazardous waste incinerators exist in the United States, and public opposition to additional sites is increasing. The U.S. Environmental Protection Agency (EPA) is considering a demonstration project using a U.S. flag vessel for at-sea incineration of hazardous wastes This project would be conducted in cooperation with the Maritime Administration of the U.S. Department of Commerce.

Thermal destruction of chemical wastes at sea by European vessels has been shown to be an environmentally acceptable and cost effective means of disposal for many types of liquid combustible chemical wastes. EPA has recommended that a U.S. incinerator ship be built that is capable of destroying liquid wastes at sea and that can explore extending the capability of at-sea incineration to solid and semi-solid materials.

The objectives of this study were to assess the key aspects of at-sea incineration and to issue a study report. An engineering evaluation was performed on several alternative forms of shipboard incineration systems, including waste selection and the disposition of any effluent or residues produced. Design requirements were also developed for a waterfront support facility for incinerator ships This facility would receive, store, analyze, process, and load wastes onto the ship in a safe and efficient manner; it would also receive any residues from the incinerator ship for analysis and disposal

Conclusions

The conclusions developed from this engineering study are twofold: those concerning the shipboard incineration system and those having to do with the waterfront support facility.

Shipboard Incineration System

Types of Incinerators—

Major characteristics of candidate incinerators for shipboard, at-sea application are compared in Table 1. The capability of each incinerator to destroy different types of waste material is noted in the table, along with maximum operating temperature, relative maintenance requirements, and present commercial applications.

The liquid injection incinerator can be used only for pumpable liquids; however, it is the most effective means of incinerating liquid wastes at high feed rates, and it is capable of attaining the temperature required (up to 1600°C) for highly efficient destruction of toxic materials. This incinerator can also serve as the afterburner for a solid waste incinerator. Maintenance requirements are low because there are no moving parts within the high temperature zone. Liquid injection incinerators are widely used in commercial applications and represent the only technology well proven at sea for destruction of hazardous wastes.

Rotary kilns are the most versatile incinerators available, capable of handling any combination of liquids, slurries, tars, or solids, including containerized

Table 1. *Comparison of Candidate Incinerators for Shipboard, At-Sea Application*

Item	*Liquid Injection*	*Rotary Kiln*	*Fluidized-Bed*	*Molten Salt*	*Multiple Hearth*	*Multiple Chamber*	*Starved-Air*
Waste Capability:							
Pumpable Liquids	X	X	X	X	X	X	X
Slurries, Sludges		X	X	X	X		X
Tars		X		X			
Solids:							
Granular		X	X	X	X		X
Irregular		X				X	
Containerized		X				X	
Maximum Operating Temperature, °C	1600	1600	980	980	1100	1000	820
Maintenance Requirements	*low*[a,c]	*medium*[a,b]	*medium*[a,c]	*medium*[a,d]	*high*[e]	*medium*[e]	*high*[e]
Commercial Application	*Widely used,*[f] *liquid wastes*	*Widely used, all wastes*	*Limited use, sludges and organic wastes*	*Demonstration tests only*	*Widely used, sewage sludge*	*Widely used, refuse*	*Resource recovery*

[a]*No moving parts in high temperature zone.*
[b]*Bearing and seal modifications required.*
[c]*Ash removal and bed replacement required.*
[d]*Salt recycle or replacement required.*
[e]*Moving parts in high temperature zone.*
[f]*Liquid injection incinerators are the only type that have been successfully utilized for shipboard, at-sea operation.*

wastes. Temperatures as high as 1600°C can be attained in the kiln. Rotary kilns represent well proven technology for land-based incineration but their use at sea would be a new application. Specially designed equipment will be required to withstand pitch, roll, vibration, and environmental conditions at sea. Maintenance requirements may be higher than for a liquid injection system. The rotary kiln used in conjunction with a liquid injection incinerator is considered to be the most versatile system for thermal destruction of a wide variety of hazardous wastes.

Fluidized-bed incinerators are more limited than rotary kilns in their range of feed materials (Table 1) and are not suited for irregular solids or tarry substances. Maximum operating temperatures are limited to 980°C to avoid fusion of the silica sand bed material. Higher temperatures of 1200°C are possible using alumina refractory particles at the bed materials. Maintenance includes ash removal and replacement of the bed when necessary. Pitch and roll of the ship, particularly during storms, would cause shifting of the large mass of bed material, both during incineration and when shut down. The bed will retain heat for restart during shutdowns of up to 1-day duration, beyond which reheating of the bed is required.

Molten salt reactor pilot and demonstration units have been used to destroy liquid, slurry, and granular solid waste materials, but no large commercial units are presently in operation. Operating temperature of the salt bed is limited to 980°C. Pitch and roll on the ship will cause sloshing of the molten salt within the reactor. A potential advantage of this system is that it can serve as a combined incinerator/scrubber by retaining particulates and contaminants in the bed, but salt regeneration or replacement is then needed periodically. The salt bed must also be removed from the reactor before solidification during shutdown. A spill of the hot, caustic salt that contains toxic contaminants could pose hazards aboard ship.

Multiple hearth incinerators are widely used for sewage sludge disposal, but they can also accept granular solid and liquids (injected through the auxiliary fuel nozzles). Operating temperatures are limited to 1100°C because of the internal mechanical components (rotating shaft, rabble arms, etc.). Maintenance of internal moving parts would be frequent because of ship motion as well as thermal stress. Also, the presence of any fusible ash could render the system inoperable until cleaned out.

Multiple chamber incinerators are used extensively for industrial disposal of bulk solid wastes. Liquid wastes can be injected with the auxiliary fuel. Since slurries and sludges may fall through the incinerator grates, they are not suitable for this incinerator. Solids/air mixing is not as thorough as in rotary kilns, and high excess air rates are required, resulting in operating temperatures of approximately 1000°C.

A number of incinerator designs, including multiple hearths, can be operated as starved-air combustors by restricting air input to less than the amount required for stoichiometric conditions. These systems may have high efficiencies, but hazardous by-products may be formed if there is insufficient oxygen for complete reaction, and an afterburner is required to burn combustible emissions. Use of this mode of incinerator operation is usually limited to by-product recovery from sludges or solids.

Emission Control Devices—

Emission control devices commonly used with land-based incinerators have many limitations for shipboard operation, including size, weight, and fresh water requirements. Table 2 summarizes the major advantages and limitations of emission control devices potentially suitable for at-sea incineration of hazardous wastes. A high-energy venturi scrubber represents the lowest weight, volume, and installed cost emission control system evaluated, if the sea water can be used for scrubbing and discharged into the sea. A closed-loop system requiring a settling tank would be impractical because of space and weight requirements.

Waste Feed Systems—

A shipboard waste feed system is required to retrieve the waste from storage and transport it to the incinerator without spillage under operating conditions of pitch, roll, and vibration. Liquid wastes and some slurries can be transported to the incinerator by conventional pumps, piping, and valves. Solids can be loaded into sealed containers on land: either smaller fiber containers can be fed directly into the incinerator, or larger standard bulk material containers can be discharged directly into a sealed hopper. Handling of 55-gal drums (particularly potential leakers) and shredding operations involve too much risk aboard ship.

Waste Selection—

Wastes can be selected for at-sea incineration only after a complete analysis of their physical, chemical, and thermal properties. Physical properties must be known to determine if the waste is compatible with the incinerator type and waste handling system. Chemical and thermal properties affect the combustion characteristics of the waste. Normally, a minimum heating value of 4400 to 5540 kcal/kg (8,000 to 10,000 Btu/lb) is necessary to sustain combustion, but this is only an approximate limit. The M/T Vulcanus has burned organochlorine wastes with chlorine content as high as 63% and heat content as low as 3,860 kcal/kg (6,950 Btu/lb) without firing auxiliary fuel.

Monitoring—

Dedicated shipboard laboratory personnel are required to assure operational safety by analyzing the shipboard environment for waste constituents and by verifying waste destruction efficiency. Environmental monitoring during at-sea incineration is essential to ensure personnel safety and to protect the environment.

Waterfront Support Facility

The waterfront facility is a critical part of the entire system for chemical waste disposal using incinerator ships. A dedicated, full-service facility must accommodate wastes in almost any physical form and in several types of containers, some of which may be old, corroded, and possibly leaking. Ideally, the facility would service waste delivery by truck, rail, and barge. The proposed facility would consecutively accommodate up to two incinerator ships, each of which would be on a 2-week cycle. Capability must be provided for preparing and blending wastes for optimum transfer and combustion, and for unloading any ash residue from the incineration process from each ship. Figure 1 is a generalized process flow diagram for the facility.

Design—

The waterfront facility is designed to prevent emissions of hazardous ma-

Table 2. *Advantages and Limitations of Selected Emission Control Devices*

Device	Advantages	Limitations
Dry Electrostatic Precipitator	*Dry dust collection inc. heavy metals* *Low pressure drop and power requirement* *Efficient removal of fine particles* *No waste sludge generated*	*Relatively high capital cost* *Sensitive to change in flow rate* *Particle resistivity affects removal & economics* *Not capable of removing gaseous pollutants* *Fouling potential with tacky particles* *Primary collection of large particles required* *Electrical shorting possible aboard ship* *High corrosion damage expected with halogens* *Limited commercial experience for hazardous waste incineration*
Wet Electrostatic Precipitator	*Simultaneous gas absorption and dust removal* *Low energy consumption* *No dust resistivity problems* *Efficient removal of fine particles* *Control of tacky particles buildup*	*Relatively high capital cost* *Low gas absorption efficiency* *Sensitive to changes in flow rate* *Dust collection is wet* *Demister possibly required* *Electrical shorting possible aboard ship* *High corrosion damage expected with halogens* *Limited commercial experience for hazardous waste incineration*
Fabric Filter	*Dry dust collection inc. heavy metals* *High efficiency at low to moderate pressure drop* *Efficient removal of fine particles* *No sludge or liquid wastes* *No liquid freezing problems* *Dry sorbent injection for removal of gaseous pollutants possible*	*Gas temperatures cannot exceed 290°C although practical maximum is 95°C* *Fabrics may be susceptible to chemical attack* *Not capable of removing gaseous pollutants without modification* *Demister required after pre-quench* *Relatively large system size and costs* *Storage required for dry sorbent, waste cake and spent materials; disposal required for waste cake and spent materials* *No commercial experience with hazardous waste incineration*
Molten Salt Scrubber	*Incineration and scrubbing of gaseous and particulate emissions possible in a single device* *Heavy metals removal* *Hot incinerator gases can serve to preheat salt bath* *Salt bath operates as afterburner* *Pilot experience with chlorinated hydrocarbon wastes*	*Limited commercial experience* *Slip-stream testing needed* *Batch process with limited information on cycle times* *Budgetary capital costs and operating costs not available* *Relatively large space requirement* *Danger potential in case of molten salt accident*
High Energy Venturi Scrubber with Mist Eliminator Tower	*Simultaneous gas absorption and dust removal* *Suitable for high temperature, high moisture and high dust-loading applications* *Cut diameter of 0.5µm is attainable* *Collection efficiency may be varied* *Commercially proven with hazardous waste incineration* *Resin-coated FRP materials available for halogenic gases* *Effective scrubbing with fresh water or sea water* *Relatively low weight and capital cost*	*Corrosion and erosion problems with metallic construction* *Additional corrosion problems with sea water* *Dust is collected wet* *Moderate to high pressure drop* *Only moderate removal of gaseous pollutants* *Settling pond required for closed-loop operation*
Spray Tower	*Simultaneous gas absorption and dust removal* *Suitable for high temperature, high moisture, and high dust-loading applications* *Collection efficiency may be varied*	*High efficiency may require high pump discharge pressures* *Dust is collected wet* *Nozzles are susceptible to plugging* *Requires downstream mist eliminator* *Design based on experience and experimental testing* *Settling pond required for closed-loop operation*

Table 2. *(continued)*

Device	Advantages	Limitations
Plate-type Scrubbers and Packed Bed	*Simultaneous gas absorption and dust removal* *High removal efficiency for gaseous and aerosol pollutants* *Low to moderate pressure drop* *Commercially proven with hazardous waste incineration*	*Low efficiency for fine particles* *Not suitable for high temperature or high dust-loading applications* *Requires downstream mist eliminator* *Corrosion and erosion problems with metallic construction* *Additional corrosion problems with sea water* *Settling pond required for closed-loop operation* *For tray towers, motion of ship results in uneven weir heights*

terials, to contain spills, leaks, and other accidents, and to minimize harm to personnel and the environment in the event of accidents.

Ideally, the facility should be located where transportation time and distance are minimal. Structural standards must be carefully followed; these would normally be defined by the Uniform Building Code and additional location-specific building regulations. The design must also meet safety, health, and environmental criteria, which include provisions for facility monitoring, personnel safety, and contingency planning in the event of both major and minor releases of chemical wastes that have the potential to pollute the land, water, or air. These criteria are generally specified in Federal regulations. A proposed layout of the facility is shown in Figure 2. Approximately 75,000 m^2 (18 acres) of land will be required and a staff of approximately 40 will be needed to operate on a two-shift schedule.

Waste Handling—

Liquid waste, solid waste, and ash residue from incineration will be processed and stored separately. Liquid waste in drums and other containers will be sent through a shredder in the dedrumming facility. Liquid from both the containers and the decontamination of the containers will be blended to optimize transfer and combustion processes and pumped to storage tanks. Liquid waste arriving in tank trucks or tank cars will also be blended and pumped to the storage tanks along with the tanker decontamination rinse.

Solid waste arriving at the site will be unloaded at the unloading rack, prepared for incineration by shredding, and placed in bulk material containers to be loaded onto the ship. Any ash residue from the at-sea burn will be returned to the waterfront facility and kept in the residue storage area until removed for ultimate disposal, probably in a landfill approved for hazardous waste disposal

Review of Existing Terminal Facilities—

A review of existing terminal facilities in the United States was conducted by Diversified Maritime Services, Inc, as part of this study. Facilities that regularly accommodate vessels similar in length and draft to the conceptual incineration vessel were identified, without regard to the type of commodity or material being handled. Only those terminals having a minimum water depth at loading berths of 7.6 M (25 ft) were included. This list of terminals was then limited to those that are handling either liquid and/or dry cargoes that are hazardous or commodities that possess physical and chemical characteristics that are similar to those anticipated for hazardous wastes (ignitability, corrosivity, reactivity, toxicity). The latter group of terminals was evaluated from the standpoint of their potential for conversion to a liquid and/or solid hazardous waste marine terminal. Marine terminal and materials handling experts were consulted regarding reasonable and practical alternatives in the development of a hazardous waste marine terminal.

On the East, Gulf, and West coasts of the continental United States, there are 139 ports and 1,221 terminal docks, piers or wharves that have sufficient water depth and space to receive the chemical waste incineration vessel as designed. Of the 1,221 terminal docks, piers and wharves, 381 handle refined petroleum products or liquefied chemicals (and allied products). These terminals are concentrated primarily in the states of Texas, New Jersey, Louisiana, California, and New York Except for military terminals, ownership of these facilities is predominantly private.

Most of the major and many of the smaller bulk liquid terminal companies that offer services to the public are members of the Independent Liquid Terminal Association, established in 1974. Through that association, they are relatively well informed of environmental rules and regulations that are being developed in compliance with congressional legislation. Accordingly, these companies are not only familiar with long-existing local, state, and Federal regulations for handling commercial bulk liquid commodities (which are mainly concerned with fire, explosion, and safety matters), but they are also acquainted with recent EPA regulations for implementing the Resource Conservation and Recovery Act. Several of these companies have filed or plan to file "Notification of Hazardous Waste Activity" (EPA Form 8700-12) to qualify their terminals for interim status. The knowledge and expertise of such firms could contribute to the development of a waterfront facility.

Recommendations

The recommended incineration system for destruction of both solid and liquid hazardous wastes at sea is a rotary kiln coupled to a liquid injection incinerator. Two or more identical liquid injection incinerators (depending on size of the ship selected) should be used for the destruction of liquid wastes. A single rotary kiln should be installed in combination with one of the liquid injection incinerators for evaluation before additional kilns are added.

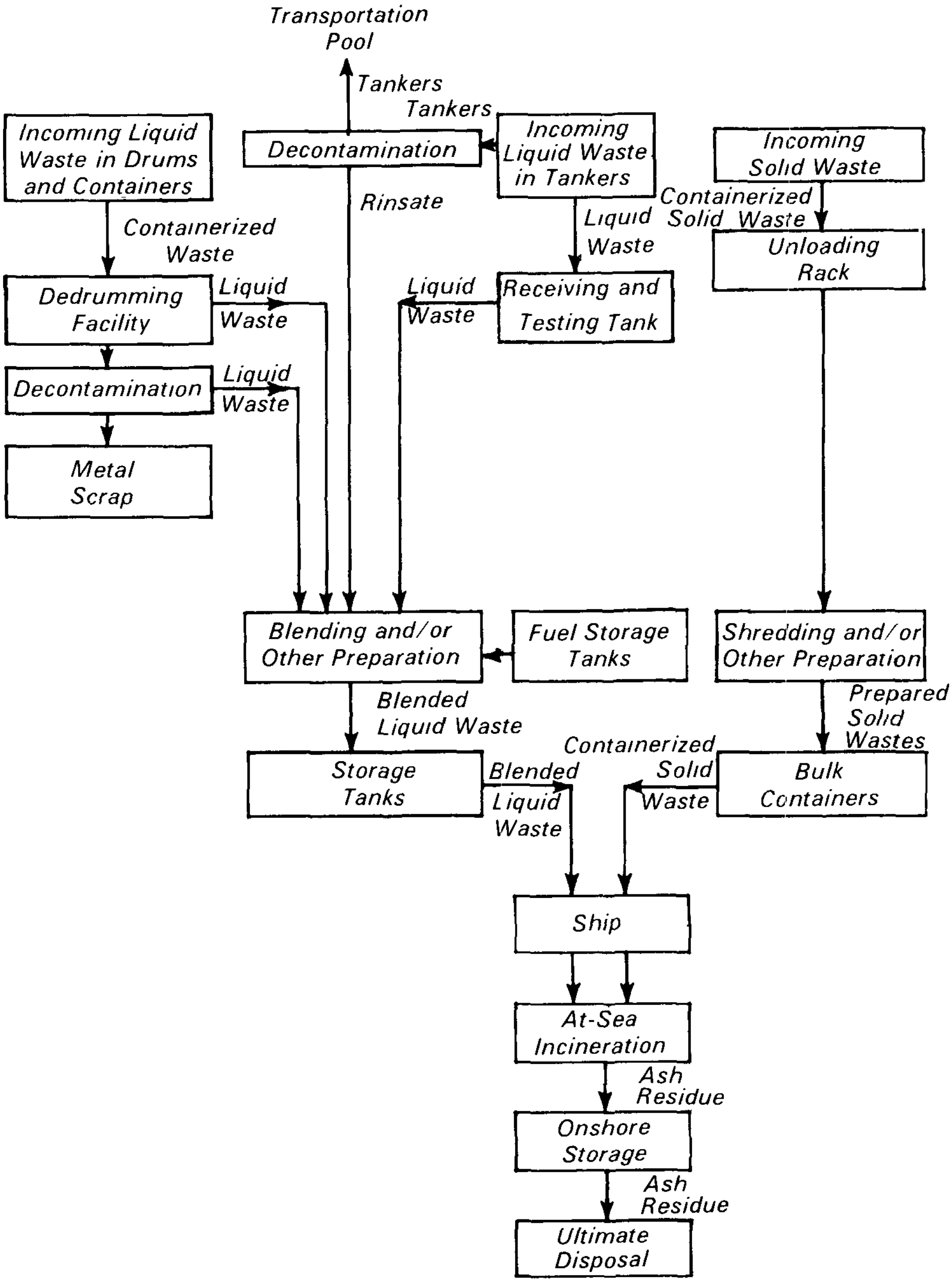

Figure 1. *Waterfront facility process flow.*

The ship layouts shown in Figure 3 indicate some of the ways that incineration systems can be integrated on board ships to provide desired incineration capacity and operational time at sea. Studies should be made for each ship size under consideration to determine the optimum number of incinerators and incineration time versus ship loading and transit times.

A high-energy venturi scrubber with a pre-quench and a mist eliminator tower utilizing sea water should be considered for shipboard evaluation. Marine environmental effects of single-pass sea water scrubbing system must be evaluated, however.

Ideally, liquid wastes should be stored in inert, gas-blanketed, lined tanks. Flowmeters are recommended for monitoring the liquid waste feed rate to each incinerator burner. Solid material should be processed on land and loaded into sealed bulk material carriers or incinerable containers compatible with shipboard safety requirements to minimize hazards of waste handling on board ship. Use of 55-gal drums and shredding operations on board are not recommended.

Environmental monitoring during at-sea incineration must be conducted to ensure personnel safety and protection of the environment. A shipboard laboratory should be provided for analysis and identification of effluent waste samples and verification of destruction efficiency.

A waterfront facility is essential to support the operation of incinerator ships. The facility must be designed to receive, store, analyze, process, and load wastes aboard the ship in a safe and efficient manner, and to receive any residues from the incineration process for ultimate disposal. Some existing private and military terminals may be used for this purpose.

A U.S. incinerator ship can serve two broad functions: first, it can be used for the destruction of hazardous wastes in a location minimizing the risk to public health and the environment; second, it can provide a safe site to continue EPA research and development efforts in hazardous waste incineration. Furthermore, an incineration vessel would provide needed experience in the large-scale processing of hazardous waste materials. The effects of process variations in a commercial-scale incinerator on hazardous waste destruction efficiencies needed to be further investigated, along with many types of wastes not yet tested. In addition to destroying hazardous wastes, the proposed incineration vessel could effectively test incinerator designs, emission control concepts, and improved sampling/monitoring equipment and methods.

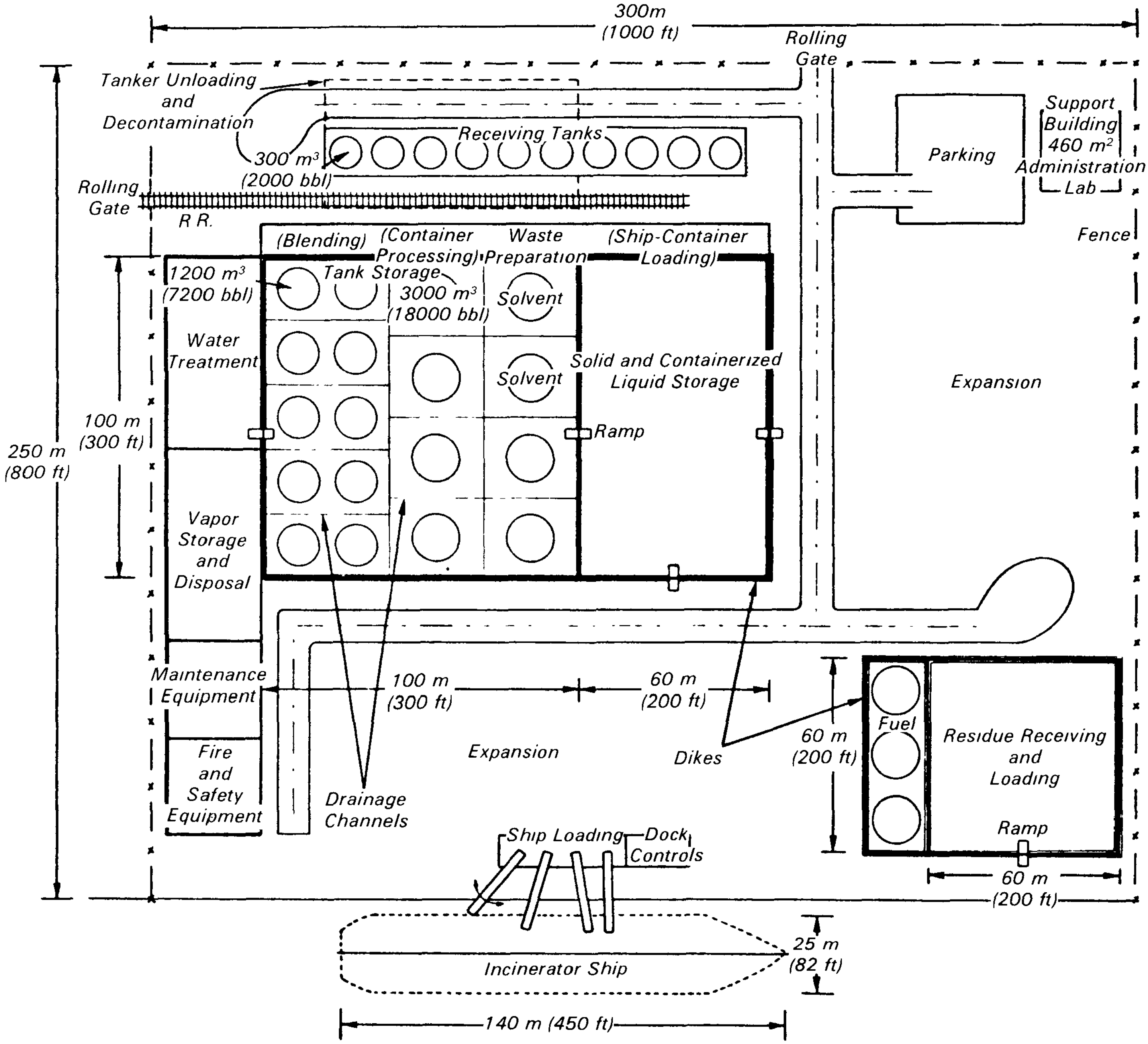

Figure 2. *Waterfront facility layout.*

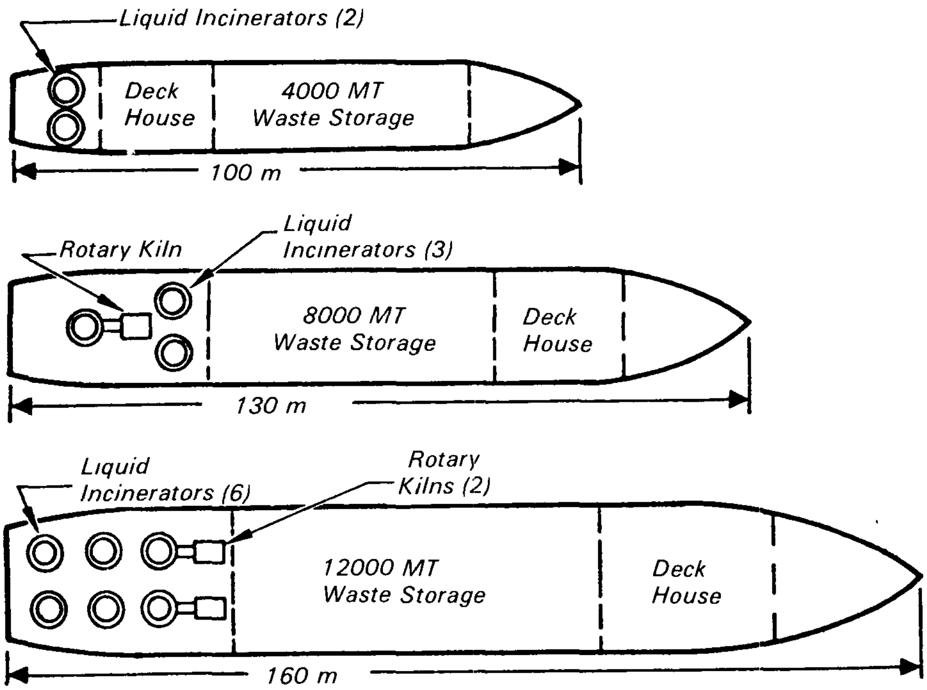

Figure 3. *Alternative incinerator ship configurations.*

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The complete report, entitled "Report of the Interagency Ad Hoc Work Group for the Chemical Waste Incineration Ship Program," (Order No. PB 81-112 849; Cost: $20.00, subject to change) will be available only from:

National Technical Information Service
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